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**Christensen, Linda; Nielsen, Otto Anker; Rich, Jeppe; Knudsen, Mette**

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# Optimizing airport infrastructure for a country: The case of Greenland

Linda Christensen, Otto Anker Nielsen, Jeppe Rich, Mette Knudsen[1]

DTU Management, Transport Department

## ABSTRACT

In November 2018, the Greenlandic Parliament decided to extend the runways at two cities, Nuuk and Ilulissat, making them the main airports for international air traffic and to build a third regional airport. The decision is the result of 40 years' discussion, which is outlined in the paper.

The paper places the final decision in a theoretical framework of Greenland as a peripheral and very remote country for which air travel is the only way of mobility. Literature from the latest ten years shows that improvement in air travel can contribute to economic development. On the other hand, the investment in the new airports is economically risky considered the small size of the economy. The paper therefore uses cost benefit analyses (CBA) to assess if the decision is cost-effective even without the induced and wider economic effects of the new airports, which are difficult to forecast.

Based on several CBA developed over the years, the decision on the airport package seems to be cost-effective in case some of the induced effects are taken into account. For the capital Nuuk, the decision is clearly cost-effective without including induced effects. For Ilulissat, the effect depends on to what extent an airline is willing to follow up and establish a new direct connection from Europe or the American east coast. Therefore, airport authorities are also recommended to 'sell' the new airports to airlines.

During the 40-year long process of discussion, the authors' institute was 15 years ago asked to develop an optimization model for air traffic in Greenland. This model (the TGB model) is described in the paper and it is concluded that it would be possible to improve the network and save annual subsidies to the internal service traffic (PSO). Unfortunately, the model was never implemented. The authors recommend to update and improve the model that is currently outdated and to use it to optimize the network when the new airports are finished.

**KEYWORDS:** Air transport; Air traffic network optimization; Airport localization; Greenland; Cost benefit analyses; Remote country.

**JEL classification**: R12 R42

## 1 INTRODUCTION

After 40 years of discussion about new airports, a majority of the Greenlandic Parliament decided in November 2018[2] to invest 3,500 million DKK[3] in an airport package. The airport package includes two international airports with new/extended 2200 metres runways at the capital Nuuk and at Ilulissat that is located in the most attractive part of the country for tourism. Furthermore, it includes a new regional airport with a 1500 metres runway at Qaqortoq close to the southern point of Greenland. Currently (August 2019), no decision has been taken with respect to the future of the two existing international airports at Kangerlussuaq and Narsarsuaq. A committee has been set up to analyse the problems and to present suggestions to the Parliament.

Compared to the economy of Greenland, the investment is huge, corresponding to 40% of the country's annual GDP. On the other hand, the geographical conditions of Greenland do not allow interurban road

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[1] Today, affiliation at COWI

[2] Inatsisartutlov nr. 4 af 22. november 2018 om rammebetingelser for anlæg, drift og finansiering af international lufthavn i Nuuk og i Ilulissat samt regional lufthavn i Qaqortoq (Source 18).

[3] 1 EUR ~ 7.5 DKK

transport and only slow - and during winter unstable - sea transport along the coast. Air transport therefore plays a central role for the society. The improvement of the infrastructure of the country and the time savings for inhabitants, visiting tourists, and business travellers is substantial.

The airport infrastructure has been analysed and discussed seriously for the last 30 years in Greenland without any decision having been taken until now. In a historical perspective the need for serving different parts of the big country has made it difficult to decide to locate a new airport in one part of the country without considering the needs of other parts. Furthermore, the demand from other public affairs has been important, too.

From a technical perspective the air traffic network is the life nerve of mobility, communication and trade. It is however complicated to optimise the network. At a certain time during the long considerations, DTU Transport at the Technical University of Denmark was asked to develop a model to analyse alternative solutions. Up till now, the model has not been in use even though it was shown that it is possible to obtain big savings and improvements of the transport system. When the new airports are ready it might be possible to optimise the network in order to reduce the cost of the public service obligations (PSO) for serving the rest of the country. Furthermore, the home rule authorities and politicians have often discussed missing competition, which has been seen as a reason for a probably unneeded high demand for PSO from the national budget. This question will therefore be addressed, too.

The paper at hand presents the background for the decision in both a historical and technical perspective. During the historical policy process, cost benefit analyses have been central. The development in the official cost benefit analyses and the changing recommendations they caused will therefore be a main question in the historical presentation.

An important observation is that it has never seriously been considered to include secondary and wider economic effects of airports in the decision process; they are only assessed in a few of the analyses. The consequence of not considering secondary and wider economic effects, especially from tourism will therefore be another question discussed in the paper based on the newest literature about airport infrastructure’s wider economic effect on development in remote and peripheral regions.

Below, the geography, the infrastructure and the air traffic network are presented with the purpose of better understanding the background of the decided investment. In chapter 2, the theoretical frameworks for each of the questions presented above will be introduced and Greenland’s situation in relation to each of the mentioned frameworks will be described. Chapter 3 gives an overview of the historical development in the discussions and analyses of a changed infrastructure for different parts of Greenland. Chapter 4 presents the aviation network model developed by DTU Transport. In chapter 5 the different cost benefit analyses are compared and differences are concluded. In chapter 6 the analyses are discussed and related to the theoretical framework set up in chapter 2. Finally, in chapter 7 the strengths and weaknesses of the decided airport package are concluded.

## 1.1 Geography and history of Greenland

Greenland is the world’s largest island (2,670 km from south to north) with only 56,000 inhabitants in a mountainous arctic area. For references to locations and airports/heliports see Figure 1, which also shows the backbone of the air network served by Air Greenland (25% owned by the Danish Government and two equal shares owned by SAS and the Greenlandic Government), Air Iceland Connect and a smaller local airline, Diskoline.

The present air transport network is built upon military decisions taken during World War II with the main international airport located in Kangerlussuaq (2815 metres runway) at the top of the fiord “Sønderstrømfjord”, 150 km from the coast and 10 km from the icecap. Narsarsuaq with an 1830 metres runway is located inland by a fiord 50 km from the sea close to the southern tip of Greenland. The main consideration was to find locations far from populated areas, with no fog, but with access to the sea in order to transport construction materials and “minimal” accessibility for German submarines.

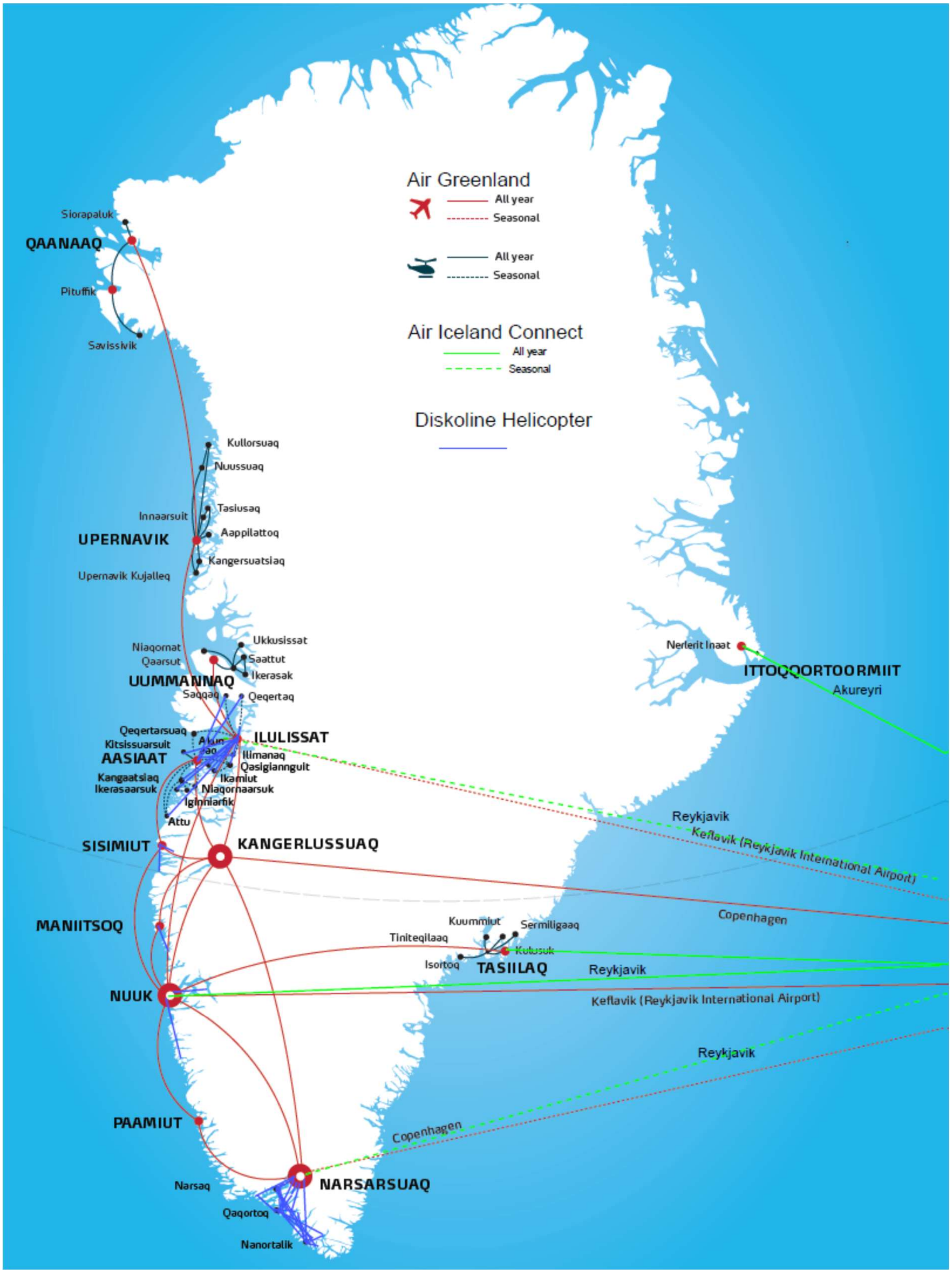

Figure 1: Greenland with the scheduled air traffic network in 2019. Sources: Air Greenland (map and own network), Supplemented by the authors from Diskoline and Mittarfeqarfiit (www.mit.gl), and from Air Iceland Connect (https://www.airicelandconnect.com/information/about-air-iceland-connect).

The future of Kangerlussuaq airport, which was taken over from US Air Force in 1991, is still up for debate. The nearby settlement[4] has 530 inhabitants, and accommodates a hotel and a couple of youth

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[4] Settlements are small villages, in Greenland called 'bygd'.

hostels for passengers who need to stay due to postponed connections to the rest of the country caused by e.g. sea fog and turbulence, or adventure tourists attracted by e.g. the inland icecap or a crowd of musk oxes. The terminal buildings and the settlement are placed both to the north and the south of the runway with 4 kilometre in between. The oldest terminal building having US military war standards need modernization. The runway needs a costly repair due to melting permafrost beneath. However, the need for investment in the runway is unsolved technically and depends on the final decision about the length of the runway. Several scenarios for the future of the airport are in play, e.g. a heliport or short runway for small fixed-wing airplanes, a reconstruction of the airport with a runway for regional connections (e.g. 1500 metres), or with a long runway up to 3,500 metres for military purposes.

Narsarsuaq airport will probably be replaced by a heliport. Nearby there is only a small settlement with 130 inhabitants and a historical sight from the Nordic Vikings who settled there around year 1000.

After the first Viking settling, Greenland was colonised around 300 years ago by the Danish-Norwegian Kingdom (since 1814 the Danish Kingdom). In 1953 the status was changed to a Danish county and from 1979 Greenland got more independency. In 1979-2009 Greenland had a home rule under which transport was under the auspices of the Danish authorities, however, with an agreement that Greenland had a right to be heard about the external transport and could take part in decisions about internal transport (Source 1[5]). Since 2009 Greenland has had its own legislative assembly and authorities that takes all decisions for Greenland about, among others, transport. Greenland still gets an annual appropriation from the Danish state budget representing around half of Greenland's national budget and not all sectors have been taken over by Greenland's own authorities yet. Nearly all political parties in Greenland want independency from Denmark, however, they do not agree about when and under which conditions. Greenland is not member of the European Union.

The capital Nuuk with 18,000 inhabitants is located at the west coast, one third up the coast from the southern point and 320 km to the south of Kangerlussuaq. Nuuk got an airport with a 950 metres runway in 1981. The same year Ilulissat, the third biggest city with 4,500 inhabitants located 250 km to the north of Kangerlussuaq, got an airport with an 854 metres runway. Both Nuuk and Ilulissat airports are due to the short runways served by the fixed-wing airplanes Dash-8 or Bombardier 200 turbo-prop airplanes with 37 seats from Kangerlussuaq and Iceland (to Ilulissat only as a summer connection). In southern Greenland, Narsarsuaq airport is served by feeder traffic from Nuuk and Kangerlussuaq and a summer connection to Iceland. The main town in Southern Greenland, Qaqortoq (3,000 inhabitants) is only served by a heliport with a connection to Narsarsuaq.

In 1986 Greenland's Home Rule Authorities took over the internal traffic in Greenland. In 1995, it was decided that 4 towns should have an airport for fixed-wing aircrafts (799 metres runways) and from 1997 further 3 towns were included (Source 1). 6 of these were finished from 1998 to 2001, whereas the one at Paamiut was postponed to 2007 (Source 11).

The second largest city, Sisimiut (5,500 inhabitants) at the coast to the west of Kangerlussuaq and a few other towns have today connections to both Kangerlussuaq and Nuuk while the rest of the towns at the west coast including Qaanaaq to the far north are served by 37 seat Dash-8 from Nuuk or along the coast. The settlements along the west coast are served by helicopters from the nearby towns.

Tasiilaq (2,040 inhabitants) at the east coast has a heliport from where it is connected to an airport from WWII on a nearby island with the settlement Kulusuk (240 inhabitants). 800 km further to the north by the coast the town Ittoqqortoormiit (368 inhabitants) is also connected by a heliport to an air-stripe, Nerlerit Inaat, which was constructed at an oil exploration area. Both airports have connections to Iceland, making one-day visits possible. To the far north is located Thule Airbase at Pittufik, owned by US Air Force and not open for civil air traffic.

Air Greenland serves as it may be seen from Figure 1 nearly all airports and heliports in Greenland. Iceland Air Connect supplements with scheduled connections from Iceland to Nuuk, Ilulissat, Kulusuk and Nerlerit Inaat (the latter from the north of Iceland). Diskoline won a tender for the helicopter routes in southern Greenland and supplemented with several local routes in mid-Greenland and around the Disko Bay. Finally Kangerlussuaq has charter traffic to several international destinations supporting the growing cruise industry and Thule Airbase. The annual number of international passengers is less than

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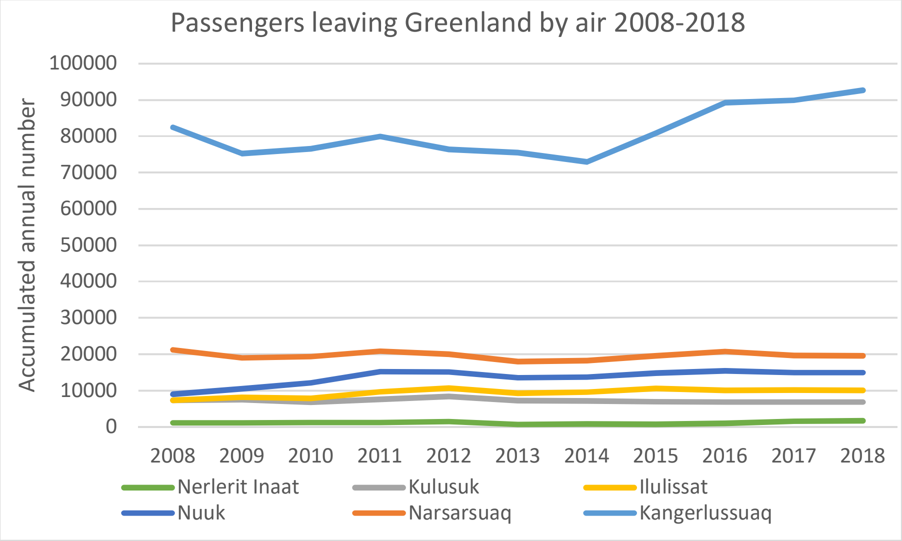
[5] For all sources, please consult the list after the references

200,000. It has increased by 12% since the crisis in 2008, see Figure 2. After Appendix 2, a figure with all passengers and airports is shown.

Figure 2 Accumulated number of annual outbound international passengers from each airport (Source: Statistics Greenland)



## 2 THEORETICAL FOUNDATION OF THE STUDY

The precondition for Greenlandic policy is the low population density and long distances internally in Greenland and to the population centres in North America and Europe. A main purpose of the COST Atard[6] Action of which this paper is a result has been to unveil the effect that airports have in peripheral and remote locations. The possible development of Greenland will therefore be discussed with an outset in the new literature about airports in peripheral and remote regions and the possible economic development these give rise to. Different evaluation methodologies and technical methods to plan an air traffic network are furthermore presented in the second part of the chapter.

### 2.1 Peripheral and remote location

Greenland is one of the most peripheral countries in the world. Being peripheral can be measured in several ways. Schürmann and Talaat, (2000) use a relative accessibility concept measuring e.g. kilometre road in each region or as access to the nearest node. Measured this way, Greenland is not peripheral as all towns and settlements have their own airport/heliport/helistop. More complex indicators are however needed to understand the implications of a peripheral location. Three types of indicators are identified in the literature: 1) 'travel cost' (includes both value of time and price) measuring the effort to get to a capital or to cities of a certain size, 2) 'daily accessibility', measuring the number of capital cities and cities of a certain size that can be reached by a one day's return travel, and 3) 'potential accessibility', measuring the number of activities such as jobs, markets, higher education and wealth, which can be reached, weighted by the effort needed to reach them in terms of travel cost (e.g. Halpern, 2020; Schürmann and Talaat, 2000; Spiekermann and Aalbu, 2004; Spiekermann and Neubauer, 2002).

Greenland as a whole is in all three ways very peripheral to more central places in Europe and North America: ticket prices are high, and it is impossible to visit an activity or city on a one-day trip due to long distances and the lack of direct connections. Many towns and all settlements are furthermore very peripheral in relation to the capital Nuuk.

An important purpose of the airport package is therefore to reduce the effect of peripheral location by shortening travel time and the need for flight connections to reach Europe and North America from

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[6] ATARD: Air Transport and regional Development

Nuuk and Ilulissat and to reduce the peripheral location of the towns in southern Greenland in relation to Nuuk and the central west coast.

Remoteness is defined by OECD[7] and can be distinguished between urban, intermediate and rural regions, which are defined at a TL3 level (in Europe NUTS3). According to this definition, a ’local unit’ (a smaller administrative unit than TL3) is rural when the population density is less than 150 inhabitants per square kilometre. The region, which is an aggregation of several local units, is predominantly rural in case the share of the region’s population in rural areas is more than 50%. On top of this comes additional criteria about cities with at least 50,000 and 200,000 inhabitants, which is not relevant for Greenland.

In the case of Greenland, the smallest administrative entity is the municipality of which Greenland currently only has four. For all, the density is less than 150 inhabitants per square kilometre due to big uninhabited landmasses and the icecap included in the municipalities. Nuuk might however be seen as intermediate when measured as the city of Nuuk separately.

Martini et al (2020) have addressed another problem when defining remoteness in the case of peripheral island regions as e.g. the Azores islands. These have high population densities and are therefore not defined as remote. Instead Martini et al introduced an ‘island correction’: They classify an island as remote if the driving/ferry time to the closest European inland city is more than 4 hours. Even though Greenland’s urban areas are not islands, they can be considered as ‘urban islands’ in a big mountainous nature without connecting roads. In this sense we will define Greenland and all the cities/towns/settlements as remote.

Low accessibility, peripherality and remoteness influence the development and economic performance of an area in question in relation to core regions. According to the development and dependency theories from the late 1960s and early 1970s, an uneven relationship exists between strong industrialised countries in the core and weak, mainly agriculturally based countries or regions in the periphery where the former countries are able to extract surplus from and impose unfair competition on the latter leading to their continuing economic disadvantage (Brown & Hall, 2000).  The high transportation cost places firms located within the periphery in a comparative disadvantage. Peripheral areas are more likely to have a low level of economic vitality and dependency of traditional industries, reliance on imported technologies and ideas and a remoteness from decision-making leading to a sense of alienation and lack of power, and poor information flows, infrastructure and amenities. Access to statistical information is limited, too (Botterill et al. 2000).

The dependency theory has later been criticised and the rise of new wealthy industrialised countries has shown that the theory is not working quite well. For many peripheral countries and regions tourism provides opportunities for economic development based on e.g. high scenic values or outstanding cultures. Many peripheral areas may also have abundance of natural resources for extraction and agriculture (Botterill et. al., 2000, Brown & Hall, 2000).

On the other hand, it has been shown that remote rural regions tend to experience slower population growth than other regions and sometimes even decline (Bollman, 2008, Brezzi et al, 2011).  Out-migration of the young generation from peripheral regions results in an aging population structure (Botterill et al., 2000). The employment rate is typically lower in remote rural regions and the growth rate of labour productivity is in most European countries lower in remote rural regions than in predominant urban regions (Brezzi et al, 2011).

Some of these structures are clearly observed in Greenland. According to Statistics Greenland (2017), life expectancy is only 68.5 years for men born in 2011-15 and 73.7 for women, which is far below the life expectancy in for instance Denmark. Important reasons are a high level of infant mortality and of suicides especially for young men aged 15-35 years. Greenland has had an annual net out-migration around 1% for the last 30 years. (Statistics Greenland, 2017).

Again, according to Statistics Greenland (2017), the labour force includes 74% of the 18-64 years old living in Greenland the full year and more than half of the employed population only has a 9 years of school education. The unemployment rate oscillated in 2012 to 2015 between 8% in the third quarter to

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[7] https://www.oecd.org/cfe/regional-policy/OECD_regional_typology_Nov2012.pdf

12% in the first quarter. It is higher in the settlements than in towns, and especially high for the youngsters (29% in the settlements). Fishery and catching/hunting including the on-land industry represent the main income for Greenland.

## 2.2 Peripherality, remoteness and air transport

One problem for peripheral regions is the low connectivity. Martini et. al. (2020) show that the connectivity from remote regions in Europe is lower than from intermediate and core regions. When measuring the connectivity as the average number of links needed to get from regions with airports in one country (measured at NUTS 2 level) to all other regions, the connectivity from remote regions has been oscillating around three in the period from 2008 to 2016 for remote regions, but only 2.7 for intermediate regions and 1.8 for core regions (core regions are 10 regions chosen by Martini et. al.) In this study, the connectivity of Copenhagen is 1.87 in 2016 which means that it is 3.87 for Nuuk, Ilulissat and a few other towns with direct connection to Kangerlussuaq or Reykjavik from where there is one link to Copenhagen (representing 65% of the population). For all other towns and settlements having an airport or a heliport with a scheduled air connection (32% of the population), the connectivity is 5.31 on average (counted at Figure 1). The last 3% are even worse off as only served by sea transport. In winter period towns and settlements are worse off, too. On top of the scheduled low connectivity come unstable connections due to fog, turbulence, and winter weather.

Another problem is the economic burden of the airports and air trafficking in remote areas. Small airports are not profitable and the same is the case with routes servicing minor towns and settlements. The profitability of small airports furthermore decreased during the first decade of the century (Müller et al., 2012). An econometric break-even analysis of 154 European airports showed that, on average, about 400,000 passengers annually were sufficient to cover operational costs of airports in terms of earnings before interest and tax in 2002, but by 2009, about 800,000 passengers per year were required to obtain break-even (Müller et al., 2012).

Halpern (2020) mentions that the number of jobs per passenger in Norway increases when the size of the airport decreases (except for Oslo which has many international passengers and taxfree sale resulting in more employees). This fact also results in an economic burden for the very small airports in Greenland which have to have a high level of security, risk avoidance and winter maintenance independent of the number of passengers.

Different kinds of governmental support, e.g. public service obligations (PSO), are needed in many countries around the world when airlines cannot offer service at reasonable fares and frequencies without subsidy (Fageda et al. 2020). Cross-subsidies between more profitable routes and minor routes or airports are quite common, too (Müller et al., 2012, Halpern, 2020). A main worry for the Greenlandic politicians over the years has been, if the needed PSO is too high due to lack of competition. Fageda et al. (2020) have made an overview of the PSO and similar subsidies. However, none of them are comparable with Greenland due to shorter distances and in most cases bigger societies.

In Greenland the airports are owned and run by a public organisation, Mittarfeqarfiit, and all routes except the three profitable routes between Kangerlussuaq and Nuuk, Ilulissat and Narsarsuaq are put out for tender every five years in order to find airlines that will offer the service with the lowest possible support. In Greenland, Air Greenland has won nearly all routes until he latest tender.

## 2.3 Air travel and regional development in remote regions

An interesting effect of the airport package is the possible positive effect of airports on regional economy. As part of the COST Atard Action the effect of airports on local economy in the remote and peripheral regions has been analysed. The effects can be divided into direct effects, indirect/induced effects, and wider economic effects (Huderek-Glapska, 2020, Gillen, 2020).

The direct effects are the employment and business effects in the construction period, changed cost of travelling, and the increased number of employees in the airports and airlines when the new airports are in service. They are rather easy to measure afterwards by, among others, conducting a survey among the local companies (Bråthen and Givoni, 2017), but also, in the forecast situation where experience from other airports and simple calculations of the need of employees can be estimated.

Indirect and induced effects are stimulating effects from the employees on income and employment in the surrounding area, the social impact of improved access, the effect on local economy of an increasing number of tourists, and the increased options for business and trade (Bråthen and Givoni, 2017, Gillen, 2020, Huderek-Glapska, 2020). Indirect effects can be forecasted by modelling, even though the social effects are more difficulty to measure (Halpern, 2020).

Gillen (2020) defines wider economic effects to be those portions of social value going to either consumers or producers that have not been fully internalized due to a market failure of sorts. In other words, he defines wider economic effects as additional social benefit or costs not captured by user benefits. They represent the long run contribution to productivity and GDP growth. Some authors add catalytic impacts as a supplementary concept different from wider economic effects (see e.g. Forsyth & Niemeier, 2016), while others mention them as similar (Huderek-Glapska, 2020). In this paper we follow Gillen (2020) and only use the phrase 'wider economic effects'. The wider economic effects of the investment are more complicated to assess and require an understanding and measurement of the changed mobility and economic activity.

The documents used for chapter 3 of the paper at hand use the phrase 'dynamic effects' which includes the effects of an increase in tourism. Such effects are according to our definition mainly indirect effects. They might however also include the opportunity to start up new companies attracting more tourists or producing new products needing immediate access to the European markets. In this sense it is a wider economic benefit of the airports.

As part of the COST Atard Action some of the studies analyse the relation between the development in number of air travellers and the development in the region. The following studies are interesting because they address regions with minor airports or airports in the peripheral parts of the countries.

Mukkala & Tervo (2013) use panel data from 1991-2010 for 86 core, intermediate and peripheral regions in Europe. Peripheral regions are all Spanish, Portuguese, and Norwegian regions, one Irish and one French region. They use a Granger non-causality method by which it is possible to unveil the direction of causalities. They show that for the peripheral regions there is a causality from number of air passengers to GDP and employment and from accessibility to GDP and employment. Especially the relation from air passengers to GDP is evident. Thus, air transportation plays a crucial role in boosting development in remote regions. The more peripheral the region is, the more important it is to have an efficient connection. For intermediate and especially core regions, airport activity does not cause regional growth according to Mukkala & Tervo (2013).

Ringbom (2020) uses economic panel data from 1980-2016 for the Finnish NUTS3 regions outside the Helsinki region to analyse the relation between regional economic development and air passenger traffic (regions without airports and a few other regions are excluded). He finds both a long run and a short run positive effect of production and investments on the volume of passenger traffic. Furthermore, there is a strong and significant long run positive effect from passenger traffic to economic activities, whereas the short run causality is weak. Mukkala & Tervo's (2013) do not distinguishing between short and long run effects, so perhaps their results are more long run effects?

Todorova & Haralampiev (2020) use regional panel data for 1995-2015 for the three main airport regions in Bulgaria to show a long run causality from a growth in GDP to a growth in number of air passengers. They find no short run causality and no causality from air passengers to GDP growth. The used panel data series is shorter than the one used by Ringbom (2020) which might explain why they are not able to identify any short run causality. Contrary to the two above papers, Todorova & Haralampiev (2020) analyse the relation for intermediate and core regions.

Button and Yuan (2013) find a Granger causality from volume of freight by air to differences in the employment and income. The relation is weak, so the authors only conclude the result to be indicative. The analysis solely includes big US airports why it cannot be used for remote airports. On the other hand, the above results seem stronger for remote or peripheral airports than for core airports. This suggests that the same might relate to air freight.

Finally, Freiria & Antunes (2020) analyse the impact of Oporto airport in the Norte Region around the airport. They provide evidence that Oporto Airport activity (measured by the number of employees and the aeronautical revenue in 2000-2016) has a significant impact on the economic performance of the region. They show that the impact can be stronger in the areas distant from the airport than in the closer ones. For instance, air transport activity had a significant impact on the industry in the areas distant from the airport, and not in the Greater Oporto area around the airport. The conclusion of this study is interesting for Greenland due to the interest in improving accessibility and development in other parts of the country, too.

## 2.4 Evaluation method

A common method to evaluate the effect of a new infrastructure is a cost benefit analysis (CBA). In a CBA analysis all cost and benefits of the investments and future changes in service and need for maintenance are expressed in monetary terms and represented in a common base year using a deflation rate which is normally defined by the authorities. The resulting net cost (or benefit) is compared to a base scenario without any investment. In the comparison, the internal rate of return and the cost-benefit ration are calculated. Normally these are used for comparison of different solutions for an investment (e.g. the localisation of an airport). For details, consult e.g. (Banister & Berechman, 2000). CBA is the only evaluation method used in Greenland.

CBA represents a systematic accumulation of the net effect of changed mobility and investment costs. However, it is a partial equilibrium technique and consequently inappropriate for analysing the wider economic impact of policies (Njoya & Forsyth, 2020). It is normally static and does not consider the path to (partial) equilibrium. While the CBA may account for employment effects due to the investment, it may not capture how jobs are transferred from other sectors.

## 2.5 Transport models and network optimization

The decision about the airport was technically based on the work by the Transport Commission (Source 11). The Commission took its outset in a traditional transport model in which the number of passengers and their travel pattern were determined on the basis of exogenous inputs, such as economic growth rate and spatial distribution of the population and tourists (see Table 5). The demand models were relatively simple multinomial logit models (Ortuzar & Willumsen, 2011) and not directly integrated in the model system in the sense that changes in the level of service can dynamically change the demand. Therefore, these models should mainly be seen as a means to form different scenarios for an investment decision.

However, another equally important purpose of the airport package could be to increase the travel frequencies and reduce the travel times between the settlements and the minor towns, and between the minor towns and Nuuk. To support such a decision, an airport and air traffic network optimization model (the TGB model) ordered by the home rule was developed in 2005-07 by DTU Transport.

The principles in the developed model are described in chapter 4. The model can be used to analyse alternative scenarios in more detail to find the optimal network configuration for each case. As a result, this paper is mainly focused on the route choice models and how these can be aimed at designing (and redesigning) the aviation network when taking into account the network design and the airport configuration.

The model is a bi-level optimisation model where, at the lower level, a Stochastic User Equilibrium (Sheffi, 1985) schedule-based assignment model (Nielsen & Frederiksen, 2006 & 2008) is implemented. This model incorporates capacity constraints and is able to handle the low-frequent nature of many legs. The assignment model is run on a weekly schedule to take account of the remote location of many destinations which are only served once or twice a week. The model can be used for both large strategic long-term decisions (where the policy makers need not to take all tactical and operational decisions into account, since the model optimizes these), for tactical decisions (e.g. on the air fleet composition and the leg structure), and for operational decisions related to flight schedules.

## 2.6 Available airplanes and need for runway

Decisions about which kind of airport to construct and the length of the runway depend on the available airplanes. For international airports with connections to Europe and the east coast of America, an airplane with at least 200 seats is expected by the airlines (Source 12), i.e. Airbus-200 or Boeing-757. These airplanes need a runway of at least 2200 metres. And even with this length they cannot take off (Airbus) or land (Boing) with a full load in the most challenging winter conditions (Source 11). With a runway of 1799 metres, only Boing 737 for 180 passengers can land with a full load. Unfortunately, only few airlines use the Boing 737 which makes the 1799 metres runway less attractive (Source 12).

As Greenland has nearly no agriculture, all fresh food must be brought in from abroad by air. Due to the limited population, the daily or weekly supply is so modest that it must be flown in the belly of the passenger airplanes. Of the actual airplanes in the market, the Airbus 330-200 that serves Kangerlussuaq today is best suited due to a much larger cargo capacity than the Boeing 757.

The Airbus is more expensive in operation cost (at the plane level); however, due to both a greater passenger capacity and a much larger cargo capacity, the cost per passenger and tonne cargo is lower at full load. It is also faster than the Boeing, which reduces the cost per passenger further and makes it more attractive for passengers.

Another consideration is the export of fresh fish and seafood especially from Ilulissat. For this a direct connection to Reykjavik is important because Reykjavik already exports fresh fish and therefore can be relied on for trade. Again, the big Airbus and a 2200 metres runway is needed.

In the lower end of demand, the problems with finding appropriate aircrafts are similar. The production of the 50 seats propelled Dash-7 was stopped already in the 1990s. Several reports from the late 1990s and early 2000s discuss the possibilities to replace Dash-7, because it is expensive to repair. Air Greenland has replaced Dash-7 by the Dash-8 with 37 seats. The last three were sold as late as 2015 to Canada where they are still in use. Unfortunately, production of Dash-8 was stopped in 2009 (Source 11).

In general, small jet airplanes are cheaper per seat kilometres than propelled aircrafts – in case they are full. And this is of course another problem in Greenland, as the settlements and towns are small and the number of passengers low. Luckily, many other villages, especially in Canada and Australia, need airborne contact with the outer world, so the production of small fix-winged aircrafts with less than 20 seats, e.g. DHC-6 Twin Otter, has been taken up again and the market is increasing (Source 11). For airports served by small airplanes with space for less than 20 passengers, the demand for security and risk avoidance is lower (e.g. the airport can share the fire brigade with the settlement, which is not allowed when taking down bigger airplanes[8]. Mittarfeqarfiit (Source 14) shows that nearly half of the operational cost for the seven small airports could be saved in case they are downsized to airplanes for less than 20 passengers. This might also be a reason why Dash-8 with 37 seats has gone out of production, it is too big for the small markets and not profitable for bigger markets.

# 3 OVERVIEW OF THE POLICY PROCESS

Since the Home Rule was established in 1979, the air transport system has been under constant discussion. The discussions have included e.g. location and size of the airports, free competition contra monopoly, fare systems and subsidies to the minor airports, heliports and helistops, service contracts, and types and sizes of aircrafts and helicopters.

## 3.1 Policy process up to 2009

During the first 20 years, Air Greenland got a subsidised basic contract with the Home Rule Authorities about domestic air service. The original one-fare system used by the former Danish State Company was replaced by differentiated fares with substantial subsidies from the Home Rule Authorities combined with cross-subsidies from the profitable routes between Kangerlussuaq and Nuuk, Ilulissat and Narsarsuaq, respectively (Source 1).

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[8] Security and emergency is regulated by ICAO. However, most of the regulation including emergency for small airports is only recommendations, which have to be specified in national rules. For Greenland and Denmark the rules are stated in the aviation law end detailed in BLs. (Civil Aviation Laws) BL 3-9 states the rules about fire and rescue service: According to point 3.2 fire and rescue service has to be established in case a public airport used for commercial transport is sanctioned for airplanes with a maximum load at 10 ton or more, or have 20 seats or more and transport one or more passengers.

### 3.1.1 Nuuk and Ilulissat airports

Already in 1991, 10 years after the airport in Nuuk was built, it was recommended that Nuuk should take over the international airport status. The next time the question was raised officially, was in a report from 1996 resulting in a decision in 1997 by the Home Rule Parliament not to expand Nuuk airport for the time being as there was more need for establishing fixed-wing airports in 3 small towns. Furthermore it was stated that the investment would be too high considering the expected growth-rate in traffic (Source 1).

A consultant report from 2001 assessed both an 1199 and an 1799 extension of the runway in Nuuk and an 1199 extension in Ilulissat (Source 2). The short runways would serve connections to Keflavik in Iceland, reducing the travel time to Copenhagen substantially. With the long runway in Nuuk, connections directly to Copenhagen would be possible and it was presupposed that Kangerlussuaq would be closed. This would result in extended travel time and an extra flight change for Ilulissat and all airports to the north of Nuuk, except in case the runway in Ilulissat was extended to 1199 metres. However, an extended runway in Ilulissat with connection to a hub in Keflavik would according to the report probably reduce the frequency due to bigger airplanes than those serving the route at that time. For all other passengers than those with destinations in Ilulissat or Nuuk, the fare would increase and so would the travel time and number of flight changes. The investments in the airport (see Table 1) were assessed to result in higher fares.

| **Location** | **Runway** metres | **Investment** million DKK, running prices | | | | |
|---|---|---|---|---|---|---|
| | | 2001 and / or 2002 | 2004 | 2007a / 2007b | Transport Commission | TGB model |
| Nuuk | 1199 | 80 | | | 122 | |
| Nuuk | 1799 | 406 | | 485 | 677 | 496 |
| Nuuk | 2200 | 670 | | | 927 | 733 |
| Ilulissat (current airport) | 1199 | 50 | | 56 | 73 | 56 |
| Ilulissat (moved airport) | 1799 | | | 670 | 769 | 685 |
| Ilulissat (moved airport) | 2200 | | | | | 1,011 |
| Qaqortoq | 1199 | 200-250 | 360 | 360-400 | 681 | |
| Qaqortoq | 1799 | | | 900 | 1,389 | |

Table 1 Assessed investment in extended or new airports dependent on location and length of runway (sources: See the used reports in the text)

As a result of a political process in the Home Rule Parliament and an announcement from SAS that they would close their connection from Copenhagen to Greenland in 2003, a ministerial report was presented the following year with a new solution (Source 4). By focusing on the Dash-7 aircrafts that were assessed to be outdated and had to be replaced by modern aircrafts with a need for longer runways, the report recommended an expansion of the runways in Nuuk and Ilulissat to 1199 metres and a new airport in Qaqortoq (combined with closing the airport in Narsarsuaq) without closing Kangerlussuaq. For all three airports it would generate a positive yield (16% for Nuuk, 10% for Ilulissat, and 9% for Qaqortoq based on a 25-year investment horizon). Contrary to the consultant report from the year before, the report did not expect a lower frequency to Ilulissat. Instead it focused on the opportunity to get more tourists from the American east coast and other parts of Europe than Denmark. Savings were found by replacing the Dash-7 aircrafts serving the new small airports by smaller fixed-wing aircrafts with less than 20 seats. This was possible for all airports but the one to the far north. (Source 5).

In the following years the ambitions for airport investments increased and a better understanding of the need to assess the whole airport infrastructure and air traffic network seemed to come about in the administration (Source 7, page 15) and the airport and network optimization model was ordered short after.

In 2007, a working group including representatives from the municipalities focused on development of trade and tourism (Source 8). It recommended a 2200 metres runway because of an expected need for airplanes with a capacity of at least 200 passengers and 25 tonnes of freight, which was actually used by Air Greenland to Kangerlussuaq (Airbus 330-200). A shorter runway of 1799 metres was expected to outcompete Kangerlussuaq without offering space for aircrafts with the capacity for the actual need for freight transport with fresh food etc. In Ilulissat, an extension of the existing runway to 1199 metres would not fulfil a need for export of fresh fish. However, the existing runway could not be extended further, and a more costly replacement to the north with a 1799 metres runway was recommended.

### 3.1.2 Airport structure in Southern Greenland

In 1998, Greenland Home Rule Authorities (Source 1) assessed that in case a new international airport (runway 1799 metres) should be built in Qaqortoq in Southern Greenland, it would cost at least 400 million DKK. If this should be financed by airport taxes and the passengers should save money from reduced fares, the number of passengers had to be at least tripled.

In 2000-2001 the infrastructure serving Southern Greenland was analysed by Buch and Partners (Source 3). They set up three main scenarios (see Table 1 for assessed investments):
- Maintaining Narsarsuaq as international airport
- Maintaining Narsarsuaq and establishing a regional airport (runway 1199 m) in Qaqortoq.
- Closing Narsarsuaq and establishing a new international airport (runway 1799 metres) in Qaqortoq.

The investment in an international airport in Qaqortoq was assessed to be so high that keeping the international airport in Narsarsuaq was the most profitable solution. It was shown that new minimalistic fixed-wing air-stripes at Qaqortoq and the other minor towns was more profitable than keeping the heliports in the two/three towns. A 100 km road between Narsarsuaq, Qaqortoq and the town nearby (Narsaq) was assessed to cost the same as a new international airport in Qaqortoq, whereas a road only between Qaqortoq and Narsaq was assessed to be twice as expensive as a minor regional airport in Qaqortoq. On top of these huge investments came running costs much higher than in Europe to keep the road open during winter. The road solution was therefore not economically profitable in any case.

SAS' decision to close service to Greenland changed the situation in Southern Greenland and the above mentioned ministerial report (Source 4) ended up with a positive result by *moving* the airport to Qaqortoq (runway of 1199 metres) and not to keep both as considered in 2001. The report also emphasizes that a new airport in Qaqortoq would improve the possibility to get more development in Southern Greenland and increase connections between Qaqortoq and the rest of the country.

In 2007 a mixed group with participants from the Home rule authorities and the municipalities similar to the one analysing the airport in Nuuk, was set up to analyse an airport in Qaqortoq. However, the participants from the municipalities were so frustrated about the missing action which had already been proven to be profitably that they instead wrote some angry letters in the report (Source 9).

The runway in Narsarsuaq was repaired for 30 million DKK in 2008-2010, a cost which could have been saved or reduced in case of moving the airport. The fixed-wing airport at Paamiut with only 1,380 inhabitants halfway between Nuuk and Qaqortoq was built in 2005-07 for 172 million DKK.

## 3.2 Policy process and final decision in the self-rule period

### 3.2.1 Transport Commission

In October 2009 Greenland's new Parliament decided to set up a Transport Commission and asked it to suggest a vision for the future, which could support the development towards independency. A main task for the Commission was to present recommendations for further political reading. (Source 11). The main part of the report from the commission was however thorough cost benefit analyses of different solutions for all airports in Greenland.

The Commission analysed 6 main project scenarios for Nuuk of which two consisted of two alternatives. In scenario one, Kangerlussuaq is maintained as international airport and the runway in Nuuk is extended to 1199 metres. In the rest, Kangerlussuaq is closed. In scenario 2-4 the runway is extended to 1199, 1799, and 2200 metres, respectively. In alternative 5 and 6 a new airport is built at different islands to the south of Nuuk with a runway at 3000 and 2800 metres, respectively. For both a shorter alternative at 2200 metres is included, too. The assessed investment in the expanded airport is shown in Table 1 for alternatives 2-4. It is around 50% higher than earlier. A minor part is due to inflation, while others are extra costs to a changed access road, a new airport building, a control tower etc. On top comes demolishing of Kangerlussuaq airport and replacement costs for the inhabitants.

Alternative 2 had the highest rate of return, 25.8% (see Table 6). With this alternative, Greenland has no international airport and all flights from Europe will need to have a hub in Iceland. This will cause loss of workplaces and income in Greenland in both the construction and operation phases. The Commission also found that the possibility of having an international airport in the country might generate some synergy effects which would not arise in case of a hub elsewhere. The Commission therefore could not recommend Alternative 2. Instead the Commission recommended alternative 4 with the 2200 metres runway that had the highest internal rate of return when looking apart from alternative 2 (14.8%).

For Southern Greenland, the Transport Commission analysed two alternatives to maintaining the airport in Narsarsuaq, one close to Qaqortoq with a runway of 1199 metres and another 10 km to northwest with a runway at 1799 metres that require an access road for around 200 million DKK. The overall investment is therefore much higher than the earlier assessments, see Table 1. A location closer to Qaqortoq offers less options to expand the airport.

The cost benefit analyses showed that the short runway is more profitable with an internal rate of return of 9.5-9.9% compared to 2.2% with the long runway. However, both alternatives are more profitable than maintaining the airport in Narsarsuaq. The short runway cannot be served from e.g. Copenhagen, all international air traffic needs to go via Kangerlussuaq or Keflavik resulting in increased fares and travel time. An alternative with a road to Narsarsuaq instead of a new airport was confirmed not to be profitable at all.

An internal rate of return of 2.2% for the long runway means that it is not profitable. However, with a higher demand, the profitability will increase. The Transport Commission therefore recommended the airport to be constructed with the short runway, however, with an option of future expansion in case of an increasing demand, when promising mines in southern Greenland are considered to be utilized.

The Commission also made an alternative analysis with a short road to the fiord leading up to the town Narsaq 20 km away. A road to the coast with a combined bus and boat connection during the summer season would reduce the travel time between the towns compared to the actual helicopter service. With two daily connections the internal rate of return would be 20.7% and the profitability of the long runway, would increase, too. However, the Commission did not assess the risk by using small boats with a capacity of only 20 passengers.

The analyses for Ilulissat included two project alternatives with runways at 1199 and 1799 metre, respectively. Due to the mountain by the end of the runway, the second alternative required the runway to be turned a few degrees. In both alternatives Kangerlussuaq is maintained. The first alternative has a low positive rate of return (2.3-2.4%) while the second's was negative. The Commission made some alternative analyses that included induced traffic from developed tourism. The internal rate of return was increased to 5.9-6.3% for the first scenario depending on between others the forecast in annual growth in BNP (see Table 7). In this case the second scenario still has a negative internal rate of return. The same is the case for an analysis with Kangerlussuaq closed. The Transport Commission therefore recommended an extension of the runway to only 1199 metres.

### 3.2.2 The Rambøll forecast of passengers in 2015

After the Transport Commission delivered their report in 2011 the preparation of the final airport package slowly started.

In 2015, a more thorough investigation of a possible development of the tourism as an effect of expansion of the airport in Ilulissat were made by a consultant (Rambøll) ordered by the Government of Greenland (Source 12).

The Rambøll report forecasts the number of tourists by comparing with the development in the tourism in three other North Atlantic destinations (Iceland, Svalbard, and Northern Norway), where tourism had increased substantially the former 5 years (data for 2010-2014 were used). Based on collected prices, a price elasticity of -4.5 for the holiday journey as a whole is estimated. This is however reduced by 30% to -3.2 for the further analysis due to a less developed tourism industry in Greenland with e.g. less hotels and fewer tour organizers. It is stated that the high price elasticity is only relevant for a shorter yearspan until a new equilibrium is found. For business travellers and residents, the price elasticity is lower, -0.5 and -0.8, respectively.

From comparison with other North Atlantic airports Rambøll assess the 2200 metres runway to be the right length. It opens up for connections to all Western European and North American destinations by medium size airplanes with 150-170 seats (200 seats to Copenhagen). A scenario with a 1100 metres runway has the highest internal rate of return (see Table 8). On the other hand, a 2200 metres runway will result in a higher net present value and opens up for induced income growth from more tourists and in the long run a wider economic benefit.

A runway of 1799 metres was considered, too. However, this will reduce the types of aircrafts, which can serve the route without seat-restrictions to medium-sized aircrafts. Not all airlines have these types of airplanes and the choice will therefore reduce the competition. Fares are assessed to decrease by only 10%. It was preferred that the length of the two runways were similar to make use of the same aircraft types and to use the airports as alternate airports in case of bad weather, they argued. The coastal airports are influenced by fog, turbulence or other kind of bad weather in 20% of the time (Source 11).

A runway of 2800 metres in Ilulissat has been considered too, based on a plan worked out in cooperation between the municipality and a private company (The Newport study, see Source 12). This size of airport could open up for wide body aircrafts from e.g. Asia and therefore a larger increase in number of tourists, the Newport study argued. However, Rambøll finds the forecast overoptimistic and doubts that a longer runway will attract bigger airplanes or more tourists from e.g. Asia.

### 3.2.3 The 2015 law preparing the final decision

The Government of Greenland presented in October 2015 a motion for an airport package consisting of:

- The runway of Ilulissat should be turned a little and extended to 2200 metre. It should be the future international airport.
- The runway of the airport in Nuuk should be expanded to 1799 metres with an option for further expansion to 2200 metres.
- In Southern Greenland a regional airport with a runway of 1199 metres with a possible expansion to 1399 metres at Qaqortoq peninsula and a road connected to a ferry to Narsaq should be projected.
- The two towns at the east coast of Greenland should have new airports prepared for more tourists from Iceland. These should be located close to the two towns so that an extra helicopter flight from the airports was no longer needed.
- Further investigation and analyses should be made about the future of Kangerlussuaq and Narsarsuaq airports, including the need and cost for repair of the runways and buildings at the former.

During the reading, the Parliament's Committee on Public Works suggested another motion in which the structure of the small airports and heliports should be changed with the purpose of reducing the overall cost and need for service contracts (PSO). Some of the heliports should be upgraded to airports with short runways for fixed-wing aircrafts with a capacity at maximum 19 passengers and some of the fixed-wing airports should be downsized to airplanes with a capacity of maximum 19 passengers. Regularity should be improved through modern technology in the airports. Runways should, wherever possible, be similar with a view to supporting the use of similar aircrafts at many airports. (Source 13)

According to the report from the Work Committee, which was signed by all parties, the airports in Nuuk and Ilulissat should be developed as the two main international entrances to the country, which would have consequences for Kangerlussuaq. Further investigations of the three airports should be prioritized. The work with the Report about Environmental Assessment should be started for the big airports.

The 5 projects were changed in the following way in the parliament decision:

- The runways of the airports in Nuuk and Ilulissat should be at least 2200 metres and in Qaqortoq and Tasiilaq (by the east coast) at least 1499 metres
- The ferry between Qaqortoq and Narsaq was given up and replaced by a regional fixed-wing airport in Narsaq.

For the first time, financing of the investments was considered. It was decided that establishing the airport should be carried out by a corporation. Instead of self-financing, which would reduce the possibility to finance and maintain the core welfare functions of the society, the committee preferred financing by private companies or public-private cooperation. It was presupposed that the government would negotiate contracts that secured the basic interests of the society and the best access to capital. Local companies should be given priority for work contracts.

### 3.2.4 Deloitte's cost benefit analysis and the criticism of the Economic Advisor

Deloitte (Source 15) has produced an economic analysis of three new airports at Nuuk, Ilulissat and Qaqortoq, consisting of a cost benefit analysis and an analysis of the capital flows. Both were based on information delivered from external sources and Deloitte had included them in accordance with the rules set up by the Greenland's Ministry of Finance. They used some of the same prerequisite as the Transport Commission (an investment horizon of 25 years and a discount rate of 4%). The value of saved travel and waiting time is not reported and no distortion loss was included because the airports should be financed by incomes from the airports and from savings at the small airports / heliports and the service contracts, they argued.

Two project alternatives were set up, one in which Kangerlussuaq and Narsarsuaq are replaced by heliports, and another in which Kangerlussuaq is maintained as a regional airport with a runway of 1500 metres. The former scenario is producing positive net present value of 280 million DKK, the latter a negative net present value of -241 million DKK due to extra investments of around 500 million DKK in Kangerlussuaq. The former had an economic break even in 2040.

The Economic Council report from May 2018 warned the government and parliament about the big risk they are taking by adopting the airport package (Source 16). E.g. a 5-10% increase in the investment will result in an extra cost of 180-360 million DKK, which can be compared with an estimated profit in 2041-43 around 270 million DKK, they argue. The Council advised the government 1) to ensure a very tight steering of the construction work and budget, 2) to expand the construction period by postponing the start of the second and third airport, 3) to reconsider the size of the runway in Qaqortoq as it is not profitable with the suggested length and 4) not to maintain the two airports in Kangerlussuaq and Narsarsuaq.

The Economic Council also criticized Deloitte’s cost benefit analysis from a more technical point of view. It points to several methodological mistakes and e.g. that they are not taking into account the expected reduction in flight frequency, especially during the winter period. Despite the criticism of the methodological mistakes, which would - in case they were corrected - lead to the conclusion that the basis scenario and the scenario with expansion of the runways were more or less equal, the Council expected the dynamic effects of more tourists to result in an important gain for the society. This is in fact the same conclusion Rambøll reached at.

## 3.3 Market and Fares

A main consideration for politicians in Greenland has been how to obtain better competition in aviation.

Even though Air Greenland's contract with the Home Rule Authorities was non-exclusive, in 1996 Air Greenland still had a monopoly in practice on all internal routes in Greenland. SAS had a license to the route between Greenland and Denmark by a contract that allowed a company from Greenland to serve the route, too. However, Air Greenland did not use the option and SAS had in practise monopoly on the international routes (Source 1).

In 1995, a government report recommended a partly free air transport market internationally as well as internally in Greenland. To change the two monopolies, in 1998 the Home Rule Authorities opened the three profitable fixed-wing feeder routes from Kangerlussuaq to Nuuk, Ilulissat, and Narsarsuaq to free competition (Source 1). However, Air Greenland was the only airline to bit. Contrary to the expected increased competition and lower fares, Air Greenland got a monopoly on the three routes. The airline even increased the already profitable prices in 2001 (Source 6).

A 2004 report suggested that the unexpected result was due to high fixed costs, long distance to other transport markets and a low number of passengers. Air Greenland was the only airline able to overcome the barriers and make a bit because they already had the service infrastructure in the airports. Hangars, workshops and material to fight the winter snow and ice had been given to Air Greenland Corporate when it was established. Furthermore, Air Greenland had the contracts on all the internal routes with subsidies. All other airlines would be far away from their home base with workshops and hangars and had to start up from scratch with new infrastructure investment (Source 7).

With the purpose of establishing a controlled private participation in transport by air to and from Greenland, it was furthermore legally stated in 1997 that any exclusive right for SAS to maintain external routes to Greenland was annulled. Air Greenland won the right for routes from Copenhagen to Kangerlussuaq and Narsarsuaq for 1997-2003 (Source 1). In the following years, SAS and Air Greenland shared the route to Kangerlussuaq. When SAS in 2003 stopped the Kangerlussuaq route because of low economic returns, Air Greenland got a non-exclusive contract for air traffic from Copenhagen until 2012. The airline also had unused permissions to routes to Iceland and Canada (Source 6).

A former direct SAS route between Copenhagen and Narsarsuaq during the summer period was closed in the late 1990s and replaced by an irregular route from Keflavik to Narsarsuaq (deduced from Source 3). With the purpose of strengthening tourism in Southern Greenland, the Home Rule Authorities made an agreement for 2003-05 with Iceland's transport ministry and Iceland Air about a three-month summer service between the two airports. The agreement was economically supported by both governments (Source 6).

A system with service contracts with state subsidies to serve the non-profitable destinations was furthermore decided. All contracts were implemented from 2001. They included increased fares to reduce the government subsidies. In the following years, fares were further increased especially from 2004 to allow more government budget for improvements in the education sector inside Greenland. The fares gradually changed, too, to become differentiated by cost, even though the more expensive helicopter service per seat kilometre still got higher subsidies than the fixed-wing service (Source 7).

With the tender in 2001 a small local airline got two contracts on helicopter service. The rest were signed with Air Greenland. However, with the new tender for the service contracts in 2005, the small airline lost again and was afterwards merged with Air Greenland (Source 10).

During the following years several reports discussed how the Home Government, and later the Government of Greenland, could get insight into the service contracts and the real needed level of subsidies to cover the cost for the domestic service. To this end, a report from Greenland's Competition Council (Source 10) presented several suggestions to increase competition inspired by practice in other countries with societies in need of public subsidies to their air service.

The main suggestion was that the administration's tender procedure should be shortened from 5 to 3 years in order to reduce the risk that a losing airline would ceased, closed service or retained from the market as it happened in 2005. With a shorter contract period the loosing airline could try again shortly after. A further improvement could be sequential calls in which groups of routes were put to tender each year. On top of offering a losing airline to bit on other routes the following year, it would increase the possibility for smaller airlines to bit on a minor group of routes one year and try for another group at a later call instead of risking to win too many routes with respect to their capacity. Another important suggestion was that all airlines should have equal access to the infrastructure in the airports. This requires that the airport owns the infrastructure and rents it out to the winner. An open Sky agreement should also be considered, the Competition Council suggested.

When the next call for tender for the internal routes was published in 2010, the call for tender was again published for a five years period and the contract was in 2014 furthermore extended to 2016 due to election in 2014. A few small airlines got contracts, of which several were unused. Finally, with the 2016-2021contract, a new actor, Diskoline entered the market with helicopter service in southern Greenland and several routes in Mid-Greenland and around the Disko Bay (see Figure 1).

## 3.4 Decision about the airport package

In accordance with the motion from 2015 the government had established a new organisation named Kalaallit Airports Corporate to maintain the development and run the new/expanded international airports. Six companies were prequalified to bit on the final airport package, one of these is Chinese, three were Danish or had Danish participants[9]. The Chinese participant was according to Danish press controversial.

After an election in spring 2018, a new majority government including three political parties presented a bill of a law for the airport package consisting of the expansion of the runways in Nuuk and Ilulissat to 2200 metres and a new airport in Qaqortoq with a runway at 1499 metres. As it may be seen, the airports at the east coast are left out of the package.

The recommendations from the Economic Council to expand the construction period over a longer time span is, however, not followed. Nevertheless, the Chair of the Government Kim Kielsen might have had doubts whether the investment would be too risky. At least, September 8th the Danish Prime minister turned up in Nuuk offering support from the Danish Parliament of one third of the investment and a similar share of the state guaranties. The offer was afterwards confirmed by the Danish Parliament.

Even though the agreement with the Danish prime minister must have been prepared in advance, it seems as if the rest of the government was not prepared for the suggestion. It resulted in the smallest and most nationalistic party leaving the government in anger. They protested against the further dependency on Denmark the investment would result in for Greenland and thereby postpone the final independency for Greenland. However, the government continued as a minority government and during the reading of the bill, another party supported the decision. Contrary to the decision in 2015, the final airport package was decided by only a small majority.

# 4 TGB MODEL APPROACH

In 2005 DTU Transport was asked by the Home Rule Authorities to develop an optimization model for airports, flight network, and choice of aircraft types. The model should be delivered to the administration, which should be able to run the model and analyse different solutions for changes in the airport structure. The work included three tasks 1) developing the model, 2) using the model to calculate cost benefit analyses for alternative changes in the airport structure, and 3) delivering a computer to the administration with the model installed, and teaching staff members how to handle the model. In the following, the model is described, and a couple of cost benefit analyses outlined.

## 4.1 Overview of the model system

The model framework can be considered as a representation of a “three player game” consisting of – and finding – the equilibrium between:

1. Home Rule Authorities decisions (which are fed into the system manually as exogenous assumptions)
    - The formation of the airport infrastructure (location of airports, length of runways).
    - Subsidies
    - Combination of routes in packages.
    - Minimum service frequencies.
2. Airline decisions
    - Combination of legs in a domestic network structure.
    - International connections.
    - Schedules and airplane allocation.
    - Fares.
3. Passenger decisions
    - Demand (number of trips, destinations, mode choice).
    - Route choice and departure time preferences.

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[9] http://kair.gl/da/2018/03/27/pressemeddelelse-3/

Transport planners will seek a solution which is optimal from the Home Rule Authorities' point of view (socio-economic optimum). However, while the Home Rule Authorities may decide on the infrastructure, it does not operate the airlines. As a result, it will only indirectly (through infrastructure changes) affect passengers and not directly through transport operations.

The model system can be used to optimize the network and schedules seen from the airlines' point of view. This can improve the economy of the airline but might also improve the performance from the passenger's point of view since more attractive services generate more passengers, higher load factors and more revenue.

The model system can also be used by the Home Rule Authorities to evaluate the socio-economic benefits for the society of the air traffic policies.

### 4.1.1 Outline of the model

The model system as a whole includes demand models and socio-economic impact models. These models forecast the overall tourist demand on the basis of socio-economic drivers such as GDP and population from selected countries. The paper, however, focuses on the interaction between the route choice models and the optimization model since these models contain the main innovative elements. These interacting models are then analysed conditional on the demand formation projected for different scenarios.

The optimization model designs the overall air transport network, i.e. the leg structure given the localization of the airports (including heliports), departure times, and types of aircrafts in operation, and calculates the cost of operation including the number of aircrafts needed.

The route choice model assigns passengers and freight (separated into mail and other freight) to the air transport network. The model operates with exact timetables, and takes into account seat and weight constraints on each leg. Passenger choices in the network are modelled by the route choice model. However, the available route options depend upon the network design, i.e. the leg structure, the departure times, and the aircraft used (fast jet planes contrary to slower propelled airplanes and helicopters), which is formed by the optimization model. Each type of aircraft has seat and weight capacity restrictions dependent on runway length and time of year (winter constrains) that have to be considered in the route choice model.

In operational research (OR), the model can be seen as a bi-level problem with optimizing the network at the upper-level and modelling user behaviour at the lower-level. The optimization of the network at the upper level depends upon the passenger flows, which are modelled at the lower level, while the flows at the lower level depend upon the air transport network, which is generated at the upper level.

The work thus illustrates how a very complex planning and optimization problem can be solved by combining traffic modelling and optimization models.

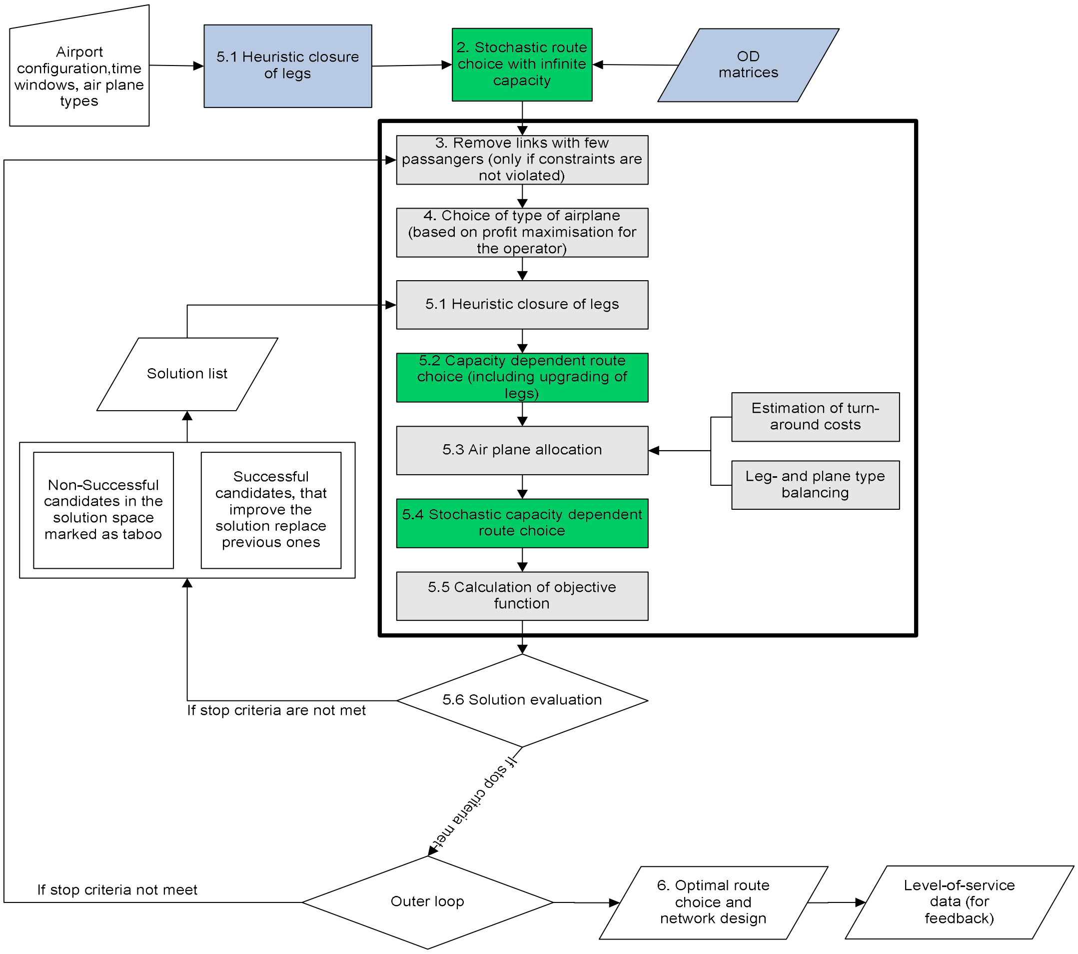
### 4.1.2 Stepwise description of solution

Although the model theoretically is a bi-level problem with an upper-level optimization of the network and a lower-level modelling of user behaviour, there is no clear decomposition between the two levels in the implementation of the solution algorithm framework (see Figure 3). The lower-level optimization model has to be run numerous times in the model flow. Moreover, the upper-level problem is not a single model, but a bundle of several modules put together sequentially. In addition, there are external modules, which generate a gross-network and determine demand. These are exogenous to the optimization process and will not be described in detail in the present paper.

The idea of the solution algorithm is first to remove clearly infeasible legs in order to narrow down the solution space. When this has been obtained, a taboo search algorithm takes over, where potential improved solutions are examined.

In the algorithm, the main focus is on separate legs that are optimized individually. This is only possible to a certain extent, because it may imply inconsistencies in the final solution. These inconsistencies occur because the schedule may be unbalanced (a different number of flights in and out of an airport). As a result, modules that balance the network and the airplane usage have been implemented in the optimization heuristic.

Figure 3: Overall model structure.



The main solution approach (see Figure 3) follows 6 steps:

**Step 1:** A gross network is generated:

- A matrix of all possible legs between airports is defined
- The level of detail of the schedule is set to a precision of departure times at half and full hour for all destinations.
- Feasible aircrafts for each leg are defined. The feasibility of a given leg depends on:
  - The lengths of the runways at the origin and destination airports (how large airplanes can be served).
  - The distance range of each airplane type.

**Step 2:** Route choice with no capacity constraints (the "optimal" passenger schedule) is estimated (see Section 4.2).

**Step 3:** Links with very few passengers are deleted (However, only to the extent this does not violate minimum service constraints). Since the (gross) graph is enormous, this heuristic was added in order to reduce the optimization problem to a size that is solvable by methods in the later phases of the overall optimization algorithm.

**Step 4:** Airplane types are allocated. Calculations are based on weekly schedules with a phase-in and phase-out period of 3 days:

- Each leg can be operated by a list of possible airplane types with different sizes and operations costs

- Based on modelled passenger potentials, all legs are downgraded to the optimal type of airplane based upon pure business economic decisions (the airline objective function)

**Step 5:** Iterative network improvement (taboo search algorithm);

- 5.1: Closing legs with the lowest utility given a set of minimal criteria for operations. A "taboo" flag indicates the legs, which have not been investigated yet.
- 5.2: A new network traffic equilibrium assignment of passengers is run to reallocate flow after the leg has been closed. After 5 iterations with the assignment model, airplanes may be upgraded during assignment if they cannot serve the demand (within the allowed types of airplanes for the specific leg, see 4.2.4). The network is afterwards redesigned due to possible increased speed of the allocated airplane (large airplanes may fly faster).
- 5.3: Airplane allocation and scheduling. This step includes estimation of turn-around costs and turn-around time (Section 4.2.6), and balancing of legs and airplanes on airports using a heuristic method (section 4.2.7). The balancing of airplanes means that some legs have to be served by larger and faster airplanes than in step 5.2.
- 5.4: A new stochastic capacity dependent route choice is run given the fixed new network resulting from step 5.3.
- 5.5: The overall utility function is calculated. If this is improved compared to the prior iteration, the changes take place, otherwise, they are regretted and marked as taboo.
- 5.6: Stop criterion (either that all legs have been analysed for closing, or a certain number has been examined – e.g. the 100 candidates with lowest utility).

**Step 6:** Final route choice model.

Steps 3-5 are repeated nine times with gradually increased restrictions and accuracy of the assignment models, and with larger requirement to number of passengers (step 3) and with more legs to be examined in step 5.6.

This heuristic first uses a passenger-based approach to reduce the possible solution space (step 3). In practice this approach reduces the problem size with respect to number of legs from 50,750 to 1,971 in the base scenario. This reduces the optimization problem to a size, where a more advanced optimization heuristic takes over. Table 2 illustrates the model configuration that had been found most efficient- "Minimum passengers" define the threshold below which legs are removed without further analyses. "Iterations" define the number of iterations in the inner loop (taboo search). The first 5 steps are only used to re-estimate the solution when removing legs due to the "Minimum Passengers" criteria. However, the taboo search is run twice for technical reasons in order to re-evaluate the objective function and solve the lower level assignment problem.

| Outer loop step | Minimum passengers | Iterations in the taboo search (inner loop) | Assignment iterations | Runs (legs) |
|---|---|---|---|---|
| Gross network | | | | 50,750 |
| 1 | 0.1 | 2 | 15 | 9,462 |
| 2 | 0.2 | 2 | 15 | 6,960 |
| 3 | 0.5 | 2 | 15 | 3,470 |
| 4 | 1 | 2 | 15 | 2,406 |
| 5 | 1.5 | 2 | 15 | 1,971 |
| 6 | 3 | 50 | 20 | 1,176 |
| 7 | 3 | 50 | 20 | 1,119 |
| 8 | 3 | 100 | 25 | 1,114 |
| 9 | 3 | 200 | 25 | 991 |

Table 2 Model configuration of the outer loop.

From step 6, a heuristic is used for the calculation of the optimal airplane disposition and scheduling in the outer loop (Step 5.3 in Figure 3). The method for this sub-problem, consist of two core elements: Calculation of turn-around time as a lower level sub-problem and balancing of airplanes as the upper level sub-problem, where the cost of balancing is given by the lower level calculation. This heuristic provides a much more precise estimation of the object function value than just the passenger flows. However, it was first found feasible to solve this problem within a reasonable calculation time for network sizes below 5,000 legs, and it did not add much to the solution before the minimum passenger threshold was set to 3. As the network is improved, the number of "assignment iterations" (MSA) is increased in order to improve convergence in the route choice. Furthermore, as the network becomes smaller, the assignment run time becomes lower, too. A more rigid optimization model was attempted for the airplane allocation by formulating this as a mathematical problem (MP) and solving it by MOSEL and XpressMP[10]. This, however, was only possible for problems up to 600 legs and was too slow to be run iteratively with the time-table and leg optimization models. It was also necessary to introduce simplifications of the mathematical model in order to solve it. In the final model, it was therefore decided not to use the MP model but only the heuristic procedure (refer to Section 4.2.7) for the last step as well.

All-in-all using the above combination of heuristics made it possible to optimize the air network in Greenland conditional to the passengers' choice of route and departure time.

### 4.1.3 Optimization the socio-economic performance

The object function of the optimization model $Z(X \mid Q)$ as given in formula (1) is assumed additive separable in passenger utility $U(X \mid Q)$, operation cost $C(X \mid Q)$, and fare revenue $F(X \mid Q)$. Formulated in this way it facilitates an explicit weighted formulation of the "three player game" as described in Section 4.1. $Q$ defines the exogenous setup including the infrastructure, airport configuration, and overall demand. $X$ defines the solution-space related to the decisions of the airline, e.g. the upper level problem. The solution space for the lower level heuristic that describes passenger behaviour is essentially a mapping of $X$ and $Q$, e.g. $G(X,Q)$. This conditional relationship between passenger utility and operational decisions is the workhorse of the model since it facilitates the looping between the lower and upper level heuristic.

$$(1) \qquad Z(X \mid Q) = \beta_1 U(X \mid Q) + \beta_2 C(X \mid Q) + \beta_3 F(X \mid Q)$$

The function is maximized, and the parameterization of the three components will affect the layout of the resulting air network $X$.

The passenger utility $U(X \mid Q)$ is a function of frequency (disutility of few departures), waiting time, travel time, transfer time, number of transfers (the extra disutility of transferring), and fare. These quantities are calculated by the lower-level model as will be discussed below in Section 4.2.

The costs of operations $C(X \mid Q)$ include take-off costs (including handling at the airport), a distance dependent cost, and a turn-around cost. The turn-around cost is the costs of not using the airplane between arrival and departure, i.e. lost return of investment and personnel costs. These costs depend on the type of aircraft and usually increase with the size of the aircraft. However, the unit cost per PAX (passenger) is usually lower for larger aircrafts. For instance, in Greenland, helicopters have to be used to locations without runways (heliports and helistops), however, helicopters have a much higher unit cost than airplanes.

The $F(X \mid Q)$ revenue is a direct mapping of demand and the network structure. Fares are determined in an exogenous manner.

The two overall optimization criteria for the service network design are partly conflicting;

- To minimize the operations costs and maximize revenue (airline objective)
- To maximize the utility for passengers and the society (socio-economic objective)

These criteria can be generalised by a combined object function;

$$(2) \qquad \underset{\{X\}}{Max}\, Z(X \mid Q) = \underset{\{X\}}{Max}\left[\beta_3 F(X \mid Q) - \left(\beta_1 U(X \mid Q) - \beta_2 C(X \mid Q)\right) \mid \beta_1, \beta_2, \beta_3\right]$$

The object function can be configured as pure company profit maximization, i.e.

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[10] http://www.dashoptimization.com/home/products/products_overview.html.

(3) $$\underset{\{X\}}{Max}\, Z(X \mid Q) = \underset{\{X\}}{Max}\left[\beta_3 F(X \mid Q) - \beta_2 C(X \mid Q) \mid \beta_2, \beta_3\right]$$

Normally it is reasonable to assume that airlines try to maximize this objective and that the route network would reflect such function in a completely free market. $\beta_3$ may, however, be less than 1, if the fares include taxes.

The function can also be configured as a pure socio-economic optimization, i.e.

(4) $$\underset{\{X\}}{Max}\, Z(X \mid Q) = \underset{\{X\}}{Max}\left[\beta_1 U(X \mid Q) - \beta_2 C(X \mid Q) \mid \beta_1, \beta_2\right]$$

In other words, the passengers should obtain a minimum generalised travel cost taking the operation costs into account. This socio-economic optimization results in a different route network than the operational optimization. In case of substantial differences between the two solutions, it could favour regulations, e.g., a change in the operational conditions through subsidies or taxes and duties.

It can be argued that since a share of the ticket revenues is submitted to the Greenland Home Government, the socio-economic optimization might also include some of the ticket revenue in the socio-economic evaluation (i.e. $0 < \beta_3 < 1$), especially concerning the revenue that comes from foreigners. The revenue might also be considered less distorting for the economy than the tax on income (less tax distortion). From the point of view of the Greenland Home Government it could also be argued that the operation cost has a partly increasing effect on employment and that $\beta_2$ should be less than 1.

In political analysis it is possible to run sensitivity calculations and to evaluate the optimized structure of the route network given different assumptions and political priorities. The applications implemented so far, however, have used a purely operational configuration as it is presumed that Air Greenland primary designs the route network based on profitability considerations. It is presupposed that only a minimum service demand is set up by the service contract.

## 4.2 The route choice model

The route choice model at the lower level is formulated as a Stochastic (Mixed Probit) Multi-class User Equilibrium Model (Sheffi, 1985). A special capacity consideration is that mail has the highest priority so that postal sacks can literally replace passengers within the cabin of domestic airplanes. Passengers, on the other hand, have a higher priority than ordinary freight. Due to these special capacity restrictions in combination with the need for a schedule-based assignment model, the model cannot be solved analytically. More specifically, the model is a non-analytical non-linear non-continuous mapping of the solution to the upper level optimization problem, which itself has a calculation complexity that necessitates a combined use of heuristics and exact solution algorithms.

### 4.2.1 Passenger behaviour prediction – the lower level problem

Each passenger is assumed to maximize his/her own utility. As a result, each individual faces an optimization problem, which he/she tries to optimize due to constraints and his/her preference structure. If the utility function of user $n$ and route $r$ is given by $U_{n,r}$ utility maximisation will imply that if route $r$ is selected then $U_{n,r} > U_{n,r'}$ for all $r' \neq r$. If the problem were formulated as a deterministic problem, the solution would be trivial in that the route with the best utility would be preferred. However, since passengers typically have partly incomplete knowledge of alternatives and have different preferences as well, a stochastic representation is preferable. Due to this $U_{n,r}$ is formulated as a random variable where random components are represented in various forms.

Due to the specification of passenger utility, the complete model operates with two different objective functions in the traffic model and the optimization model, respectively. In the traffic model the objective function describes preferences of the passengers (e.g. time and cost trade-offs) and includes a random term and stochastic coefficients in order to more realistically replicate true route choice behaviour.

### 4.2.2 Route choice model description

The passenger route choice model finds the stochastic user-equilibrium, i.e. the situation where no passengers' perceived utility can be improved by his/her unitarily changing route at the desired time of departure.

The route choice is assumed dependent on trip purpose, preferences of passengers, and the use of time. For all airports, capacity restrictions with respect to aircraft types and the number of passengers per airplane is needed due to the short runways. The three current international civil airports were served by a 245 seat Airbus-200 (Kangerlussuaq), a 180 seat Boing-757 (Nasarsuaq) and Fokker 50 (Kulusuk).

The strict capacity restrictions combined with the low frequency of many legs leads to the decision to implement a Stochastic User Equilibrium (Sheffi, 1985) schedule-based assignment model (Nielsen & Frederiksen, 2006 & 2008). The assignment is run on a weekly schedule in which some legs are only served once or twice a week. In addition, the model is modified to reflect special issues in Greenland.

Firstly, since passenger capacity is a strongly limiting factor in the network, passengers may simply be rejected if an airplane is full and not only delayed as in classical equilibrium traffic assignment models. To be more specific, special attention was paid to four issues as seen below;

- The higher priority of airmail compared to passengers, and passengers compared to cargo results in a need for a sequential conditional approach to model this instead of a traditional multi-class equilibrium method.
- Payload restrictions may restrict the number of passengers and the amount of cargo.
- Passengers may even have to wait until the next week or they may origin from the week before. First a cyclic graph approach was explored. Eventually, a before and after demand and network period was preferred.
- Airplane schedules for a full week have to be part of the model.

Ideally, the full week schedule means that the week should represent equilibrium where demand and supply are in balance. However, passengers travelling close to the edges of the time-band (the week) usually get improper schedules because they are either forced back (an early departure) or forward (late departure during the week). Some persons may even not get a flight at all. To overcome this problem, we introduced phase-in and phase-out periods before and after the model week. A three-day extension of the time-window turned out to be sufficient.

### 4.2.3 Utility functions for passengers

The utility function for the choice of route for different trip purpose for passengers include a range of different attributes that express the relative indirect utility of the routes (see Table 3). This function include early departure penalty (variation of "hidden waiting time"), late departure penalty (traditional "hidden waiting time), travel time (traditional in-vehicle-time used in the airplane), transfer time (time between the exit and entry of planes), transfer penalty (disutility by non-direct travels), overnight penalty (disutility and cost when overnight transfers/stays are needed), cost (fares) and an error term. Table 3 also includes a variable for weight per seat that describes the average weight per passenger including luggage and weight units for mail and cargo. The ranking of travellers, mail and cargo was taken care of by a set of flag variables.

The behavioural parameters all followed log-normal distributions (over the population) in the model, with the relative size between passenger classes and time components based on experience from Denmark.

### 4.2.4 Capacity restrictions

In each of the three assignment steps described in Section 4.1.1, capacity restraints are included. Air mail has higher priority than air freight within the cargo room and air mail will in some cases also have higher priority than passengers within the airplane cabin. This means that air the mail sacks (typically as a multiply of four seats) are placed on the seats (up to a certain amount of seats). For each departure, the capacity constraints were examined by the model by taking all these elements into account.

| Parameter | Business | Tourism | Visiting | Mail | Cargo |
|---|---|---|---|---|---|
| BASIS Value of time | 2.29 | 1.62 | 1.62 | 1 | 0.5 |
| Access time | 3.435 | 2.430 | 2.430 | 1.500 | 0.750 |
| Variance | 0.3435 | 0.2430 | 0.2430 | 0.1500 | 0.0750 |
| Change time | 0.916 | 0.648 | 0.648 | 1 | 0.5 |
| Variance | 0.0916 | 0.0648 | 0.0648 | 0.1000 | 0.0500 |
| Time to airport | 2.748 | 1.944 | 1.944 | 1 | 0.5 |
| Variance | 0.2748 | 0.1944 | 0.1944 | 0.1000 | 0.0500 |
| Hidden wait time in zone | 0.687 | 0.162 | 0.486 | 1 | 0.5 |
| Variance | 0.0687 | 0.0162 | 0.0486 | 0.1000 | 0.0500 |
| Change penalty | 137.4 | 97.2 | 97.2 | 0 | 0 |
| Variance | 6.87 | 4.86 | 4.86 | 0 | 0 |
| Early departure | 0.687 | 0.162 | 0.486 | 1.000 | 0.500 |
| Variance | 0.069 | 0.016 | 0.049 | 0.100 | 0.050 |
| Ticket price | 1 | 1 | 1 | 1 | 1 |
| Variance | 0 | 0 | 0 | 0 | 0 |
| Distribution type | 7 | 7 | 7 | 7 | 7 |
| Variance | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Weight per seat | 100 | 100 | 100 | 100 | 100 |
| Seats in plane | 1 | 1 | 1 | 1 | 0 |
| Cargo room | 0 | 0 | 0 | 1 | 1 |
| Ranking Load | 1 | 1 | 1 | 0 | 2 |

Table 3 Parameters in the route choice model (Value of time units are DKK/Minute, other values are in DKK)

### 4.2.5 The network design model

The role of the network design model, which was introduced in Section 4.1.1, is to design the air network. This involves:

- Design of a leg-structure, e.g. which cities should be connected with direct connections.
- A route-schedule, in the model formulated with discrete departure times (30 minutes segmentation).
- Use of aircrafts (types and numbers).

This is calculated conditional on the expected passenger flows, which are the results of the mapping of the route choice model (and the OD matrices) on the output of the network design. In the solution algorithm, the optimization model and the route choice model is run iteratively in a taboo-search algorithm.

A central point in the model is the conversion from a leg-wise optimization (optimization link-by-link without considering bindings between legs) to an optimum, in which the flight-schedule corresponds to a balanced network. If the network is not balanced, a situation with more incoming than outgoing airplanes (or vice versa) in a given node (airport) may occur.

To create a balanced network a separate leg-balancing heuristic was implemented (See section 4.2.7). A second problem was to calculate correct turn-around costs. This was implemented in a separate turn-around cost model (Section 4.2.6) that distinguishes between three cost-components for each plane in operation, e.g. departure costs, flying time, and waiting cost.

The calculation of turn-around costs and time runs iteratively with the airplane balancing. This is because each change of airplane type at a leg (leg balancing) may change the turn-around costs and times for both the departure and arrival airport. This, in turn, requires a recalculation of the model concerning types of airplanes.

### 4.2.6 Turn-around times and costs

For the first arrival in an airport, the turn -around time is calculated as the departure time for the next departure by the specific type of airplane (after a minimum buffer time) minus the arrival time. If the airplane is staying overnight the waiting cost is reduced, since the model only operates with hours of allowed operation. Also, if the turn-around time is high (more than a day), the number is reduced since the airplanes must be assumed to be reallocated in this case. This calculation is then repeated for the next arrival, etc.

The turn-around cost, *C(e)* is then calculated as

$$C(e) = DepartureCost + T(e) \cdot WaitCost + FlyingTime \cdot FlyingCost \qquad (5)$$

The "WaitCost" is here a function of a fixed cost, waiting time, and time dependent cost.

This procedure is repeated for all airplane types and for all airports.

### 4.2.7 Leg balancing

The general principle in the leg-balancing model is to ensure balance of arriving and departing airplanes for each airport one by one. By starting with the airport with the fewest number of legs, the balancing problem with the fewest degrees of freedom is solved first. In this way the algorithm finishes in the largest hubs (Nuuk, Kangerlussuaq) where it should be easier to ensure a balance. Even if there is a lack of balance here (e.g. from 45 to 44 legs), it is in relative terms less problematic than if a small airport is assigned 1 from-leg and 2 to-legs.

The principle in the leg-balancing is to successively remove legs until balance is met. Subsequently balance is ensured by airplane types by upgrading legs to larger plane types if possible.

The general airplane optimization model deletes legs one by one (or several legs in one process, but without considering balancing). This meant that initially up to 50% of all airports were unbalanced. However, because many airports meet the minimum service constraints, it is in practice less.

After running the heuristic for the leg-balancing, most - if not all - airports were balanced. Only in very special cases balancing may not be met. After the leg balancing the balancing of plane types was carried out. Overall, the heuristic ensures an efficient solution to the balancing problem, which from an MP viewpoint has great computational complexity. This in turn ensures that the input to the optimization model complies with a realistic flight schedule. However, it should be underlined that even though balance is ensured, a final plane optimization model may still upgrade legs in order to reduce turn-around costs. Also, it may in rare occasions be beneficial to introduce empty legs.

The practical implementation and the calibration of the model turned out to be complex. For instance, the fact that we have had limited information regarding the business model of Air Greenland gives rise to uncertainty in the measurement of production costs which in turn may cause the model to be biased. However, in the final version, the model was able to replicate the network in the reference year sufficiently.

### 4.2.8 Application of the model in practise

After having developed the network optimisation model it was applied to test both in for a base year and for future scenarios. Some of the major changes in the airport structure which were up to discussion were tested and compared to the base year situation.

### 4.2.9 Base-year situation

The first test was how the model would optimize the network for the base-year situation compared to the existing network. It turned out that the model found a better solution in terms of socio-economic benefits when compared to the benefits resulting from present network. The general difference was that more frequent departures with smaller airplanes were proposed. Naturally, this would imply a change in the overall fleet of aircrafts. Nonetheless, this was decided to be the base of comparison for the International Airport scenarios in order to have the same assumptions and configuration of the model in the base year and in the scenarios. It is also clear that complete insight into the business model of Air Greenland and the associated operating costs as well as knowledge of various restrictions not considered in the model (e.g. pilots) may change the model baseline.

### 4.3 Location choice and size of a new International airport

The application of the model framework to a real-world problem was slightly more complicated than just running the framework illustrated in Figure 3. The problem is that very significant changes to the infrastructure are likely to give very significant changes to the transport demand, e.g. improved infrastructure will increase and relocate demand.

Figure 4: Modelling strategy for evaluation of future scenarios.

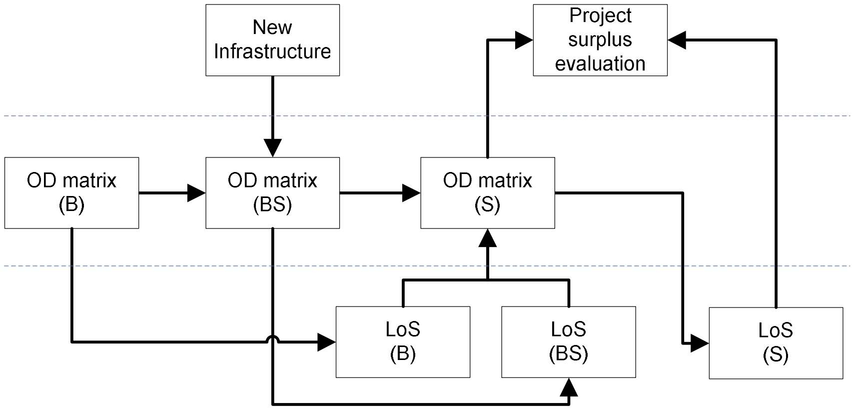


Figure 4 illustrates the modelling strategy where;

- “B” refers to the baseline situation with unchanged infrastructure and, “BS” to the baseline scenario.
- “BS” is the situation with changed infrastructure, but no induced demand.
- “S” is the scenario situation with changed infrastructure and induced demand.
- OD matrix is Origin and Destination demand matrix, and LoS is Level of Service matrices

In a conventional transport model context, there will be no distinction between the B and BS OD matrix. However, in this particular case, the old international airport (at Kangerlussuaq) is closed in order to free personal and save maintenance cost for the Kangerlussuaq runway. In order to tackle this, the model framework is processed for the B and BS OD matrices in order to get Level of Service (LoS) data that are subsequently used to forecast the induced traffic (this is partly carried out by an elasticity model). The induced traffic, measured by the OD matrix S, is then processed in the model to get a final flight schedule and aviation network, which in turn result in final LoS data. The combination of LoS data and the OD matrix S finally provides the project surplus.

The practical implementation and the calibration of the model turned out to be complex. For instance, the fact that we have had limited information regarding the business model of Air Greenland gives rise to uncertainty in the measurement of production costs which in turn may cause the model to be biased. However, in the final version, the model was able to replicate the network in the reference year sufficiently.

## 5 COST BENEFIT ANALYSES

In this chapter, the three main CBA developed by DTU, the Transport Committee and Rambøll are described in more details.

### 5.1 Application of the TGB model for international airports in Nuuk and Ilulissat

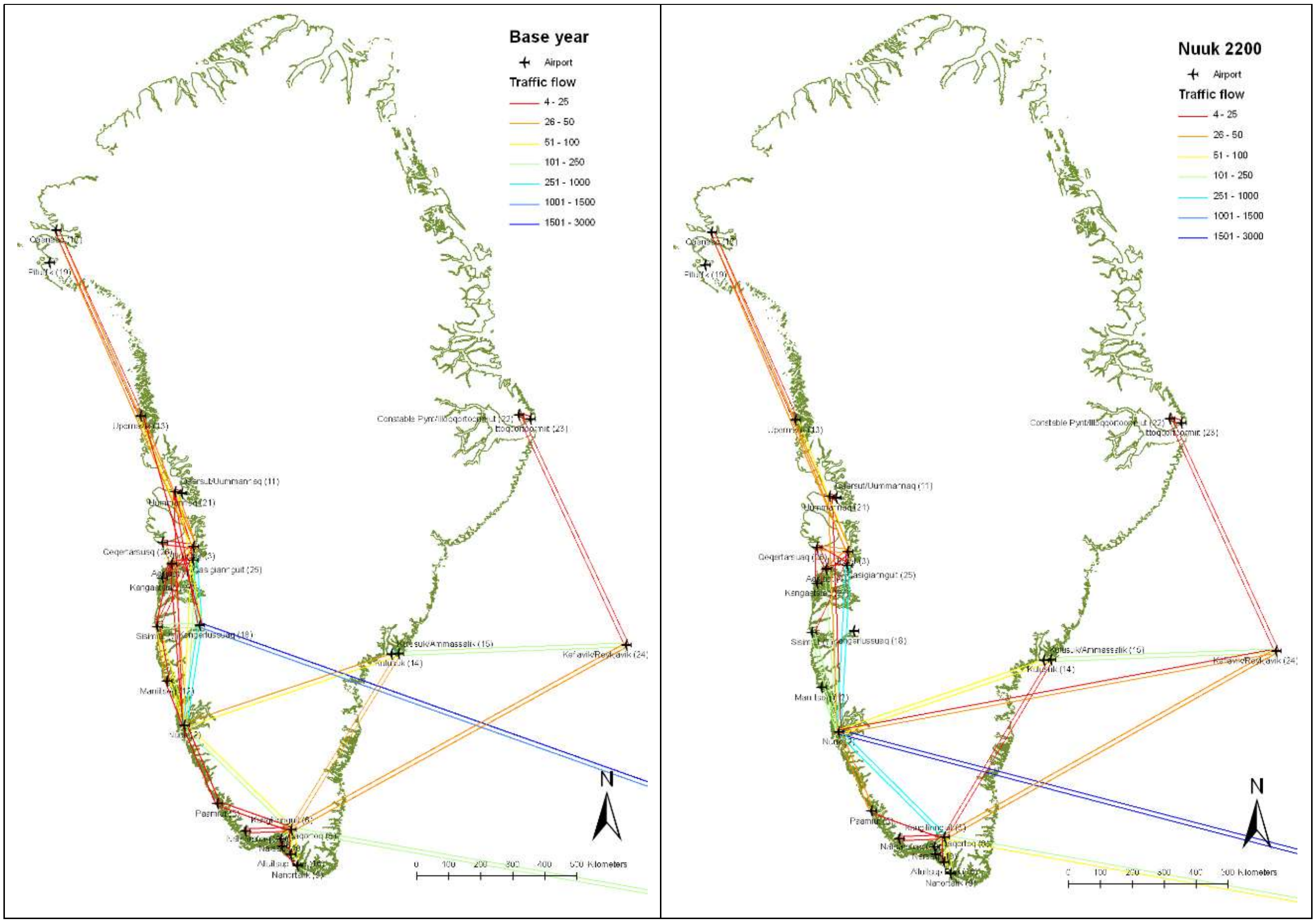
To facilitate the decision concerning relocation of the international airport in Kangerlussuaq and extension of the runways in Nuuk and Ilulissat, the TGB model was applied to three different scenarios for each city, i.e. 1799, 2200 and 3000 metres for Nuuk, and 1199, 1799 and 2200 metres for Ilulissat, respectively. The alternatives are compared in a social cost-benefit analysis and benchmarked to a base situation in which the location of the international airport remains in Kangerlussuaq. Apart from the difference in runway lengths, there are considerable differences in construction and maintenance costs (see Table 1 for the used construction cost) and also in the demand estimates, especially for tourists.

| | **Nuuk, Runway in metres** | | | **Ilulissat, Runway in metres** | | |
|---|---|---|---|---|---|---|
| | 1799 | 2200 | 3000 | 1199 | 1799 | 2200 |
| Investment | -610 | -829 | -2113 | -55 | -633 | -932 |
| Cost, public | 503 | 497 | 509 | 102 | 51 | 116 |
| Cost, airlines | 836 | 1143 | 1126 | 232 | -91 | 822 |
| Benefit, users | 2039 | 2101 | 2065 | -27 | 783 | 584 |
| Net present value | 2732 | 2875 | 1304 | 250 | 111 | 591 |
| Internal rate of return | 26.8% | 21.0% | 8.8% | 29.7% | 6.8% | 8.9% |
| Benefit/cost ratio | 5.32 | 4.32 | 1.9 | 5.3 | 1.17 | 1.6 |

Table 4 Results from cost benefit analyses for the three scenarios for each of the two cities. Million DKK in 2010 price level and internal rate of return in % annually (Source: TGB model)

With the extensions of the runway in Nuuk, the main routes will change to direct connections between Copenhagen and Nuuk and from Nuuk to either Ilulissat or Narsarsuaq. The changes of runway lengths result in a restructuring of the main routes as well as a general network reduction. In general, the number of routes is reduced considerably when Kangerlussuaq airport is closed, because a great deal of the feeder traffic will be taken care of by direct routes. The extension of the runway in Nuuk reduces the number of routes in the model by almost 20% and the number of departures by almost 5%. These reductions give rise to shorter travel times which, on average, are reduced by 2-2.5 hours per passenger. Table 4 shows the benefit/cost ratios and the internal rate of return together with the main contributions from the benefits and costs for each scenario for both cities. More detailed results are found in Appendix 2. The main reasons for the differences between the Nuuk scenarios are the initial costs, production costs, and ticket revenue for airlines. Another important factor is the cost of leaving Kangerlussuaq (a saved cost of 495 million DKK).

Figure 5: Possible change in traffic flow (passengers per week) as a result of a new international airport in Nuuk.

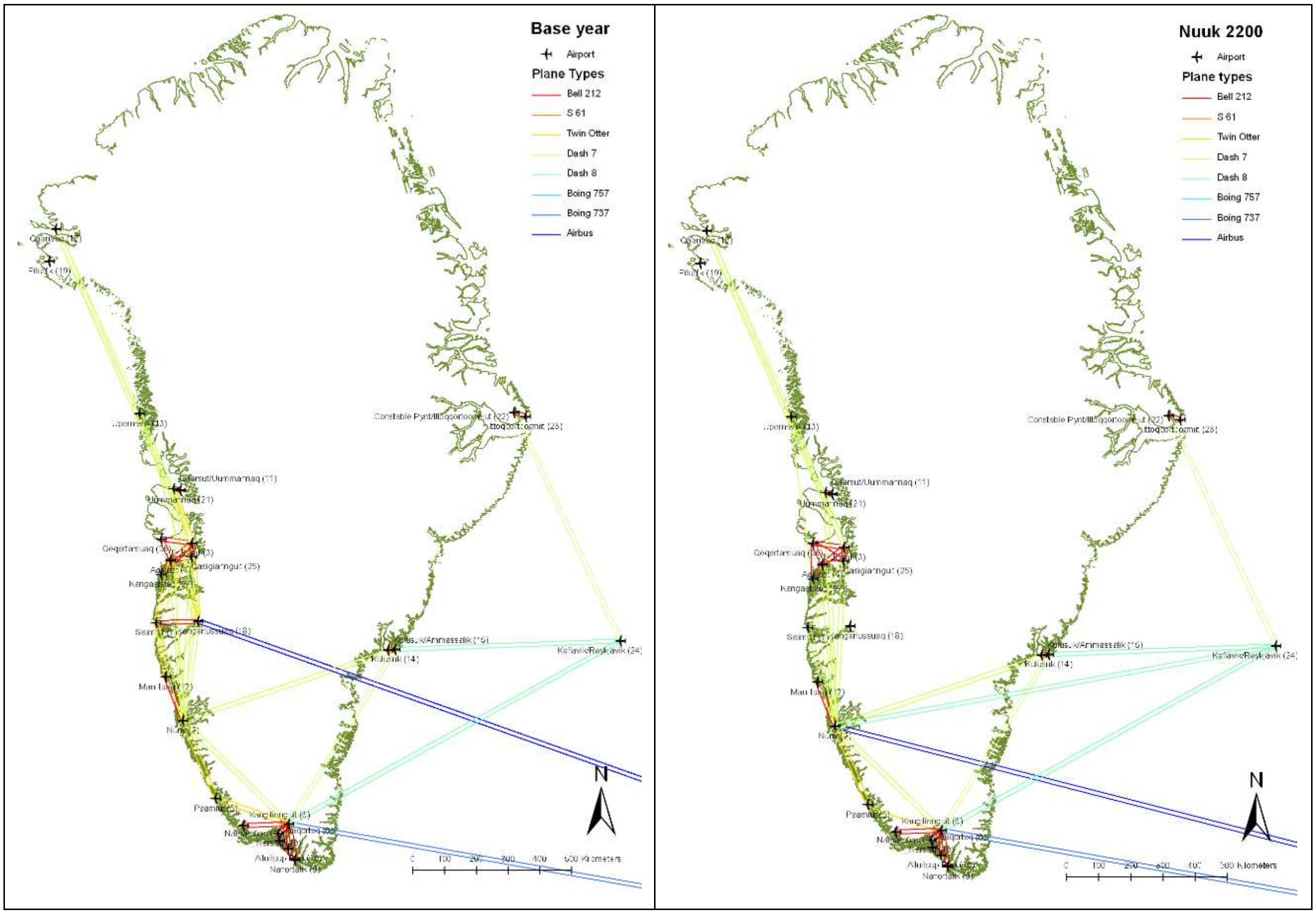


The service network has almost the same routes in the three Nuuk scenarios, but the airplane types differ between Copenhagen and Nuuk. The Nuuk 2200 and Nuuk 3000 metres scenarios have benefits of equal size, because the model configuration allows the same type of planes to land, Airbus 300-200.

The faster airplanes make a slight difference in level of service which gives rise to different demand and production costs, see section 2.6. The Nuuk 1799 scenario turned out to be the most cost-effective of the three projects (internal rate of return of 26.8%). The underlying assumption is that the ticket price between Copenhagen and Nuuk will be identical to the ticket price between Copenhagen and Kangerlussuaq, even though prices might even be lowered due to increased volumes. The internal rate of return is 21.0% for the Nuuk 2200 metres scenario and only 8.8% for the Nuuk 3000 metres scenario.

In Figure 5: Possible change in traffic flow (passengers per week) as a result of a new international airport in Nuuk. passenger flows is illustrated and in Figure 6, the allocation of plane types for the specific legs is illustrated. As shown, the local route network is served by a mix of Dash-7, Twin-otters, and helicopters. The change to Twin-otters will make it possible to reduce the PSO as described in section 2.6.

Figure 6: Possible change in the type of planes as a result of a new international airport in Nuuk.



The model clearly indicates that significant socio-economic benefits can be expected, when the main airport is moved from Kangerlussuaq to Nuuk. This conclusion even holds (for the two smallest projects) when only consumer surplus measures are included. The change in travel demand has a considerable impact on the model results, but even without including the change in demand and without traffic growth, both the Nuuk 1799 metres and the Nuuk 2200 metres scenario turn out to be cost-effective.

In the Ilulissat scenarios where Kangerlussuaq is maintained (see Table 4), a direct route from Copenhagen could be an option with the 2200 metres runway, resulting in a significant share of the traffic from Copenhagen going directly to Ilulissat. All three Ilulissat scenarios turn out to be cost-effective. The extension of the runway to 1199 metres is the most cost-effective scenario with an internal rate of return of 29.7%. This is first of all due to the low investment when extending the existing runway. Interestingly, the extension to 2200 metres with an internal rate of return of 8.9% is more cost-effective than the 1799 extension (6.8%) even though the investment is 50% higher. This is first of all due to a substantial increase in the airline's income from fares made possible by a direct connection from Copenhagen. The Transport Commission not even analysed a 2200 metres extension.

## 5.2 The Transport Commission's CBA

The Transport Commission's analyses were based on a traditional transport model, see section 2.5. The model estimated the number of passengers based on assumptions about, among other things, the growth rate and spatial distribution of the population and tourists (see Table 5) and the known travel pattern. Travel time elasticities were not included in the model. The route choice model was based on a value of travel time of 99 DKK per hour for residents and tourists (40 DKK for time at shifts plus an additional value per shift) and 40% higher for external business travellers. The fares were based on a constant price per kilometre.

| Parameter | Growth scenario 1 | Growth scenario 2 | Growth scenario 3 |
|---|---|---|---|
| Real BNP | + 2% p.a. | + 3% p.a. | + 3½% p.a. |
| Population growth and distribution | "Main scenario" population distribution as in model 1 in the "Mobility analysis" | "Main scenario" + 22% in 2030 and population distribution as in model 1 in the "Mobility analysis" | "Main scenario" + 22% in 2030 and extra concentration in cities in the central region |
| Workforce | -5% | - | - |
| Tourists | + 2½% p.a. | + 5½% p.a. | + 5½% p.a. |
| Freight | + 2½% p.a. | + 3½% p.a. | + 4% p.a. |
| Mail | - 50% | - 50% | - 50% |

Table 5 Three scenarios for growth rate and distribution of the population.

For each of the possible airports, the Commission set up some alternatives, estimated the number of passengers by means of the transport model and made a CBA following the recommendations from the Danish Ministry of Transport set up in a calculation model called 'Teresa'[11], however with some modifications. In the cost benefit analysis, the internal rate of return and the net present value was estimated for the three growth scenarios based on the following preconditions:

- Investment horizon: 25 years (the Teresa model normally uses 50 years for long-run investments as railways and motorways)
- Discount rate: 4%
- Distortionary loss: 10% due to lower taxes than in Denmark (it was 20% in Denmark),
- Value of travel time was for residents similar to that of the route choice model, but supplemented by a value for delays (the double of the time value). Values per tonne were similarly chosen per hour per kg for mail and other freight types.
- Benefits for the tourists and business travellers not residing in Greenland were not included in the model.
- Dynamic effects from the increased number of tourists were neither included, but assessed in a sensitivity study.

In the cost benefit analyses, investment and demolishing costs, running costs for the airlines, costs for renewals and repair of the airports, fares, and values of $CO_2$ emission and noise, cost of regularity etc. were included. Detailed results from the CBA for Nuuk and Ilulissat are shown in Appendix 2 for growth scenario 2.

### 5.2.1 Nuuk

Table 6 shows the net present value and the annual rate of return for the 6+2 alternatives that the Transport Commission set up. They are shown for each of the three growth scenarios.

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[11] https://www.trm.dk/da/publikationer/2015/manual-for-samfundsoekonomisk-analyse-paa-transportomraadet

The highest internal rate of return is found for alternative 2 with the shortest runway and Kangerlussuaq closed. Due to the short runway, Greenland would lose its international airport. Alternative 4 with the 2200 metres runway with the second highest internal rate of return (14.1-14.8%) and the highest net present value for all three growth scenarios is instead the most attractive. The Commission made several sensitivity analyses with alternatives for most of the important factors. In all cases, alternative 4 came out as the best. Alternatives 5 and 6 with the airport relocated to islands to the south and with a need for new bridges and roads had the lowest internal rate of return.

| | **P1**<br>1199 m<br>Maintain | **P2**<br>1199 m<br>Close K. | **P3**<br>1799 m<br>Close K. | **P4**<br>2200 m<br>Close | **P5a**<br>3000 m<br>Close K. | **P6a**<br>2800 m<br>Close K. | **P5b**<br>2200 m<br>Close K. | **P6b**<br>2200 m<br>Close K. |
|---|---|---|---|---|---|---|---|---|
| **Growth scenario 1** | | | | | | | | |
| Net present value | 99 | 1,616 | 1,085 | 2,138 | -499 | -671 | 934 | 843 |
| Internal rate of return, yearly % | 8.0% | 23.4% | 10.0% | 14.1% | 2.7% | 2.4% | 6.5% | 6.0% |
| **Growth scenario 2** | | | | | | | | |
| Net present value | 82 | 2,230 | 1,199 | 2,309 | -337 | -510 | 1,269 | 1,178 |
| Internal rate of return, yearly % | 7.5% | 25.7% | 10.5% | 14.6% | 3.1% | 2.8% | 7.3% | 6.8% |
| **Growth scenario 3** | | | | | | | | |
| Net present value | 87 | 2,236 | 1,227 | 2,366 | -259 | -439 | 1,406 | 1,307 |
| Internal rate of return, yearly % | 7.7% | 25.8% | 10.6% | 14.8% | 3.3% | 2.9% | 7.6% | 7.1% |

Table 6 Net present values in 2010 in million DKK and internal rate of return for the 6 project alternatives and two runway alternatives for project alternatives 5 and 6. Million DKK in 2010 price level (Source: Transport Commission).

### 5.2.2 Ilulissat

The results of the two CBA alternatives for Ilulissat with runways of 1199 metres and 1799 metres and Kangerlussuaq maintained are shown in Table 7. Because Ilulissat is the main centre for tourism in Greenland, the Commission included a development in tourism directly in the transport model, letting it increase when the fares decrease. It is presupposed that the airlines improved the capacity of the aircrafts in order to follow the forecast in demand.

| Million DKK, 2010 price level | **Growth scenario 1** | | **Growth scenario 2** | | **Growth scenario 3** | |
|---|---|---|---|---|---|---|
| | 1199 m | 1799 m | 1199 m | 1799 m | 1199 m | 1799 m |
| Net present value | -19 | -765 | -19 | -921 | -18 | -922 |
| Internal rate of return, % yearly | 2.4% | -2.7% | 2.3% | -4.8% | 2.4% | -4.8% |
| **Including dynamic effects** | | | | | | |
| Dynamic effects of more tourists | 42 | 285 | 46 | 414 | 46 | 414 |
| Net present value | 23 | -480 | 27 | -507 | 28 | -508 |
| Internal rate of return, % yearly | 5.9% | -0.1% | 6.2% | -0.4% | 6.3% | -0.4% |
| **Kangerlussuaq closed, Nuuk main entrance** | | | | | | |
| Net present value | | -1,323 | | -1,726 | | -1,752 |
| Internal rate of return, % yearly | | -8.2% | | -14.8% | | -15.1% |

Table 7 Net present values in 2010 and internal rate of return for two project alternatives and three growth scenarios. Shown for the basic calculation and two alternatives with dynamic effects and provided Kangerlussuaq is closed. Million DKK in 2010 price level. (Source: Transport Commission).

The 1199 metres runway cannot be used by air planes from Copenhagen. Instead, a new summer connection by a small jet airplane (not full due to weight restrictions) from Iceland was presupposed to replace the existing propelled aircraft, and the seat capacity from Kangerlussuaq was reduced similarly. With the 1799 metres runway, a new connection to Copenhagen served by medium size aircrafts as Boing 757 (200 seats but not full due to weight restrictions) or Boing 737 is expected to replace a similar capacity from Kangerlussuaq to Copenhagen. The freight is still expected to be sent via Kangerlussuaq. In both alternatives, travel time will be decreased, but only a little in scenario one.

Finally, an analysis was made in which Kangerlussuaq is closed and Nuuk has a minimum runway of 1799 metres. In this alternative, the internal rate of return falls from -8 to -15% (dependent on the growth rate).

## 5.3 The Rambøll Report

The Rambøll report assessed two scenarios with runways of 1100 and 2200 metres, respectively, see Table 8 for Ilulissat. The 2200 metres runway opens up for connections to all Western European and North American destinations by medium size airplanes with 150-170 seats. It is expected to reduce the cost per flight and decrease fares by 20-30% and travel time from Copenhagen to 4 hours from the actual 6-7 hours. The three growth rates are taken from the Transport Commission. The main difference from the Commission's scenarios is the externalities from tourism. The diverted consumption from tourists is assessed to be 50% of the tourist's spending, but the catalytic effect is reduced by the extra production cost for their consumption.

| | **Scenario 1: 1100 metre** | | | **Scenario 2: 2200 metre** | | |
|---|---|---|---|---|---|---|
| **Growth rate:** | 0.5% | 1.5% | 2.5% | 0.5% | 1.5% | 2.5% |
| **Public** | | | | | | |
| Investment | -71 | -71 | -71 | -1,324 | -1,324 | -1,324 |
| Residual value | 20 | 20 | 20 | 379 | 379 | 379 |
| Running cost, airports | 142 | 152 | 162 | 296 | 232 | 155 |
| **User effects** | | | | | | |
| User benefits | 228 | 267 | 312 | 698 | 815 | 953 |
| Time savings | 0 | 0 | 0 | 45 | 52 | 60 |
| **Externalities** | | | | | | |
| Distortionary loss | 14 | 15 | 17 | -97 | -107 | -119 |
| Tourism | 178 | 181 | 184 | 645 | 654 | 664 |
| **Net present value** | 511 | 563 | 625 | 641 | 701 | 776 |
| **Internal rate of return** | 32.3% | 33.7% | 35.1% | 7.2% | 7.5% | 7.8% |

Table 8 Cost benefit analyses for Ilulissat. In scenario 1, both Nuuk and Ilulissat are extended to 1199 metres. In scenario 2, both are extended to 2200 metres and Kangerlussuaq is closed. Million DKK in 2010 price level and internal rate of return in % annually (Source 12).

## 5.4 Comparison between the CBA

A comparison between the results of the three CBA for Nuuk and Ilulissat cannot be done directly due to differences in discount rate and investment horizon for which TGB uses a 6% discount rate and a 50 years' investment horizon while all others use a 4% discount rate and a 25 years' investment horizon.

| | | | **Nuuk 2200 metres** | | **Ilulissat 1799 metres** | | **Ilulissat 2200 metres** | |
|---|---|---|---|---|---|---|---|---|
| | Horizon Years | Discount rate | Net present value | Internal rate of return | Net present value | Internal rate of return | Net present value | Internal rate of return |
| Report | 50 | 6% | 2875 | 21.0% | 110 | 6.8% | 591 | 8.9% |
| Recon-struction | 50 | 6% | 2879 | | 112 | | 592 | |
| | 50 | 4% | 4723 | | 488 | | 1,347 | |
| | 25 | 6% | 2108 | | 42 | | 393 | |
| | 25 | 4% | 3019 | | 258 | | 803 | |
| | 50 | 6% | | 29.4% | | 7.0% | | 9.9% |
| | 25 | 6% | | 29.4% | | 6.5% | | 9.6% |

Table 9 Calculation of net present values and internal rate of return with a 50 and 25 years' horizon and with a 6% and 4% internal rate of return for three scenarios based on the TGB model.

The authors have therefore adapted the cost benefit analyses from the TGB model to the preconditions of the rest. Unfortunately, the complete data from the models no longer exist so a reconstruction is based on the final data and a report describing the method and the included values. The results shown in Table 9 are therefore not a precise adaption. However, except for a few minor figures, it has been possible to reconstruct the results from the original analyses, especially for the net present value. For Nuuk, the results for the internal rate of return are differing. The results show that a reduction of the discount rate to 4% increases the net present value. A shorter investment horizon reduces the net present value, but less than the increase due to the lower discount rate. The internal rate of return is not affected by any of the changes.The results for Nuuk show that the 2200 metres runway generates cost-effective results from both models with a 25 years' time horizon and a 4% discount rate. For Ilulissat the TGB model still indicates a cost-effective result for the 2200 metres runway.

An important difference between the Transport Commission's CBA and the CBA based on the TGB model is that the latter presumes the passengers to Ilulissat to travel directly. However, if the direct route is not profitable, it is not opened. This problem is not tested in the TGB model, because it was based on simple forecasts set up by the Greenland Home Rule Authorities, and only with a time horizon until 2012. Another reason for a better result for Ilulissat in the TGB model is the contribution from extra passengers travelling via Ilulissat to the towns and settlements around the Disko Bay, which the other analyses do not take into account.

The Rambøll CBA also presupposes that the passengers travel on a direct route from Europe/Copenhagen which improves the result. However, according to Table 8, the net present value is close to zero if the benefit from an increased number of tourists is not included.

# 6 DISCUSSION

## 6.1 Assessment of the authorities' CBA

The economic analyses fall into two main periods, up to 2009 and after, which also represents the home rule period, and the self-rule period. In the beginning of the first period, only financial analyses were made, showing that an investment in an extended runway or a new airport was not profitable when only the extra fares from an increasing number of passengers were included. Analyses from 2002 included more economic factors such as savings by the airlines due to more cost-effective airplanes, and for the public due to lower service contracts and lower costs in the airports. Investments in renovation and savings as a result of closing down airports were furthermore included.

Even though the analyses are presented as societal or cost benefit analyses, the early analyses did not include the benefits of the travellers' time savings and external benefits such as increased noise. Normally, time savings by the costumers are the driving forces behind investments in new infrastructure. Nevertheless, the only included traveller benefit was fare savings.

You may wonder why CBA developed in the late 1990s and early 2000s by Danish consultants or Danish experts in the administration did not include at least time savings, considering it was mainstream in the transport sector in Denmark in that period. An explanation might be found in the dependency theory (see section 2.1), even though it is hard to believe.

From 2007, CBA followed the traditional and more correct scheme for such analyses. The Transport Commission's CBA seems to be the first official analysis in Greenland, consistently following the official rules set up by the Danish Ministry of Finance. The applied method includes some exceptions that are mainly argued for. The adjusted methodology is later adopted by Greenland's finance authorities.

All three CBA discussed in the paper at hand included time and fare savings by residents and business travellers financed by local companies or public institutions. Correctly, none of the analyses included benefits obtained by the tourists. The Transport Commission included environmental benefits, especially noise. Neither the TGB model nor the later analyses from Rambøll and Deloitte included environmental benefits (the TGB model included the environmental benefits in a separate analysis). However, the Transport Commission assessed the noise effects to be very small.

The direct effect on employment is not considered in any of the CBA. This would have been correct in case of full employment, which is however not the case. Only the Rambøll analysis revealed catalytic effects for the society from the increasing number of tourists generated by the airport investments. In fact, most of the analyses not even included the change in the number of tourists and other travellers due to the improvement of the airports. The Transport Commission included a development analysis for Ilulissat in a further sensitivity study. For Rambøll, the central scope was to analyse the effect of the two improved airports on tourist and business travellers based on an analysis of other Nordic destinations. The resulting number of travellers was forecasted by an estimated 'runway elasticity'. A similar study was made for the TGB model; however, the results were not included in the final model.

A more problematic choice for the cost benefit analyses is to analyse each of the airports/areas separately without including the influence from other areas or projects. Every change to an airport in the network changes fares and passenger flows in all other parts of the network. When not considering the network as a whole, only sub-optimal solutions are found. The Transport Commission maintained Kangerlussuaq when analysing Ilulissat. Considering that the Commission recommended Kangerlussuaq to be closed and replaced by an international airport in Nuuk, this solution is not correct. Therefore the Commission supplemented its study with an analysis of the airport in Ilulissat in a situation where Nuuk is the only international airport. Both analyses show that an extension of the runway in Ilulissat to 1799 metres is not profitable. The problem is, however, that Nuuk airport gets the full benefit from closing Kangerlussuaq and Ilulissat gets no benefit. Sharing of the benefit between the two airports might have been relevant, too. Considering that the TGB project shows that a 2200 metres runway is more cost-effective than the shorter runway of 1799 metres, it would have been interesting to see this solution included too.

Furthermore, it could also have been relevant to include the future infrastructure in Southern Greenland in the analyses of central Greenland. When closing Narsarsuaq and replacing it by a regional airport in Qaqortoq, it influences traffic flows in Kangerlussuaq/Nuuk and vice versa. Another example of sub-optimization is mentioned by the Transport Commission itself. When analysing the runways by Qaqortoq, connections between Qaqortoq and Narsaq are not taken into account. In the actual case, it is done afterwards, and the result is taken into account when drawing the final conclusion.

These examples illustrate the complexity of analysing the full traffic network in separate parts. The idea of the TGB model is to optimize all traffic in the whole network based on assumptions about the incoming traffic. The result of the analysis of Ilulissat also indicates that it is important to include a traffic model for the inbound/outbound air traffic to/from Greenland in the model framework in line with the methods developed by Rambøll.

### 6.2 Political decision contra economic analyses

A serious problem with the incorrect cost benefit analyses in the home rule period is that a political discussion about moving the international airports was postponed for more than 10 years. Already early on, it was clear that moving the central airport to Nuuk was economically profitable. However, the size of the needed investment and the regional effect for the region to the north of Kangerlussuaq made it politically impossible to carry through.

For Southern Greenland an unrealistic demand for maintaining an international or big regional airport, the size of the society taken into account, contributed to postpone a regionally more balanced solution. A more correct cost benefit analysis including travel time savings would probably have shown a profitable result for a minor airport at Qaqortoq already in the late 1990s. It would have been profitable and better for the society in Southern Greenland, if a minor regional airport close to Qaqortoq had been possible after the construction of the six small airports in 2001, followed up by closing Narsarsuaq airport when SAS stopped its service. Placing a small, but expensive airport in Paamiut combined with renovating the runway at Narsarsuaq instead seems to be problematic for the development in Southern Greenland.

### 6.3 Competition in air traffic and potential catalytic and wider economic effects

Since the end of the 1990s a central question related to air traffic has been how to obtain competition in order to decrease fares. The monopoly of Air Greenland on both the international and the internal traffic has only been challenged by a few routes serviced by Air Iceland Connect and a few minor helicopter service airlines during the last 10 years:

- This request for competition was the reason for sending the feeder routes between Kangerlussuaq and Nuuk, Ilulissat and Narsarsuaq, respectively, out for tender. However, the result was one biting airline and increased fares shortly after.

- SAS closed its connection from Copenhagen to Greenland and tries to get out of its ownership of Air Greenland.
- The connection between Copenhagen and Narsarsuaq was instable by the end of 1990s. The Home Rule Authorities needed to subsidise a summer connection serviced by Iceland Air between Iceland and Narsarsuaq together with the Icelandic Government.
- Only marginal competition has been obtained for the helicopter service contracts until the latest contract in 2015.

An important question is therefore, if it will be possible to attract new airlines, increase the competition and get the fares reduced by e.g. 20-30% as suggested by Rambøll (Source 12) for travellers to the extended airports in Nuuk and Ilulissat. The travel time will be reduced around two hours, which is a benefit in itself making it more attractive to visit Greenland from Europe and the American east coast. However, considering the actual international air traffic is less than 200,000 travellers distributed on two main airports and three minor airports at the east and south coasts (see Figure 2), it might be difficulty to attract new airlines.

New literature using the Granger causality to analyse development in remote regions by improving air traffic indicates a reason for being optimistic, at least in the long run, see section 2.3 with (Button and Yuan, 2013, Mukkala & Tervo, 2013, Ringbom, 2020). In case it is possible to generate air traffic, an increased development in GDP and employment should be realistic.

Rambøll (Source 12) suggests that with the choice of a runway of 2200 metres and a price reduction by 25% the number of holiday tourists will increase from 26,000 to 61,000 in 2040, and the business travellers from 11,000 to 13,500 with the fastest increase in the first 5 years after finishing the airports. However, especially the analysis by Ringbom (2020) indicates a long term effect rather than an immediate effect. Another reason to worry is that the expansion of the runway in Ilulissat to 2200 metres is expected to increase the size of the airplanes which might reduce the frequency. Rambøll expects the connections between Nuuk and Ilulissat to keep the weekly frequency at the actual level. However, a connection to Ilulissat through Nuuk will increase the travel time to a level similar to the actual one and with a double risk for sea fug and postponed connections.

It is therefore important for the new airport company Kallaalit Limited to be aware that the vast majority of airports is actively involved in route development (Halpern and Graham, 2015). They suggest their results to be particularly relevant to airports that are less advanced in route development activities and want to debate route and tourism development strategies with stakeholders. Halpern (2020) mentions that some regions have introduced incentive schemes to stimulate direct international air services (e.g. for inbound tourism). One example is the Northern Norway Charter Fund, launched at the end of 2014 with a budget of one million euros to be allocated as aid in the form of grants that reduce the risk to tour operators establishing air services to airports in northern Norway (Halpern, 2018). A special interest should probably be directed to the service sector in Ilulissat. Tourist reports at the internet mention that it is difficult to get a hotel in the high season. One of the author's personal experience this summer also showed fully booked flights in the high season. Development in airplane capacity and capacity in accommodation have to go hand in hand. On the other hand, it is also well-known that the cruise ships are not generating much wealth to the regions they visit as the visitors get all their food and accommodation on board. It is therefore important that the on-land tourism is developed before cruise tourism takes over.

Fageda et al. (2020) show that regions around the world of which the main part are less remote than Greenland need to use PSO to keep the service level up. They furthermore mentions that the PSO has a tendency to reduce competition. (Müller et al., 2012), on the other hand, show in a benchmark study of Norwegian airports that Greenland has the most cost-effective airports of all remote regions in Europe. Unfortunately, no information is available for the airlines.

## 7 CONCLUSION

The paper describes how the decision process in Greenland about airports and air traffic seems to fall in four periods. During the first 20 years of the home rule, the basic infrastructure with airports for fixed-wing aircrafts by the major cities and towns was established. The concern was only to establish new or expanded airports in case these would be profitable immediately.

In the following period from around 2000, the concern of the Home Rule Authorities was to reduce the costs in order to reduce the substantial subsidy to the traffic system with a view to being able to finance development of the education sector in Greenland. The intention was both to find a successor to the Dash-7 aircrafts, which were expensive to repair, and to reduce the cost of the service contracts for trafficking the settlements. The interest in air traffic as a way to increase tourism was increasing.

From the beginning of the self-governance period at 2009, it seems as if the focus was moved from the minor airports and the expensive service contracts towards a wish to develop the bigger airports in order to establish a well-functioning transport system with the best practical and economic solutions for the towns and cities. However, during the 15 years' period from 2000 to 2015, no new decisions were taken to implement the profitable changes.

Finally, during the latest five years the perspective is widened to understand the air traffic as a key factor in developing tourism and business. The purpose seems to be to improve air traffic as a factor in the struggle for independency. Finally, it has been possible to take the big and expensive decision to develop new and expanded airports and to reorganise the air traffic system.

In this process, the developed TGB model has been a little overlooked. The paper has shown that the use of the model offers unexpected results in contrast to the traditional transport models. As a result, there is huge potential for the society of Greenland to optimize the air traffic network and subsequently save both private and public costs and to save public subsidies (PSO). The Parliament of Greenland was progressing in the right direction with the decision in 2015 to reduce some of the fixed-wing airports to minimalistic airports and to replace some heliports with minimalistic airports. However, it will probably be possible to obtain more benefits by optimising the network and schedules. Today, the TGB model is too old, being based on twelve years old aircrafts and costs. An update of the model and improving it with a forecast model for the incoming traffic will be needed. An improved model should be based on the new airports and be prepared for analyses of the network structure, when the new airports are operating.

The paper indicates that the decision about improving the three airports is the best for the society. Even without considering direct and indirect effects of the airports, they will probably generate an economic surplus for the society in the long run. This is obvious for Nuuk. For Ilulissat it is a bit more complicated with an internal rate of return just above the discount rate. Greenland's Economic Committee is probably correct when they find the runway at Qaqortoq to be too long. However, this part of the decision has its roots in the history, where Southern Greenland has always been unfairly treated.

When also taking the direct and indirect/induced effects into account, the airport package is clearly the right decision. Indeed, these effects are more uncertain to forecast and more dependent on other activities in the society and especially in the tourist sector. With the support from the Danish Government, the investment ought to be profitable. The main problem is to get the first airlines to establish direct connections to Ilulissat from Europe and the American east coast in order to generate the induced and, in the long run, wider economic benefits. To this end, it might be needed for Kallaalit Limited and/or the public authorities of Greenland to be actively involved in route development. Economic support to the tourism industry might even be needed for a short period.

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# REFERENCES

Banister, D., Berechman, J. (2000): Transport Investment and Economic Development. UCL Press, London.

Bollman, R. (2008) “Factors driving Canada’s rural economy” Statistics Canada, Agriculture and Rural. Working Paper No. 83

Botterill, R., Owen, E., Emanuel, L., Foster, N., Gale, T., Nelson, C., Selby, M. (2000). Perceptions from the periphery: the experience of Wales. In *Tourism in Peripheral Areas: Case Studies*, edited by Brown, F. and Hall, D. Aspects of Tourism 2, Channel View Publications, Clevedon etc.

Brezzi et al OECD Extended Regional Typology: The Economic Performance of Remote Rural Regions OECD 2011.

Brown and Hall (2000): Introduction: The Paradox of Peripherality. In *Tourism in Peripheral Areas: Case Studies*, edited by Brown, F. and Hall, D. Aspects of Tourism 2, Channel View Publications, Clevedon etc.

Bråthen, S., Givoni, M., 2017. The wider impacts from transport: What do we know, what do we still need to know and what does it mean? Res. Transp. Econ. 63, 1–4. https://doi.org/10.1016/j.retrec.2017.09.005

Button, K., Yuan, J., 2013. Airfreight Transport and Economic Development: An Examination of Causality. Urban Stud. 50, 329–340. https://doi.org/10.1177/0042098012446999

Fageda. X., Suárez-Alemán, A., Serebrisky, T., Fioravanti, R. (2020): a comparative analysis of policies to support air connectivity in remote regions in Anne Graham, Nicole Adler, António Pais Antunes, Ofelia Betancor, Volodymyr Bilotkach, Gianmaria Martini, Hans-Martin Niemeier (Forthcoming), Air Transport and Regional Development (ATARD) Handbook, Routledge.

Freiria, S., Antunes, A. (2020) The impact of Oporto Airport on the development of the Norte Region of Portugal An econometric study in Anne Graham, Nicole Adler, António Pais Antunes, Ofelia Betancor, Volodymyr Bilotkach, Gianmaria Martini, Hans-Martin Niemeier (Forthcoming), Air Transport and Regional Development (ATARD) Handbook, Routledge.

Gillen, D. (2020): Wider Economic Benefits What they are, how they are Manifest and an Example from Network Air Services, in Anne Graham, Nicole Adler, António Pais Antunes, Ofelia Betancor, Volodymyr Bilotkach, Gianmaria Martini, Hans-Martin Niemeier (Forthcoming), Air Transport and Regional Development (ATARD) Handbook, Routledge.

Halpern, N. 2020: Halpern The impacts of airports in geographical peripheries in Anne Graham, Nicole Adler, António Pais Antunes, Ofelia Betancor, Volodymyr Bilotkach, Gianmaria Martini, Hans-Martin Niemeier (Forthcoming), Air Transport and Regional Development (ATARD) Handbook, Routledge.

Halpern, N., Graham, A., 2015. Airport route development: A survey of current practice. Tour. Manag. 46, 213–221. https://doi.org/10.1016/j.tourman.2014.06.011

Huderek-Glapska, S: The application of an input-output approach in measuring the impact of air transport on the economy: A critical review in Anne Graham, Nicole Adler, António Pais Antunes, Ofelia Betancor, Volodymyr Bilotkach, Gianmaria Martini, Hans-Martin Niemeier (Forthcoming), Air Transport and Regional Development (ATARD) Handbook, Routledge.

Martini, G., Porta, F., Scotti, D.: The evolution of regional air transport connectivity in Europe: A comparison between remote and core regions in Anne Graham, Nicole Adler, António Pais Antunes, Ofelia Betancor, Volodymyr Bilotkach, Gianmaria Martini, Hans-Martin Niemeier (Forthcoming), Air Transport and Regional Development (ATARD) Handbook, Routledge.

Müller, J., Niemeier, H.-M., Adler, N., 2012. Comparative study (benchmarking) on the efficiency of Avinor’s airport operations. Berlin.

Mukkala, Kirsi, Tervo, Hannu. 2013. “Regional airports and regional growth in Europe: which way does the causality run?” *Environment and Planning A* (6): 1508-1520.

Nielsen, Otto Anker & Frederiksen, Rasmus Dyhr (2006). Optimisation of timetable-based, stochastic transit assignment models based on MSA. *Annals of Operations Research*. Vol. 144, Issue 1 pp 263-285. Kluwer.

Nielsen, Otto Anker and Frederiksen, Rasmus Dyhr (2008). Large-scale schedule-based transit assignment – Further optimisation of the solution algorithm. *Schedule-based Modelling of Transportation Networks: Theory and Applications.* Series: Operations Research/Computer Science Interfaces. Vol 46. (Eds) Wilson, Nigel H.M. & Nuzzolo, Agostino. Springer, ISBN: 978-0-387-84811-2

Njoya, E.T, Forsyth, P. (2020): The use of CGE models in the evaluation of air transport policy and large-scale investment: a survey in Anne Graham, Nicole Adler, António Pais Antunes, Ofelia Betancor, Volodymyr Bilotkach, Gianmaria Martini, Hans-Martin Niemeier (Forthcoming), Air Transport and Regional Development (ATARD) Handbook, Routledge.

Ortuzar, J. d. D. Willumsen, L.G. (2011): Modelling Transport. Online ISBN: 9781119993308; DOI: 10.1002/9781119993308

Ringbom, S. (2020): The relation between air traffic and the regional development in Finland in Anne Graham, Nicole Adler, António Pais Antunes, Ofelia Betancor, Volodymyr Bilotkach, Gianmaria Martini, Hans-Martin Niemeier (Forthcoming), Air Transport and Regional Development (ATARD) Handbook, Routledge.

Schürmann, C., Talaat, A., 2000. Towards a European Peripherality Index, Berichte aus dem Institut für Raumplanung.

Sheffi, Y (1985): Urban Transportation Networks. Prentice Hall, Inc, Englewood Cliffs, NJ.

Spiekermann, K., Aalbu, H., 2004. Nordic Peripherality in Europe (No. 2), Nordregio Working Paper. Stockholm.

Spiekermann, K., Neubauer, J., 2002. European accessibility and peripherality: Concepts, models and indicators, Nordregio Working Paper.

Todorova, S., Haralampiev, K. (2020): Air Transport and Economic Growth of the RegionsCausality Analysis in Bulgaria in Anne Graham, Nicole Adler, António Pais Antunes, Ofelia Betancor, Volodymyr Bilotkach, Gianmaria Martini, Hans-Martin Niemeier (Forthcoming), Air Transport and Regional Development (ATARD) Handbook, Routledge.

## SOURCES USED IN CHAPTER 3, SORTED BY YEAR:

1. Grønlands Hjemmestyre, 1998: Rapport fra Ekspertgruppenhttp://www.transportkommissionen.gl/LinkClick.aspx?fileticket=Jkmmh29lFDs%3d&tabid=81&language=da-DK [Greenland Home Rule, 1998: Report from the Expert Group]
2. Buch and Partners, 2001a: Analyse vedrørende eventuel forlængelse af landingsbanen i Nuuk med henblik på etablering af Keflavik som hub for Atlanttrafikken til Grønland. http://www.transportkommissionen.gl/LinkClick.aspx?fileticket=JP8cHkstEWo%3d&tabid=78&language=da-DK [Buch and Partners, 2001a: Analysis of a possible extension of the runway in Nuuk with a view to establishing Keflavik as a hub for the Atlantic traffic to Greenland]
3. Buch and Partners, 2001b: En regional-, samfunds- og trafikøkonomisk vurdering af en trafikal infrastruktur i Sydgrønland. http://www.transportkommissionen.gl/LinkClick.aspx?fileticket=%2fJogqR4pvyE%3d&tabid=81&language=da-DK [Buch and Partners, 2001b: A regional, socio- and traffic economic assessment of the traffic infrastructure in Southern Greenland]
4. Landsstyreområdet for Boliger og Infrastruktur, 2002a: Redegørelse om den fremtidige flytrafikstruktur i Grønland. http://www.transportkommissionen.gl/LinkClick.aspx?fileticket=rWKSKB1%2ftto%3d&tabid=78&language=da-DK [Greenland Home Rule, Ministry of Housing and Infrastructure, 2002a: Report about the future structure of the air traffic in Greenland]
5. Landsstyreområdet for Boliger og Infrastruktur, 2002b: Supplement til Redegørelse om den fremtidige flytrafikstruktur i Grønland. Document made available from Greenland Home Government's administration. [Greenland Home Rule, Ministry of Housing and Infrastructure, 2002b: Addenda to Report about the future structure of the air traffic in Greenland]
6. Trafikministeriet og Grønlands Landsstyre, 2004: De fremtidige rammebetingelser for beflyvning af Grønland. http://www.transportkommissionen.gl/LinkClick.aspx?fileticket=WwId4VV6my4%3d&tabid=78&language=da-DK [Ministry of Transport, Greenland Home Government, 2004a: The future framework conditions for the air traffic in Greenland]
7. Landsstyreområdet for Boliger, Infrastruktur og Miljø, 2004: Trafikpolitisk Redegørelse. http://www.transportkommissionen.gl/LinkClick.aspx?fileticket=ERIBPlRTvZg%3d&tabid=81&language=da-DK [Greenland Home Government, Department for Housing, Infrastructure and Environment, 2004b: Transport political report]
8. Arbejdsgruppen om udvidelse af Ilulissat og Nuuk Lufthavn og Havn, 2007: En teknisk, fysisk og økonomisk vurdering af fremtidige lufthavns-løsninger for Nuuk og Ilulissat. http://www.transportkommissionen.gl/LinkClick.aspx?fileticket=ePs3x7ckxLw%3d&tabid=78&language=da-DK [Working group about extension of Ilulissat and Nuuk the Airport and port, 2007a: A technical, physical and financial assessment of future airport solutions for Nuuk and Ilulissat]
9. Arbejdsgruppen vedrørende trafikale infrastrukturprojekter i Sydgrønland, 2007: Vurdering af de trafikale infrastrukturprojekter i Sydgrønland. Document made available from Greenland Home Government's administration. [The working group on transport infrastructure projects in Southern Greenland, 2007b: Assessment of transport infrastructure projects in Southern Greenland]
10. Konkurrencenævnet, 2010: Konkurrencenævnets årsberetning 2009. Hovedemnet i dette års redegørelse er undersøgelse af markedet for flytransport. https://aua.gl/da/konkurrence/Konkurrencelovgivning/Konkurrencenaevnets-aarsberetninger/Konkurrencenaevnets-aarsberetning-2009 [The Competition Council, 2010: The Competition Council 's Annual Report 2009. The main subject for this year's report is an investigation of the market for air transport]

11. Transportkommissionen, 2011: Betænkning. http://www.transportkommissionen.gl/Udgivelser/tabid/85/language/da-DK/Default.aspx [The Transport Commission, 2011: Report]
12. Rambøll, 2015: Turisme - udvikling og vækst gennem ændret lufthavnsstruktur. https://naalakkersuisut.gl/~/media/Nanoq/Files/Publications/Erhverv/Turisme%20udvikling%20og%20vaekst%20gennem%20aendret%20lufthavnsstruktur/TURISME%20-%20UDVIKLING%20OG%20V%C3%86KST%20GENNEM%20%C3%86NDRET%20LUFTHAVNSSTRUKTUR%20DK.pdf [Rambøll, 2015: Tourism – development and growth by means of a changed airport structure]
13. Anlægsudvalget, 2015: Betænkning afgivet af Anlægsudvalget vedrørende EM2015/18 og EM 167 https://ina.gl/dvd/EM2015/pdf/media/2673202/pkt167_em2015_investeringer_i_lufthavne_bet_2beh_da.pdf [The Public Works Committee, 2015: Report from The Public Works Committee about EM2016/18 and 167]
14. Mittarfeqarfiit, 2015: Slides presented at a workshop with the The Public Works Committee in Kangerlussuaq 16.11.2015
15. Deloitte, 2018: Samfundsøkonomisk konsekvensvurdering ved udbygning af lufthavne, Trin 2. https://naalakkersuisut.gl/~/media/Nanoq/Files/Attached%20Files/Infrastruktur/Ekstraheret%20trin%202.pdf [Deloitte, 2018: Socio-economic impact assessment of the extension of airports, Step 2]
16. Økonomisk Råd: Notat 2018-1 Lufthavnspakkens samfundsøkonomiske implikationer. https://naalakkersuisut.gl/~/media/Nanoq/Files/Attached%20Files/Finans/DK/Oekonomisk%20raad/G%C3%98R%20lufthavne%20-%20DK.pdf [Economic Council: Note 2018-1 The socio-economic implications of the airport package]
17. Finans- og Skatteudvalget, 2018: Betænkning afgivet af Finans- og Skatteudvalget vedrørende forslag til Inatsisartutlov nr. xx af xx.xxx 2018 om rammebetingelser for anlæg, drift og finansiering af international lufthavn i Nuuk og i Ilulissat samt regional lufthavn i Qaqortoq https://ina.gl/dvd/EM2018/pdf/media/2537039/pkt21_xm2_2018_lufthavnslov_bet_2beh_dk_rettelse.pdf [Finance and Fiscal Affairs Committee, 2018: Report from the Finance and Fiscal Affairs Committee about the proposal for Inatsisartutbill number xx af xx.xxx 2018 about framework conditions for construction, operation and financing of an international airport in Nuuk and in Ilulissat and a regional airport in Qaqortoq]
18. Inatsisartutlov nr. 4 af 22. november 2018 om rammebetingelser for anlæg, drift og finansiering af international lufthavn i Nuuk og i Ilulissat samt regional lufthavn i Qaqortoq. http://lovgivning.gl/lov?rid=%7B108D5A38-6AA7-4DD4-A81A-772595776CE5%7D [Inatsisartut law number 4 by 22nd November 2018 about framework conditions for construction, operation and financing of an international airport in Nuuk and in Ilulissat and a regional airport in Qaqortoq]

# APPENDIX 1

## Examples of the Transport Commission’s cost benefit analyses for Nuuk and Ilulissat

| Million DKK, 2010 price level | **P1** 1199 m Keep K | **P2** 1199 m Close K | **P3** 1799 m Close K | **P4** 2200 m Close K | **P5a** 3000 m Close K | **P6a** 2800 m Close K | **P5b** 2200 m Close K | **P6b** 2200 m Close K |
|---|---|---|---|---|---|---|---|---|
| Investments, airport etc. | -106 | -384 | -885 | -1,085 | -1,342 | -1,966 | -1,128 | -1,627 |
| Residual value | 38 | 38 | 209 | 286 | 360 | 568 | 289 | 455 |
| **Investments, in all** | **-69** | **-346** | **-676** | **-800** | **-982** | **-1,398** | **-839** | **-1,172** |
| Investments, roads etc. net value | 0 | 0 | 0 | 0 | -542 | -308 | -542 | -308 |
| Investments, development, net value | 0 | 0 | 0 | 0 | 14 | 13 | 14 | 13 |
| **Further investments, in all** | **0** | **0** | **0** | **0** | **-527** | **-295** | **-527** | **-295** |
| Renewal and maintenance, airport | -10 | 1,131 | 1,098 | 1,123 | 795 | 841 | 820 | 852 |
| Operational cost, airlines | 257 | -111 | 499 | 1,570 | 445 | 445 | 1,496 | 1,496 |
| Income from fares, airlines | -197 | 2,472 | -988 | -988 | -1,283 | -1,283 | -963 | -963 |
| **Running cost and maintenance, in all** | **50** | **3,492** | **609** | **1,705** | **-43** | **2** | **1,353** | **1,385** |
| Time savings, users | 7 | -790 | 277 | 277 | 393 | 393 | 271 | 271 |
| Fare savings, users | 112 | -349 | 1,073 | 1,073 | 1,168 | 1,168 | 1,045 | 1,045 |
| **User benefits, in all** | **119** | **-1,139** | **1,350** | **1,350** | **1,561** | **1,561** | **1,315** | **1,315** |
| Accidents, noise and pollution | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Climate (CO2) | 9 | -6 | 53 | 83 | -74 | -74 | 79 | 79 |
| **Externalities, in all** | **9** | **-6** | **53** | **83** | **-74** | **-74** | **79** | **79** |
| Regularity | -21 | -78 | -103 | -86 | -76 | -76 | -76 | -76 |
| Distortionary loss | -7 | 307 | -34 | 57 | -196 | -231 | -35 | -59 |
| Other effects incl. effects on labour market | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Other effects, in all** | **-27** | **229** | **-136** | **-29** | **-272** | **-307** | **-111** | **-134** |
| **Net present value** | **82** | **2,230** | **1,199** | **2,309** | **-337** | **-510** | **1,269** | **1,178** |
| **Internal rate of return, % yearly** | **7.5%** | **25.7%** | **10.5%** | **14.6%** | **3.1%** | **2.8%** | **7.3%** | **6.8%** |

Cost benefit analysis for Nuuk airport. Net present values in million DKK in 2010 price level and internal rate of return for the 6 project alternatives and two runway alternatives for Growth Scenario 2.

| | **1199 metres runway** | | | **1799 metres runway** | | |
|---|---|---|---|---|---|---|
| Million DKK, 2010-price level | Growth scenario 1 | Growth scenario 2 | Growth scenario 3 | Growth scenario 1 | Growth scenario 2 | Growth scenario 3 |
| Investments, airport etc. | -64 | -64 | -64 | -670 | -670 | -670 |
| Residual value | 23 | 23 | 23 | 237 | 237 | 237 |
| **Investments, in all** | **-41** | **-41** | **-41** | **-433** | **-433** | **-433** |
| Renewal and maintenance, airport | -15 | -15 | -15 | -68 | -68 | -68 |
| Operational cost, airlines | 53 | 56 | 57 | 100 | 105 | 108 |
| Income from fares, airlines | -22 | -27 | -28 | -474 | -656 | -676 |
| **Running cost and maintenance, in all** | **16** | **14** | **14** | **-442** | **-618** | **-636** |
| Time savings, users | 0 | 0 | -1 | 80 | 92 | 99 |
| Fare savings, users | 10 | 11 | 12 | 141 | 167 | 179 |
| **User benefits, in all** | **9** | **11** | **12** | **221** | **259** | **278** |
| Accidents, noise and pollution | 0 | 0 | 0 | 0 | 0 | 0 |
| Climate (CO2) | 1 | 2 | 2 | 0 | 0 | 0 |
| **Externalities, in all** | **1** | **2** | **2** | **0** | **0** | **0** |
| Effects on taxes | 0 | 0 | 0 | 0 | 0 | 0 |
| Distortionary loss | -5 | -5 | -5 | -111 | -129 | -131 |
| Other effects incl. effects on labour market | 0 | 0 | 0 | 0 | 0 | 0 |
| **Other effects, in all** | **-5** | **-5** | **-5** | **-111** | **-129** | **-131** |
| **Net present value** | **-19** | **-19** | **-18** | **-765** | **-921** | **-922** |
| **Internal rate of return, % yearly** | **2.4%** | **2.3%** | **2.4%** | **-2.7%** | **-4.8%** | **-4.8%** |

Cost benefit analysis for Ilulissat airport. Net present values in in million DKK in 2010 price level and internal rate of return for two project alternatives and three Growth Scenarios.

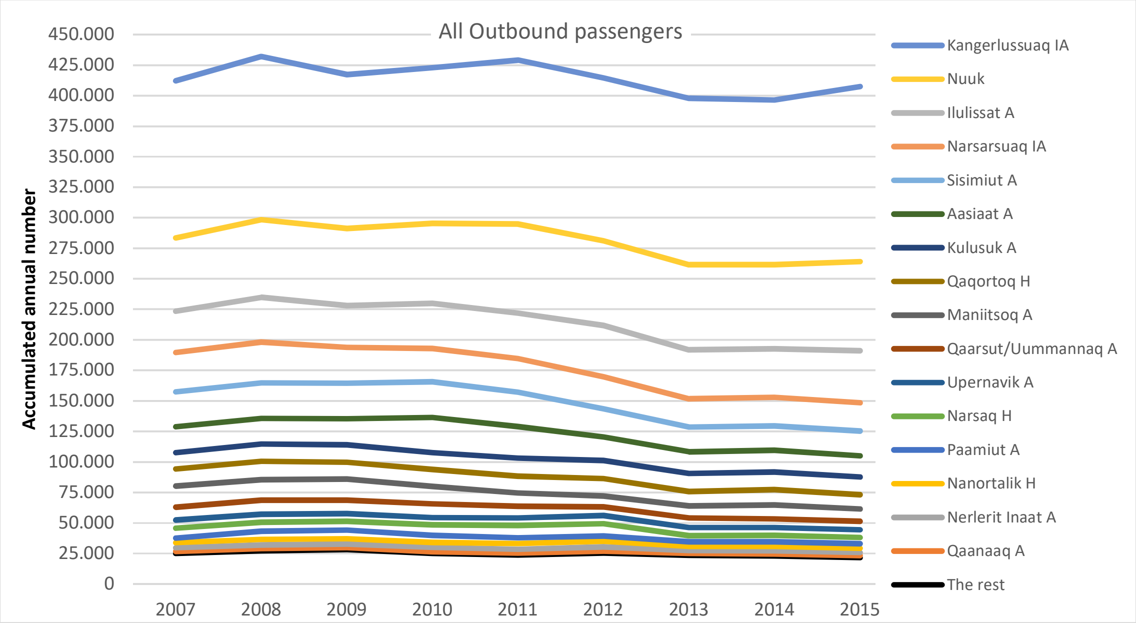
# APPENDIX 2

## Examples of the cost benefit analyses for Nuuk and Ilulissat from the TGB model

| | Nuuk, Runway in metres | | | Ilulissat, Runway in metres | | |
|---|---|---|---|---|---|---|
| | 1799 | 2200 | 3000 | 1199 | 1799 | 2200 |
| Investment - initially incl. further investments | -616 | -840 | -2179 | -50 | -647 | -955 |
| Reinvestment | -17 | -24 | -42 | -8 | -21 | -29 |
| Residual value | 23 | 35 | 108 | 3 | 35 | 52 |
| **Investment in all** | **-610** | **-829** | **-2113** | **-55** | **-633** | **-932** |
| Change in operational cost | 209 | 218 | 218 | -23 | -47 | -50 |
| Change in operational income | -316 | -337 | -337 | 100 | 162 | 170 |
| Distortionary loss | 61 | 67 | 79 | 25 | -64 | -4 |
| Benefit from leaving Kangerlussuaq | 495 | 495 | 495 | 0 | 0 | 0 |
| Repair in Kangerlussuaq | 54 | 54 | 54 | 0 | 0 | 0 |
| Running cost of new road | -37 | -37 | -124 | 0 | 0 | 0 |
| **Cost, Public** | **503** | **497** | **509** | **102** | **51** | **116** |
| Change in production cost | 622 | 263 | 263 | 216 | -458 | -440 |
| Income from fares | 292 | 974 | 974 | 20 | 401 | 1299 |
| Regularity loss | -78 | -94 | -111 | -4 | -34 | -37 |
| **Cost, Airlines** | **836** | **1143** | **1126** | **232** | **-91** | **822** |
| Time saving business travellers | 133 | 152 | 157 | -25 | 16 | 16 |
| Time savings residents | 179 | 205 | 205 | -27 | 21 | 15 |
| Savings of mail | 3 | 3 | 3 | 0 | 0 | 0 |
| Savings of freight | 12 | 12 | 12 | 0 | 4 | 2 |
| Savings fares | 1712 | 1729 | 1729 | 25 | 742 | 551 |
| Extra driving | 0 | 0 | -41 | 0 | 0 | 0 |
| **Benefit, users** | **2039** | **2101** | **2065** | **-27** | **783** | **584** |
| **Net present value** | 2732 | 2875 | 1304 | 250 | 111 | 591 |
| **Internal rate of return** | 26.8% | 21.0% | 8.8% | 29.7% | 6.8% | 8.9% |
| **Benefit / Cost ratio** | 5.32 | 4.32 | 1.9 | 5.3 | 1.17 | 1.6 |

Cost benefit analysis for Nuuk and Ilulissat airport. Net present values in million DKK in 2005 price level and internal rate of return for the two times three scenarios.

Accumulated number of all outbound passengers from each airport annually (Source: Greenland's Airport Authorities)



IA: International airport. A: Airport. H: Heliport. The rest: Mainly helistops.