Amsterdam University
of Applied Sciences

THE (CONGESTED) CITY IN THE SKY

THE CAPACITY GAME: FINDING WAYS TO UNLOCK AVIATION CAPACITY

Geert Boosten MSc

The (Congested) City in the Sky

The (Congested) City in the Sky

The capacity game: finding ways to unlock aviation capacity

Inaugural lecture

presented on Tuesday 3 October 2017

by

Geert Boosten MSc

Professor Aviation Management
at the Amsterdam University of Applied Sciences

Amsterdam University
of Applied Sciences

Cover image: BertZuiderveen.nl

Design cover and interior: Textcetera, Den Haag

ISBN 978-94-6301-148-8

Introduction

It can be hard to remember that aviation has only existed for a relatively short period of time. The first controlled flight by the Wright Brothers occurred in 1903, Royal Schiphol Group just celebrated its 100th anniversary, and the KLM Royal Dutch Airlines, founded in 1919, is the oldest airline that still operates under its original name. During this 100-year period, aviation has established a worldwide network connecting cities and regions around the globe. Liberalization and technology have democratized travel; in the air, the jet set is accompanied by the backpacker. Worldwide traffic grew from 310 million passengers in 1970 to 3.4 billion in 2015 (World Bank, 2017) and from 9.5 million registered carrier departures in 1970 to 33 million in 2015. As the sky has become more crowded, aviation has successfully controlled the impact of this impressive growth and effectively dealt with challenges like safety, security, airport and air space capacity, environment (noise and emission), access to ground transportation, and the liberalization of air traffic. Despite such major achievements, traffic continues growing at a very fast pace, and over the next 15 years, aviation will face a doubling in aircraft capacity based on the market forecast by Boeing (Boeing, 2017a) and Airbus (Airbus, 2016). The number of passengers and cargo carried may even be higher.

Is aviation able to accommodate this next major leap in development? Aviation already hits the capacity ceiling at airports and in the airspace while increasing security threats tend to diminish the existing capacity; therefore, over the next 5 to 15 years, aviation will encounter many capacity-related challenges. Past solutions are no longer sufficient to solve these challenges. The existing waiting lines and queues at Schiphol and the public response to them (Eldering & de Jong, 2017) are directly linked to the current airline and airport operating and business models, the public perception of airport service and quality standards, and the design of the airport. These items are not easy to change or adapt. Paradigmatic changes are required. The industry has to adapt and invent new approaches, introduce new technology, and redesign the day-to-day operations. Today's queues and hassles at the airport are just the tip of the iceberg; the real capacity challenge is to accommodate the forecasted growth of aviation based on the number of aircraft on order and new passengers bound to travel. The main challenge includes the development of new technology, procedures, and cooperation models that will result in a major shift in the way of working and a transition for the entire aviation industry. The second challenge is to manage the transition itself while maintaining very high operating standards for on-time performance, security, safety and cost control. There is no precedent to learn from, changes on one continent will have an impact on other continents, and choices made by the aviation industry will impact cities' and regions' economic development.

Aviation capacity is the research focus of the Aviation Management research unit (Lectoraat). Aviation capacity research resulting in possible practical capacity solutions in the workplace is the main challenge. Aviation capacity is not an isolated research area, but it is strongly linked to urban and societal development. Thus, understanding capacity requires a holistic approach. In this lecture, we will focus on the role of airports as nodes in the aviation network and their contribution to the development of the city/metropole in which they are situated. In our research, we want to explore the drivers of airport capacity, how to optimize the capacity at existing airports related to the demands of the city, and the transition process. The result is an integrated approach that will help ask different questions to understand the societal and industry limitations and next boundaries as well as optimize the capacity in the 24-hour operation. Being located in Amsterdam City and next to Amsterdam Airport Schiphol and KLM, we will refer to these entities as an example; however, the underlying trends and developments are worldwide.

Based on the discussions on Schiphol, Heathrow, and other airports, we can conclude that there are no easy solutions available. Aviation capacity is a complex matter because of the many different stakeholders, interactions among them, and potentially conflicting goals. In the meantime, aviation professionals work very hard to keep the system up and running every day; it is eminent that, in applied research, we focus our research to support the daily operations to keep up with these developments. The content of this inaugural lecture combines the insights from applied research with colleagues at the HvA and partner universities with the almost 30 years of aviation experience while working various positions and roles at Schiphol Airport and other airports around the globe.

The City in the Sky

Aviation is studied as a separate business; the aviation management research unit is a good example. But aviation is not a goal by itself; it is part of a larger system. The core business of commercial aviation is transporting people and goods for remuneration or hire from point A to point B (Skybrary, 2017), no matter where these points are on the globe. Aviation supplies the connectivity need for cities and regions. Aviation is a truly global business in terms of scale; flights departing from one continent arrive hours later on another continent. The aviation industry has created a worldwide network of airports where airlines provide connections via scheduled and unscheduled flights. Establishing these connections has been so successful that aviation has created a "City in the Sky"[1] at 30,000 feet, where more than one million people live at any moment of the day. Whereas in the past many cities were founded at crossroads or places to cross the river, the airports have taken over this role in the 21st century when travelling to other continents. The airports act as points of entry or exit for the temporary inhabitants of the City in the Sky. There are many entries and exits, but most inhabitants enter or exit via the big airports in the network. Based on the share of Schiphol Airport in global aviation, approximately 20,000 inhabitants from the City in the Sky can be linked to Amsterdam. This is far more than we would expect based on the size of Amsterdam as a city.

The City in the Sky is a true global city with roots in every continent. It also has many similarities with ordinary cities on the ground. Safety and security are of the utmost importance for all inhabitants. The life support systems in place should be robust and resilient to allow inhabitants to survive any disruption at 30,000 feet. Growth comes with congestion, and traffic management is required to avoid (further) congestion along the highways in the sky, while undisturbed accessibility to airports is crucial to allow temporary inhabitants to enter or leave the City in the Sky at the desired time and location. The impact of aviation on climate and greenhouse gas emissions is becoming a limiting factor for continuous growth. Because inhabitants in this city are constantly moving within and between continents and countries, the City in the Sky has a supra-national board of governors; ICAO is the UN specialized agency that, at the highest level, governs the international standards and recommended practices for 191 member states (ICAO, 2017a).

The challenges ahead for the City in the Sky are well defined in the ICAO Strategic Objectives (ICAO, 2017b), as shown in Figure 1. The expected doubling of air transport by 2030 could result in more than two million people permanently living at 30,000 feet – more than twice the size of the population of Amsterdam today! Providing efficient, safe, and secure capacity in the air and on the ground while also optimizing the system performance of aviation and limiting the adverse environmental impact is a tremendous challenge that underscores the need for aviation capacity research. The main question is if just expanding today's aviation practice is sufficient for meeting this challenge or is a paradigm shift needed to match the economic and connectivity as well as safety, security, and environmental objectives? Will new technology and improved procedures provide a sufficient answer to accommodate growth within strict constraints and current business models or will growth and constraints combined ultimately change the nature of the aviation business? The demand for capacity driven by a doubling of air transport *within 15 years* will put a lot of stress on the adaptability of the inhabitants of the City in the Sky, the infrastructure, and their providers and governors. The quest for capacity is a global challenge. However, the aviation capacity starts with local solutions to manage the local airport capacity, and the global capacity is the aggregate of local decisions. In other words, solutions to solve capacity issues in one neighborhood of the City in the Sky has (immediate) consequences for other neighborhoods as well. An example was Schiphol's policy in the 1990s to incentivize airlines to reduce noise by using the most modern fleet available in Amsterdam. The consequence was that the same airlines used old, noisier aircraft in other parts in Europe, causing noise pollution there. In other words, Amsterdam exported noise to other parts of Europe.

Strategic Objectives

In its ongoing mission to support and enable a global air transport network that meets or surpasses the social and economic development and broader connectivity needs of global businesses and passengers, and acknowledging the clear need to anticipate and manage the projected doubling of global air transport capacity by 2030 without unnecessary adverse impacts on system safety, efficiency, convenience or environmental performance, ICAO has established five comprehensive Strategic Objectives:

Safety:
Enhance global civil aviation safety. This Strategic Objective is focused primarily on the State's regulatory oversight capabilities. The Global Aviation Safety Plan (GASP) outlines the key activities for the triennium.

Air Navigation Capacity and Efficiency:
Increase the capacity and improve the efficiency of the global civil aviation system. Although functionally and organizationally interdependent with Safety, this Strategic Objective is focused primarily on upgrading the air navigation and aerodrome infrastructure and developing new procedures to optimize aviation system performance. The Global Air Navigation Capacity and Efficiency Plan (Global Plan) outlines the key activities for the triennium.

Security & Facilitation:
Enhance global civil aviation security and facilitation. This Strategic Objective reflects the need for ICAO's leadership in aviation security, facilitation and related border security matters.

Economic Development of Air Transport:
Foster the development of a sound and economically-viable civil aviation system. This Strategic Objective reflects the need for ICAO's leadership in harmonizing the air transport framework focused on economic policies and supporting activities.

Environmental Protection:
Minimize the adverse environmental effects of civil aviation activities. This Strategic Objective fosters ICAO's leadership in all aviation-related environmental activities and is consistent with the ICAO and UN system environmental protection policies and practices.

Figure 1. Strategic Objectives ICAO (ICAO, 2017b).

Despite the magnitude of the passengers and cargo transported in aviation, the number of airports with commercial aviation worldwide was limited to 3,944 in 2014, with most being located in North America, Asia, and Europe. These 3,944 airports with commercial traffic are the ports of entry or exit into the City in the Sky. Traffic is not evenly divided among these airports, but is rather heavily concentrated at a limited number of airports. 50% of the traffic measured in air traffic movements (ATM) is handled at only 122 (3%) of the airports, while 90% of the traffic is handled at 949 (24%) of the airports (Gelhausen, Berster, & Wilken, 2013). Therefore, the most congested airports can be found within a group of fewer than 1,000 airports worldwide and especially within the segment of 122 airports handling 50% of the worlds ATM. The remaining 75% of the airports can be characterized as underutilized. The authors question whether the expected growth will increase the capacity demand at the already heavily used airports or will the unused capacity at the other airports be activated and used in the near future (Gelhausen et al., 2013)? Although it seems obvious that using underutilized airports will easily add capacity to the system, the reality is that economies of scale, locations of markets, business models in aviation, vested interest, and regulations generate blockers to do so. Legacy and path dependency in aviation are important factors, as we will demonstrate later (Bonvillian & Weiss, 2015).

Just like in ordinary cities, the expected growth will have more impact on one part of the city than others. In the City in the Sky, the expected growth will predominantly take place in Asia, the Middle East, Latin America, and Africa. Northern America and Europe remain very big – mature aviation markets with moderate growth (Boeing, 2017b). The traffic shift between continents has already been happening for two decades; Figure 2 shows the shift between the regions in the world over the last 20 years.

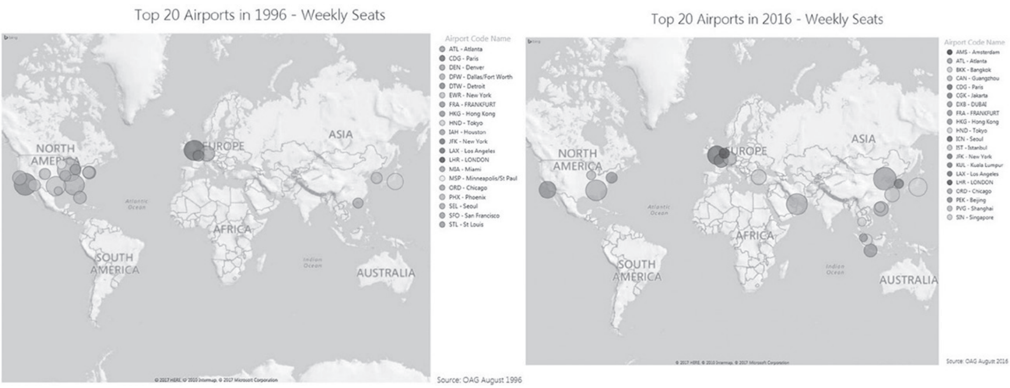

Figure 2. Traffic shift between continents 1996-2016. (Boeing, 2017b, p. 16).

Government Involvement/Regulation and Technology as Enablers of Aviation

Government involvement/regulation and technology are the two major enablers of aviation. Aviation, and thus airlines and airports, developed from a state-controlled transportation system or public service toward a commercial business with different business models and markets growing from bilateral exclusivity to open markets (Macário & van de Voorde, 2011). Deregulation, the liberalization of air transport, and the globalization of the economy resulted in the tremendous growth of the aviation system and business. Airports, air traffic control, and airlines have been able to significantly increase the scope and scale of their operation to match the growth to a certain extent, but the fast growth comes with congestion, delays, and increased complexity (Janić, 2000). Controlling the fast and ongoing growth and keeping the system effective for all stakeholders involved are significant challenges for aviation in the near future.

The City in the Sky is governed by a supra-national body and subsequently followed by regional bodies like the FAA and EASA as well as national and regional governments. Deregulation and liberalization were the main enablers for growth by opening up market access and greater freedom for airlines in the traditional large markets North America and (later) Europe. Other parts of the world followed to some extent, but in Asia, Latin America, Africa, and the Middle East, markets are still less deregulated and liberal (Doganis, 2010). This provides fewer opportunities for airlines to access these markets or to operate in the most efficient manner. In addition, at the airport level, there are differences in the evolutionary phases of development (Macário & van de Voorde, 2011). The variations in market regulations worldwide result in different regional operating modes for airlines and airports. In the Western part of the world (USA, EU) aviation is opening up toward a free market, where a level playing field exists for airlines and airports to operate and compete in. The other extreme in other parts of the world is that aviation is primarily perceived as a public service run by governments and less as an independent business. The two systems result in different drivers for aviation development in the region and sometimes in conflicts on how to compete or develop the markets.

Supra-, international, and national government bodies still determine the boundaries of the airline and airport business models. The level of control can vary; domestic markets can operate with different degrees of freedom than international traffic (between countries). For instance, opening the EU as a domestic market allowed low-cost carriers (LCC) to operate on many routes within the EU and open bases at many airports in various countries. Such a business model simply was not possible when the air traffic between the current EU countries was governed by bilateral agreements. For example, with the upcoming Brexit, UK carriers are seeking EU bases to maintain their access to the EU market and to support their business model (The Guardian, 2017).

The second enabler for aviation growth is technology. The development of new aircraft types, engine technology, and new materials resulted in a continuous decline of cost-per-seat mile, fuel consumption-per-seat mile, and CO2 emissions (Doganis, 2010). The 2010 fleet was already 80% more fuel efficient than the 1960 fleet, and the aviation industry is constantly striving to push the technology envelope to improve the aircraft performance even more to limit the impact of the expected growth on the environment (ICAO, 2010). Aircraft technology for civil aviation has strongly benefited from the demands for military aviation. Most of the fundamental technology developments in the past were initiated and funded by the military (i.e., the government). In other words, even in aircraft technology development, the government's role has been crucial in initiating the massive technological improvements aviation has seen. The civil aviation market benefited from these developments (Mazzucato, 2013).

Government involvement and technology have been and remain dominant factors in the development of aviation. The airline and airport business models can be seen as a derivative of these factors; airlines and airports alike offer business within a framework that is allowed by governments (i.e., bilateral agreements between countries) and is technically possible. This seems to be an obvious statement, but it has large consequences on how airlines and airports will be able to offer their services and generate revenues in various parts of the world. Relationships and fee and charge structures between airlines and airports and/or air traffic control (ATC) are heavily regulated and dictate how revenues are divided amongst parties.

The entry into the City in the Sky is shaped by government control and technology. A third, often less recognized factor is the role of legacy and path dependency. Decisions and choices made concerning infrastructure, technology, or government regulations in the past are the constraints for the aviation business today. Legacy also influences our mental framework and how we perceive the aviation business, the pricing models, the role of incumbents, and the relationship among all stakeholders involved. Legacy has a major impact on the adaptability or lack of adaptability of the industry (Bonvillian & Weiss, 2015). In other words, if we want to research aviation capacity in light of future industry developments, we should incorporate the role of legacy in the aviation industry as well and, more specifically, determine to what extent legacy limits the aviation industries' capabilities to change or limit the speed of change and how it defines our mindset to accept possible solutions or not.

Aviation business is the result of how airlines, airports, ATC, and other stakeholders interact within the boundaries of government involvement/regulations and technology. Choices made in the past are crucial for understanding the degrees of freedom and options to accommodate tomorrow's growth. Aviation capacity is not merely a technical issue, but also a social construct. The old blueprint of the City in the Sky is already influencing the future development of this city and the potential role of airlines and airports. The City in the Sky connects the cities on the ground with the airports as ports of entry or exit. The next step in understanding aviation capacity in a wider context is to explore the relationship between the cities on the ground and their airports.

City–Connectivity–Connections–Capacity

From a city perspective, connectivity acts as an indicator of how a city wants to be connected to other parts of the world due to economic, societal, or cultural motives. Transportation networks make cities accessible, and the more accessible a city, the more it can attract businesses, tourists, and visitors. The transportation networks between cities can act as an indicator for the interactions between cities. To gain insights, we need the focus on the available infrastructure, the capacity of the network in terms of how much travel is possible, and the flow network indicating the actual interactions between the cities (Neal, 2013).

Figure 3 shows how the city network and the aviation transportation network interact. The city creates a demand for connectivity, and the actual air connections to other cities or regions in the world are based on the city's activities and characteristics. Airlines supply connectivity by offering connections and an air transport network either via a point-to-point or a hub network depending on the strength of the demand and the airline business model.[2] The city airport is the linking pin, where demand and supply will meet and jointly create an airport network. The airport thus has a service relationship with the region to ensure that connectivity demand can be met and a business relationship with the airlines to provide up-to-date facilities and sufficient capacity to accommodate the flights needed offer the connections in an efficient, effective, and cost-sensitive manner. In this scheme, we approach aviation as a system.[3]

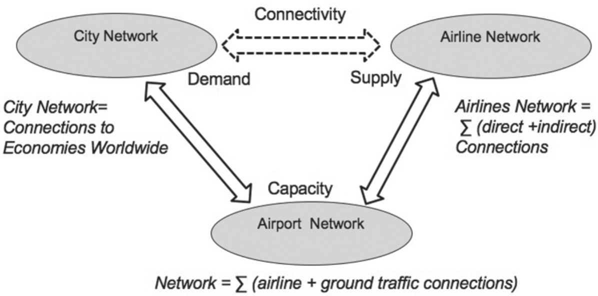

Figure 3. Relationship between city demand for connectivity and supply of connections by airlines. The airport is the place where demand and supply physically meet and is accommodated efficiently and effectively.

To understand the complex city–connectivity–connections–capacity relationship, the drivers of the main components – city-connectivity demand, airline connectivity/connections supply, city–airport–capacity, and airline–airport–capacity relationship – have to be explored.

City–Connectivity Demand

Today (mega) cities are seen as nodes in a network. As Castells stated,

> The global city is not a place, but a process. A process by which centers of production and consumption of advanced services, and their ancillary local societies, are connected in a global network, while simultaneously downplaying linkages with their hinterlands, on the basis of information flows. (Castells, 2010, p. 417)

Considering cities as nodes in global networks shifts our focus from the networks within one particular city toward the relationships between cities as nodes in the network. Connectivity is thus a vital condition for city development; a city as a node in a worldwide network cannot survive without (massive) connections to other nodes in the network. The questions that arise focus on what the real interest of a city is when seeking to be connected to another city. Understanding the world's city network requires knowledge of how cities are connected to each other and how a city's connectivity can be measured (Taylor, 2004). The city's position in the network is important; however, cities as nodes in the network are not the prime agents of the network formation. The city network is an interlocking network in which, at the sub-nodal level, the key agents – namely, service firms – can be found. In other words, the network consists of three levels: the world economy as the network level where services are dispensed; the cities as the nodal level, constituting the knowledge constellations for production of services; and the advanced producer firms that create and provide the services (Taylor, 2004). To define the network position of a city, the key firms and their connections need to be studied. Key firms are service firms that provide services that corporations require to provide their business activities; we can think of legal, banking or finance, advertising, management consultancy, insurance, or research institutions (Taylor, 2004). Building the world's city network on these indicators provides an overview of the relative position of the city in the network in terms of the number of connections as well and insights into what the dominant connections from one city to other cities in the network are. The power of a city in the network indicates the position of the service firms and the attractiveness for corporations because of the availability of crucial services. In 2004, the two major cities with a central position in the world's city network are London and New York, while Amsterdam holds a strong position very close to the center of the network. Just like the airports, there has been a worldwide shift toward the Far East/ Asia, where the new major cities in China and other countries are rapidly gaining importance in the network.

The conceptualization of the world's city networks is still in progress (Derudder, 2008). The availability of relevant data is a crucial issue. In theory, the ideal position is that we can identify the exact economic, social, and cultural network that connects one city to other cities in the world; this would provide a strong foundation for the minimal transportation network to serve the cities' demands. It will require intensive further research to establish this insight.[4]

Another question that arises is whether air transport networks can be used as a proxy for the world's city network. In theory, the air transport network should provide insights into connections and volumes transported between world cities. However, the key problem is the availability and quality of data. The available airline databases provide data about the aircraft, passenger, and cargo movements between airports, but because of the use of hubs in the system, it is very difficult to gain insights into the actual point-to-point traffic data, which are needed to assess the connectivity between cities. If data from booking sites can be used, it could be possible to overcome these problems (Derudder, 2008). The aviation data can be used as a proxy for the connectivity demand of a city. Point-to-point traffic is the best indicator for the connectivity demand of non-aviation-related activities in the city. The origin/destination (O/D) passengers or cargo really disembark in the city of destination, spend money because of activities (tourism, leisure or business) in the region, and/or strengthen business relationships. If the airport is a hub, the additional hub-transfer activities will primarily support the local aviation-related business (Neal, 2010).

The outcomes and the relevance of the world's city network studies can be very much debated; however, from an aviation capacity standpoint, the world's city network approach offers an additional angle to gain insights into the level of a city's connectivity service firms', corporations', and citizens' needs from other economies/societies given its position in the global economy and the world's city network. For an airport to be able to allocate its capacity, it is crucial to have objective knowledge of what are the most relevant and important connections from a city in the global network and what the underlying actors are. Aviation provides a proxy, but does not explain why a connection is important in absolute or relative terms or what the consequences are if a connection cannot be offered or has a lower priority. It is relevant to distinguish local connectivity from hub connectivity because a hub airport may be so efficient that is supplies connectivity to the global market that may be less relevant for the development of non-aviation-related activities in the city's region. Following this approach to understand the connectivity demand of Amsterdam and the Netherlands, we need to distinguish between the point-to-point demand and the hub-related transfer activities. The point-to-point traffic is one indicator of the local Dutch demand for connections with other cities worldwide. This traffic includes the activities of all airlines operating in Dutch airports and airports in the Dutch border region. Part of the Dutch passengers can also easily choose airports in the vicinity of the Netherlands, such as Düsseldorf, Weeze (Germany) and Brussels (Belgium); Brussels, for example, handles approximately 500,000 Dutch passengers annually (Verhallen & van Dessel, 2014).

The hub at Schiphol offers 56,535 connections (ACI, 2017) not only to the city of Amsterdam (and the Netherlands), but also to many more city pairs that are connected via the hub at Schiphol. This results in a very strong aviation cluster in Amsterdam and the Netherlands, with significant employment and economic activities. For KLM, as the main hub carrier, the largest group of passengers is the 70% of passengers transferring at Schiphol (KLM, 2017), meaning that KLM via the Amsterdam hub is an important entity in connecting foreign cities to each other. In addition, the local market benefits from this airline network, but the lower the share of local O/D on board of a KLM flight, the less important the connection is for the non-aviation Dutch economy. The Dutch-based demand for O/D connections to other cities is serviced by all carriers, and it is fair to state that the non-hub carriers at Schiphol and other airports have a (very) significant share of the O/D traffic. In 2016, the O/D traffic at Schiphol showed the highest growth; transfers still grow, but at a slower pace (Schiphol, 2017). The Amsterdam- or Dutch-based connectivity demand is a complex matter, especially because of the role of the hub at Schiphol. The Dutch-based O/D connectivity is crucial for the development of the city of Amsterdam and the Dutch economy. Further research is needed to understand the O/D travel patterns to and from Amsterdam and the Netherlands to be able to assess the real capacity demand from the non-aviation Dutch economy for aviation.[5] In other words, referring to Figure 3, the service relationship between the airport and the city needs to be further understood in relation to the city's position in the world's city network.

Airline–Connectivity–Connections Supply

The airline–connectivity–connections supply can be defined as the offering of the set of connections needed to link a city and its business, social, or cultural activities to other cities in the worldwide network; it assumes a well-known and specified set of connections from one city to (many) other cities. We have already noticed that it is very hard to specify exactly or rank these connections in terms of relevance and size.

The airlines connectivity supply is measured in terms of the city pair connections the airlines offer directly or indirectly. The direct connection is a point-to-point connection to the other city, while an indirect connection requires a transfer at a third airport, often a hub airport. The connectivity of the hub itself can be defined as the total number of connections offered through a hub airport; connections can be purchased by a passenger from airlines (SEO, 2016). The combination of direct and indirect connectivity often offers the passenger far more choices for traveling from point A to point B, which are differentiated in terms of price, travel time, travel moment, etc. The connectivity of the European hubs, including Fraport and Schiphol Airport, is still increasing (ACI, 2017), meaning many city connections are directly or indirectly offered via hubs. A traveler is supposed to choose the shortest travel time and/or the lowest fare. However, recent publications hint that passengers' travel preferences are changing; comfort and Wi-Fi availability seem to be gaining importance in passenger choice over price and travel time (Zakenreis, 2017).

The actual connections offered depend primarily on the local demand for connections to other cities. The airline decides whether a service will be offered, taking into account its business model, the airport's facilities (e.g., length of runway, terminal capacity), and alternative business options. These factors will determine if the airline is capable of offering specific connections – direct or indirect – at a reasonable price and acceptable contribution to the airline's profitability. We have seen that the airline business model is limited by regulations and technology. Regulations define the accessibility of the airport and the type of service the airline is allowed to offer: Is the airline allowed to fly to the airport and offer the type of services it wishes to offer? Especially in international traffic, limitations do apply due to bilateral agreements, security, safety, or other issues. Additional regulations on handling, staff, safety, and security are crucial for the airlines' operations cost level at the airport. Aircraft technology is related to aircraft performance and economics in general and, more specifically, the type of aircraft the airlines wants to use to service the market. In addition, what are the aircraft characteristics related to the market, payload conditions, distance flown, cost per seat/mile, and/or requirements for airport facilities (e.g., runway length) (Doganis, 2010)? For instance, the growth of LCC results in an increase of direct connections at all airport types and most in the group of small to medium-size airports (5 to 10 million passengers a year). If the city airport is a hub airport, the hub airline may offer a very large number of connections, meanings its hub connectivity is tremendous compared to non-hub airports. As previously mentioned, the hub could offer a higher connectivity than the city really requires for non-aviation activities (Neal, 2010).

The connectivity supply toward a city is first and foremost an airline business decision: Is the airline allowed to offer, is it safe and feasible to operate, and/or are there no better/profitable alternatives available to use the aircraft? For full service carriers (FSC) offering a worldwide network between cities, a hub is a very efficient node in the network that allows for many more connections that otherwise would not be feasible. This is a bonus for the local city in terms that, even if there is limited connectivity between the city and another city, the hub can provide the direct or indirect connection. The question of whether the availability of many air connections will result in new activities in the city and urban growth is difficult to answer. Recent studies in the USA have found evidence that shifts in industrial composition, especially the retail and service industry, are associated with growth in aviation networks. The relationship between regional/local economic growth and public investments in aviation needs further research (Blonigen & Cristea, 2015).[6]

Worldwide, Amsterdam's Schiphol Airport is amongst the airports with the highest connectivity, and its connectivity is still increasing as it offers 322 (of which 128 are intercontinental) direct connections to 96 countries by 111 airlines (Schiphol, 2017). The productivity and growth are truly impressive and certainly beneficiary for the Dutch aviation cluster. The main question in the context here is how the airline connectivity supply offered matches the needs of the non-aviation-related economic, cultural, and social activities in Amsterdam and the Netherlands. As previously mentioned, the answer to this question is hard to give and requires future research. A related question has to do with hub effectiveness. ACI shows that connectivity at many hubs is increasing; if we combine this with the increased (direct and indirect) connectivity of the Schiphol hub, the Amsterdam O/D passengers get many opportunities to fly directly or to connect via other hubs. The availability of numerous other options and the ability to be online while travelling could limit the importance of the direct connections. The concept of 'value of time for passengers' and how it influences their decisions is gaining importance; the passenger takes into account the door-to-door travel time and total travel cost (Jorge-Calderón, 2014). The increased size of the hub airports, the long processing times (up to three hours at the hub), and the still growing alternatives at other non-hub airports create new feasible options for passengers seeking to travel from point A to point B. Using a remote airport and transferring at another hub can be a good alternative. The idea that direct connectivity is growing due to LCC as hub connectivity (ACI, 2017) is an interesting development that needs further research to better understand passengers' behaviors and motives; the outcomes of these developments can be essential for understanding airline connectivity supply, capacity allocation, and airport development. Behavior economics are good reference for further research to investigate if passengers' travel patterns and behavior are changing and, if so, in what direction. Such an understanding will help determine the importance of various airline connections supplied to the city and prioritize connections, if needed.

Airport–City–Capacity

Just like the internet, aviation is a crucial mode for connecting a city to other cities in the world's city network. The airport is often perceived as an engine for the local economy, implying that the aeronautical and non-aeronautical activities at the airport generate and stimulate the economic development of the region. In the Netherlands, the airport's role as an economic engine is even an essential part of the government's mainport strategy. In the 1990s, Schiphol presented a model for airport added value development based on the OSI model used in the IT world; the model indicated how the airport's basic infrastructure can be used to generate additional income (retail, real estate, IT services). The increasing connectivity attracts new activities and businesses that themselves generate additional growth in traffic and connections (Macário & van de Voorde, 2011, p. 140). Figure 4 presents a derivative of this model indicating the reinforcing loop of city development and airport city development. The airport develops a two-sided market business model where different types of customers can be serviced. Following the theory of network economy, the growth of one market will fuel the growth of the other market as well (Appold & Kasarda, 2011). Access to advanced air transportation plays an important role in establishing the city's connections to other cities. City leaders are under mounting pressure to expand airport capacity in order to ensure their city's position in the world's city network.

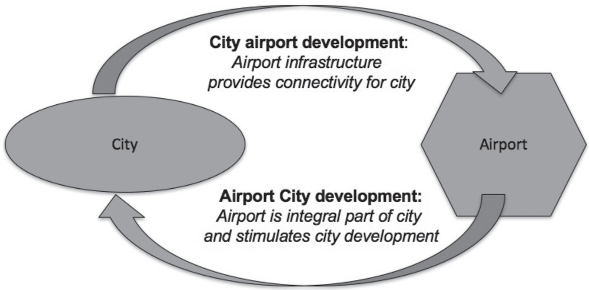

Figure 4. City–airport interaction. From city airport toward airport city, the airport contributes to the city development and the airport site becomes a hotspot in the city.

Addie (2014) stated that an influential political consensus has grown around the growth potential of the airport city. Therefore, cities are stimulated to develop their airports in order to maximize the local advantages and competitiveness of the local economy. However, globalizing airport facilities requires massive investments along with the place-based accumulation of technological knowledge and organizational and geopolitical power. Although aviation strongly claims that a positive relationship exists among investments in airport infrastructure, aviation growth, and economic structure/development in the region, these claims are very hard to verify (Addie, 2014; Knippenberger, 2010). From an aviation capacity standpoint, we notice that the global aviation development puts pressure on cities to develop their airports; cities and their airports are competing in order to keep pace with the global development. The demand for more air space, runways, and terminals is a global demand that has to be accommodated at airports in specific cities. Addie defined this as follows:

> Aero-regionalism contributes to our understanding of the relationship between the global urbanization and air transport, as well as the debated process on city-regionalism, by demonstrating how international air hubs are not only generative nodes of economic activity located in metropolitan areas, but are fundamentally conditioned by the local context. (Addie, 2014, p. 97)

As a result, the accommodation of the global aviation growth has to be realized at the local level and governed by regional/local governments and stakeholders. These local authorities have to balance the global growth with regional economic developments, knowing that expansion of aviation activities and airport infrastructure has a major impact on urban planning, ground transportation infrastructure, and quality of living as well as the production of airport-integrated urbanization (Addie, 2014). Local authorities have to safeguard the city's position within the world's city network using a local framework driven by local stakeholders' desires. This global-local paradox is crucial in the airport's complex and long-lasting development processes. For example, the discussion on mitigating noise pollution at Schiphol started in the 1960s (van Deventer, 2010), and the debate on airport expansion in London resulting in the recent reports of the Davies Committee started in 1968 (BBC, 2015).

The aero-regionalism paradox adds another balancing loop to the relationship of city and airport, as shown in Figure 5. The global economic and aviation developments as a reinforcing loop promote optimal connectivity by air and the use of the airport to strengthen the city's global position; as a balancing loop, regionalism offers the perspective to ensure that the aviation activities and airport infrastructure really fit into the dynamics of the regional economy, local transportation, and the region's social and cultural qualities. The airport is in the middle of these developments and has to find the right balance between global and regional developments; given the different nature of reinforcing and balancing loops, this is a very difficult task. Reinforcing feedback loops are self-enhancing and lead to exponential growth or to runaway overtime, whereas balancing feedback loops are equilibrating or goal-seeking structures in systems and are both sources of stability and resistance to change (Meadows, 2008).

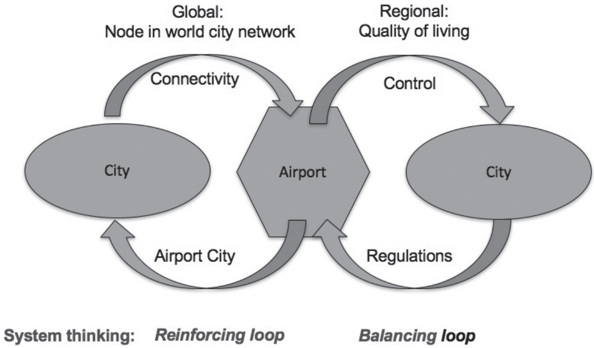

Figure 5. Impact of aero-regionalism on airport development. Global developments require growth in connectivity while the region wishes to control and integrate these developments in the region.

On the one hand, the airport faces a strong drive in globalization and, together with the airlines, might fear that missing the momentum will result in falling behind in aviation growth. On the other hand, the region wishes to implement globalization within its local system without disruption. Accommodating global aviation growth fits in the business model of the airport and its business relationships with airlines and non-aeronautical business stakeholders (i.e., real estate at the airport) while many of the regional developments want to control and – often – limit the airports' and airlines' business growth. The city's vision of the airport as a business or the airport as part of the local infrastructure as a public service is detrimental to the choices the airports and its stakeholders will make. The investments in upgrading and/or expanding airport capacity have to be considered in an environment with many potential conflicts of interests and dynamics between stakeholders in terms of pace of growth and purposes to be met. The system dynamics caused by both feedback loops should be incorporated in the considerations.

Summary City–Connectivity–Capacity

Global cities are nodes in the world's city network. Following network theory, connectivity is decisive on the relevance and position of the city in this network; thus, connectivity is a key factor for a global city. The actual connections are made at the level of economic, societal, or cultural actors. Due to specialization, history, and cultural backgrounds, a city will have more and stronger links to specific cities. Unfortunately, it is not possible to determine the exact position of each city in the network or the relevance of each connection to other cities; therefore, it is important to find a proxy to get the best estimate for this connectivity. Aviation can act as a proxy for a city's connectivity demand. The size and number of connections will ultimately define the city's demand for connectivity.

The airlines will provide the connections based on the actual demand and within the boundary conditions of regulations, technology (including infrastructure), and business models. Ultimately within these conditions, whether or not an airline offers a connection is a business decision. In theory, the airline will only provide those connections with a sufficient demand. This is true for LCC, which mostly operate point-to-point networks; but in reality, to be efficient and effective, FSC operate via hub-and-spoke systems, where the hubs generate many connections among many cities. The local city's economy/society/cultural position demands a specific set of origin/destination connections that can be offered via point-to-point or hub networks. The transfer offered by the hub is less relevant for the city's non-aviation activities, but supports a stronger aviation cluster at the hub airport. Connectivity can be direct or indirect. Given the tremendous growth of hub connectivity and point-to-point networks at non-hub airports, today's traveler has many options to travel from point A to point B. Total travel time, costs, comfort, and online access are becoming increasingly important, and we have to realize that successful hubs become more congested and have increasingly longer processing times. Hub avoidance can be a legitimate option.

The relationship between the city and airport is complex. The city's connectedness to the world's city network and aviation growth are global developments that have to be accommodated within a regional context. One question is whether aviation growth has a strong influence on the city's development in the long run; air transport connections add value, but determining to what extent is still difficult and requires further research.[7] The airport and airline business models are geared to keep pace with the worldwide development while the region wants to control the impact on and added value of the airport for the region. Both feedback loops (the reinforcing global network and the balancing regional position) influence the demand for capacity by the airport in terms of the total aviation activities that have to be accommodated. The tensions between the two feedback loops often result in long-lasting processes to decide on the next steps in airport development.

Further research is needed to gain insights into the real demand for a city's connectivity. This is crucial to assess the level of aviation connectivity to meet this demand; the travel patterns need to be studied to evaluate how the O/D demand in a city is met and how the status of the connections between cities is related to the economic, social, or cultural activities within the city. If the city airport is a hub, further research is needed to distinguish to what extent the hub differentiates between the aviation and non-aviation industry demands and activities in the city. Finally, the connectivity demand will be the basis for the minimum aviation capacity the airport needs to accommodate. System thinking and system dynamics are crucial elements for understanding the dynamic interaction between the global and local drivers of airport capacity.

City–Connectivity–Connections–Capacity–Control

We assume that, as long as there are no capacity limitations in the aero-regional complex, aviation can entirely fulfill its role to meet the city's connectivity demand in an efficient and effective manner according to the airlines' and airports' business models. The aviation activities are governed by standard worldwide, national, and local regulations as well as standard practices and procedures. One question that arises is what will happen if the airport's capacity can no longer meet the airlines' demand for runway capacity and other aviation-related facilities? At this moment, we deliberately do not differentiate whether this additional demand is caused by growth of the city's connectivity demand for non-aviation activities or solely by growth in aviation activities like hub development or LCC growth.

The question about what will happen if capacity is limited is expressed in Figure 6, where a lock is put on the available airport capacity; the reason capacity is limited can vary, but the main result is a (potential) mismatch between the city's demand for connectivity and the airline connections. A potential conflict between the business-driven airline and airport incentives to grow (reinforcing loop) and the regional preferences to fit the airport's development within the city development in a controlled manner (balancing loop) might become actual.

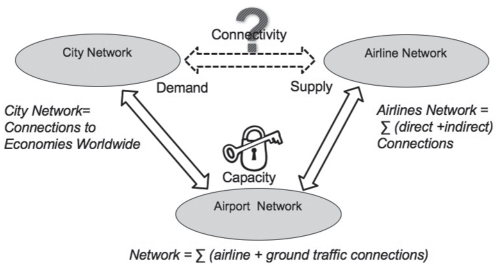

Figure 6. Airport capacity is insufficient to meet the connectivity offered by the airlines. Choices have to be made if not all connections can be offered. The main question is who will make these choices: the airline, the city, or both?

The fact that airport capacity limits the actual aviation growth is the case at many large airports worldwide. In 2016, this situation occurred – again – in the Netherlands: Schiphol's aviation growth exceeded expectations as expressed in the Alderstafel, which defined the conditions and limitations for aviation growth until 2020 (Alders, 2013). The objective was to maintain a good balance between the expected aviation growth in terms of aircraft movements, connectivity, and connections and the impact (e.g., noise, emissions) of aviation on the region. Part of the solution was to integrate the capacity of regional airports and Schiphol in an airport system. In 2016, parties at the Alderstafel realized that the 2020 limits would be reached in 2017, meaning that expected growth would be blocked for at least three years. In February 2017, it became evident that the mechanisms put in place to control growth at Schiphol and other airports were not as effective as expected. Thus, the government announced that the traffic distribution rules between Schiphol and Lelystad Airport were difficult to apply in practice (Cohen, 2017b). The independent slot-coordinator indicated that airlines question the slot allocation mechanism at Schiphol now that the demand for slots exceeds the limit and that there is no good system in place to differentiate among airlines' requests (Cohen, 2017a). In addition, KLM's CEO has argued that all parties have to return to the table to re-evaluate the current situation and the contribution KLM has made to the growth while reducing the noise (Cohen, 2017e).

The Dutch aviation cluster at Schiphol has been very successful. The airport has record-breaking passenger numbers and ATM; both the hub and non-hub carriers contributed to this success. Yet there is a clear difference between the global trend for more aviation and the regional drive to control the impact of aviation. For the aviation sector, the need for growth is part of the business model; the demand for additional airport capacity fits within the airline and airport strategy and company goals. Aviation focuses primarily on the relationship between airline and airport as shown in Figure 6, where the airport should facilitate the business opportunities that arise. The other connection in Figure 6, between city and airport, represents the added value of airport development for the regional economy, but this is difficult to assess and a very complex matter. The assessment requires a tradeoff among potentially conflicting parameters, such as the demand for increased connectivity to other cities on the economic, social, and cultural activities of the city, the impact of airport development on regional urban planning, ground transportation, environmental conditions such as noise and air pollution, and quality of living as well as the direct economic contribution of a strong aviation cluster on the local economy. Studies often show a strong relationship (correlation) between aviation growth in terms of increased connectivity and economic growth, but the causation of these factors is weak and therefore also impact fewer destinations or frequencies on economic growth (Smit, Koopman, & Faber, 2013). As previously mentioned, these questions need further research,[8] especially where studies on added value of connectivity are not conclusive and deliver different visions and outcomes. The complexity increases exponentially when the parameters are valuated in an integrated model that differentiates between global developments and regional impact.

The third connection in Figure 6, between city demand and airline supply in connectivity, is a truly interesting one. Ultimately, this connection represents the balance of power between the city and the airline. Which party decides on what criteria on the growth and specific connections in the case of capacity scarcity, when the entire demand cannot be met? Is connectivity growth at large – and, more specifically, the actual connections offered – primarily an airline business decision or should it be driven by the city (being the aggregate of business, social, and cultural activities)? This question is reflected in the discussion on slot allocation rules and slot ownership. The existing scarce airport capacity should be optimally used and allocated. New entrants must have real opportunities to access the market, and the slot allocation should be transparent (Debyser, 2016). At Schiphol slot-allocation is a major issue now that slots are scarce; allowing secondary slot trading is presented as a possible solution to optimize the use of existing capacity (de Wit & Burghouwt, 2017). Within aviation, the allocation of scarce capacity at congested airports has built up a firm legacy on slot allocation and other mechanisms that strive for optimal continuation of the day-to-day business. The solutions found in the past in terms of how to deal with scarcity at airports were the best outcomes for the time when this scarcity occurred. Today this legacy could also become a blocker for further development; airlines have invested based on current practices, and governments apply these rules to allocate capacity. The decisions from the past become our mental framework on how to operate; legacy in sectors like transportation often becomes a (hidden) blocker for innovation for both reasons mentioned – namely, current practice and mindset (Bonvillian & Weiss, 2015). Unlocking capacity has to incorporate insights from legacy before defining and selecting options.

At the societal level, the key question on airport capacity at congested airports is how to control the capacity development and allocation of scarce capacity. As shown in Figure 6, the three crucial factors are the (global) business driver of airlines and airports, the complex (regional) relationship between airport and city, and the match between market demand for connectivity with optimal allocation of existing capacity. Integrating the reinforcing and balancing feedback loops as shown in Figure 5 into the dynamics of limited airport capacity shown in Figure 6 can result in the construction of a "cyclic governance model for aviation capacity" (Boosten, 2017).The model is shown in Figure 7. Following the model clockwise, a reinforcing loop of the globalization and aviation development is expressed. It shows how the city is connected via the worldwide aviation network and specific airline connections in the airline networks. The connections, measured via (frequencies X destinations) (ACI, 2017), are reflected in the airlines' schedules, which represent the actual airline demand for airport capacity. Airport capacity can grow through a sequence of improving technology to reduce the impact of aviation on the airport's surroundings while maintaining or enhancing safety. By increasing the airport's capacity and productivity, the airport will act as an economic engine for the city to support the city's economic, social, and cultural positioning in the world. Aviation business and globalization are the main drivers of this clockwise cycle.

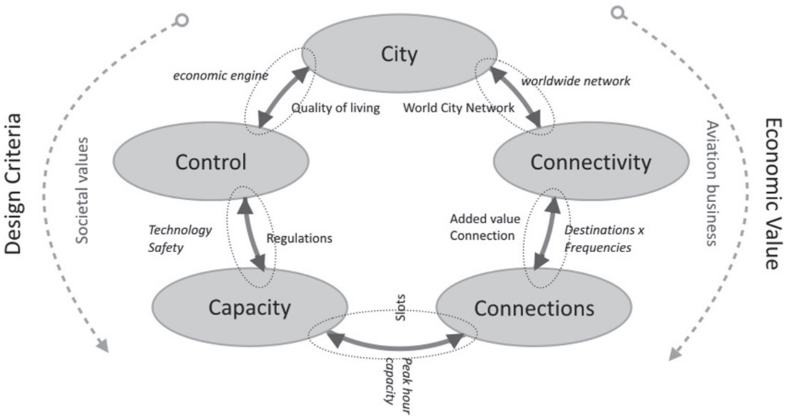

Figure 7. Cyclical governance model aviation capacity. The model focuses on the various interactive relationships among the city, airport, and optimum use of existing or future airport capacity. The model is cyclical due to iterations between and within the model's building blocks (Boosten, 2017).

Following the governance model anti-clockwise, a balancing loop represented by regionalism drives the cycle. The city defines its design criteria and societal values toward the added value of aviation for the development of the city and its positioning in the world's city network. The city values of quality of living (welfare and social well-being) need to have a large influence on airport capacity development. Control is established by regulations, limitations, and procedures based on the city's design criteria and societal values. Capacity will be developed and allocated to realize the demanded level of connections and connectivity; this level is determined by the business, society, and cultural needs of the city's stakeholders to maintain or strengthen the position in the world's city network.

The objective of the design criteria is to establish a robust, redundant, resilient, and reliable aviation operating model (Stoop, 2017) that embeds more elements than noise, emissions, and air pollution. The criteria incorporate short- and long-term standards for economic growth and quality of living in the city; the need for safe and secure airport operations; care for the climate, the environment and scarce resources; urban planning to allow space for both the city and aviation development; public commitment for airport development; incorporation of ground transportation; and flexibility to adapt to future developments. The design criteria for aviation capacity are defined at the local, regional, or national level, but are often related to global developments such as the Paris Climate Agreement, other treaties, and EU directives on the use of scarce resources. These establish serious targets for the reduction of CO2 emissions, the reduction of the use of fossil fuels, and increased sustainable/renewable energy as well as efforts to incentivize these targets in pricing models, the internalization of external costs, emission quotas, or in influencing changes in consumer behavior.

Aviation is an essential partner for the local community and crucial for a city's network position in the world's city network. Although aviation, through a tremendous effort, has realized a substantial reduction in noise, fuel consumption, and emissions, the impact of increased aviation activities in a region still has to meet the local design criteria and societal values. Explicitly or implicitly, these criteria are decisive for aviation capacity; translated into regulations, limitations/constraints, or procedures, these control the aviation development in the region.

Airline, airport, and governmental/societal policies to develop airports into a hub or to expand existing hubs bring additional dynamics into the system. We have seen that the added value of the additional hub connectivity will land primarily with the aviation-related business. The externalities or negative byproducts in terms of noise and emission pollution, safety risks, and others land primarily within the city and the local communities surrounding the airport. Hubs tend to grow fast, as we have seen in Amsterdam, and if a society fails to implement robust and effective instruments to control aviation growth, this will end in undesired situations, such as the current situation in the Netherlands. Controlling hub development is, by definition, a balancing act between the economic advantages of a larger aviation cluster and the impact on the quality of living in the airport's vicinity.

The governance model is cyclical and interactive because neither cycle, clockwise or anticlockwise, is fully in control. Stakeholders have their own responsibilities: the aviation as a business and the city for its global and regional positioning. The cycle is not managed from one central command center, nor is it a linear process. Although each cycle starts and ends at the city level, different subsets of stakeholders are involved in different steps in the cycle. At each step, stakeholders interact and strive for (sub-)solutions that, in turn, influence and/or interact with solutions in the previous or next steps in the cycle. Crucial in the cyclical governance model for aviation capacity is how control is established and with whom. If globalization and aviation growth are the driving force, the city ends up in a defensive position to safeguard its societal values. The local community will be reactive to aviation that is in control of developments and setting the agenda; the reinforcing loop generates exponential growth. If the city is in the lead in defining the overall goals and targets, aviation might face unworkable conditions given their business models and subsequent operating models; the balancing loop is resistant to change. The challenges for city development and aviation capacity are enormous and often perceived as conflicting instead of supporting (e.g., fewer emissions than today and doubling the air transportation). From an aviation capacity standpoint, it is relevant that parties express their goals and targets but leave room for stakeholders to find the best solutions. Regulations, limitations, and procedures should be open in terms that encourage and stimulate innovation. Targets, regulations, limitations, and procedures are designed to control a complex aviation operating environment. The tools implemented will influence stakeholders' behavior and could incur undesired or unexpected effects and events, such as the unwanted control of slots or the generating of new carriers' interest to start operating at the airport. What we can learn from the Alderstafel is that system dynamics and thinking in systems (Meadows, 2008) should be applied to explore the robustness of the intended policies. Iterations in decision making are required before enforcing a regulation or implementing a system of dynamic control that allows regulators to adapt rapidly to undesired or unexpected consequences of policies.

The Dutch Safety Board's recently published report demonstrates that the current operating procedures are vulnerable at the level of 500,000 ATM and can/will result in serious safety incidents (Veiligheid, 2017). The Dutch policy has long sought to spread the aircraft noise over a large area around Schiphol Airport. The runway usage is related to the noise contour, resulting in multiple daily changes of runway configurations for landings and take-offs. Now operating at the level of 500,000 ATM, the frequent daily runway changes incur safety risks for approaching aircraft. Other examples of a measure that is not robust is the relocation of airlines to Lelystad Airport and the current debate on the standard arrival and departure routes to this airport (Dijksma, 2017). Building scenarios to explore multiple situations will help analyze the potential impact of a measure under different circumstances.

Looking at aviation capacity discussions worldwide, it is fair to say the right balance between both cycles has not yet been found. Globalization and aviation growth are in the driver's seat; the new aircraft on order are influencing regional discussions on the need for aviation capacity. For cities, it is important to formulate their own design criteria for aviation and regional urban development on short notice to allow their stakeholders to be prepared to enter the debate that will deliver the hard and soft criteria for all stakeholders to be used to regulate and control the actual airport development and aviation growth in the city. Defining how to check intended policies for robustness in terms of flexibility and adaptability is an important issue here that also requires further research.

City–Connectivity–Connections–Capacity–Control–Cooperation

Thus far, we have been reviewing aviation capacity at global and local levels with a focus on connectivity demand and supply, the role of the airport to facilitate connectivity, and an understanding of how to control aviation development if there is a shortage in airport capacity. This discussion has delivered an understanding of the added value of aviation for the position of a city in the world's city network and a governance model for aviation capacity at the city level. The cooperation between city and aviation is crucial for understanding the local policies and concrete measures in place to control aviation capacity's development.

These local policies and measures are a crucial input for the parties in the daily aviation operations seeking to cooperate with one another as they set the boundaries, constraints, and performance levels. The example of the multiple runway configuration changes at Schiphol showed that the societal design criterion to spread the noise over a large area and to put in the noise contour central to runway usage created serious operating problems for both air traffic controllers and pilots. At aviation's operating level, given the day-to-day 24-hour operations, the objective is to realize airlines' schedules with a high on-time performance in a safe, secure, and cost-sensitive manner. Aviation operations themselves require close harmony among many independent parties, like the airport, airlines, ATC, government agencies, and handling parties. Cooperation and co-makership are the key concepts for ensuring smooth operations and excellent passenger experiences.

The biggest challenge is to transform the agreed-upon policies and intended measures between aviation and society at the city level into workable day-to-day cooperation regimes for all aviation parties involved. The pressure increases the moment that the airport or the air space (terminal maneuvering area) runs short of capacity, due to peak hour scheduling, operational disruptions, or delays. At all times, maintaining the highest standards of safety and security is a pre-requisite. Each party at the operational level is driven and assessed by their own companies' or institutions' targets and values; at the operational level, aviation capacity is a real hassle and a daily challenge for producing connections on time and at the right service and quality level. The degrees of freedom to operate are limited. Operating procedures and cooperation models are strongly influenced by legacy in terms of the design and layout of infrastructure, facilities and systems, facility allocation mechanism, slot control and pricing models, vested interests, public habits or expectations, and negotiation and decision-making procedures (Bonvillian & Weiss, 2015).

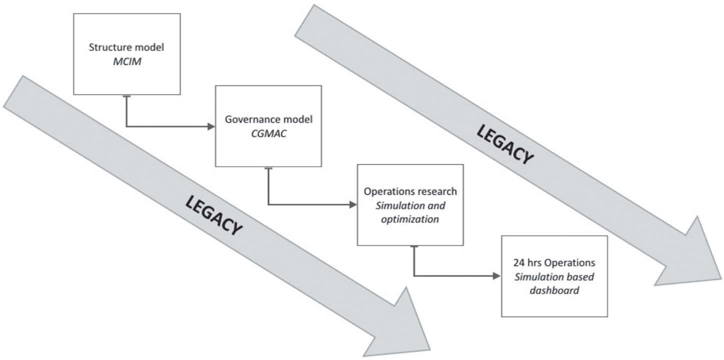

Figure 8. Understanding and optimizing aviation capacity. The fundamental discussion on aviation capacity governance is input on how to structure and manage the day-to-day aviation operations in the 24-hour scope.

Figure 8 shows the relationship and handover points among the fundamental understanding of aviation trends and business at the global level (enabled by technology and regulation), the cyclical governance model for aviation capacity at the local level, the need for deep understanding of the day-to-day operations within agreed-upon limits and constraints at one airport and within the airport network, and finally how to apply these insights to optimize the 24-hour day-to-day operations in aviation. Insights in the daily operations and capacity usage at airports can be gained by applying simulation and optimization techniques.

The Aviation Management research unit applies these tools in its capacity lab. The ultimate objective is to implement the research findings and results in daily operations in order to improve the existing capacity usage. At existing airports, operation procedures and regulations were designed in the past; therefore, path dependency, infrastructure layout, and business/governmental choices made in the past limit the degrees of freedom for operators to adapt to new situations or insights (Bonvillian & Weiss, 2015). We will address the impact of legacy later when we discuss the need for innovation and innovation blockers.

Aviation capacity research at the operational level immediately raises the question as to what airport capacity is and how it is defined. Although many publications deal with airport capacity, no unique definition of airport capacity exists. In 2007, the EU adopted an action plan for airport capacity, efficiency, and safety in Europe to develop five key actions – namely, making better use of existing airport capacity, taking a consistent approach to air safety operations at aerodromes, promoting co-modality (i.e., the integration of different transportation modes), improving airports' environmental capacity in terms of noise management and planning framework for new airport infrastructure, and developing and implementing cost-effective technological solutions (Debyser, 2016). A definition of airport capacity is lacking, but it is interesting that the EU Commission approaches airport capacity as the capacity of the aviation network in Europe. We have to distinguish between the optimal use of the existing capacity of one single airport and the optimization of the airport capacity in the network. As we have already seen, most aviation traffic stems from a relatively very limited number of airports (Gelhausen et al., 2013); given the high frequency of traffic among large airports, delays, disruptions, or adverse weather at one airport will immediately have a serious impact on the operations at other airports in the network (Inalhan & Pasaoglu, 2014). The difference between airport and aviation capacity is that airport capacity aims to optimize the capacity at one airport while aviation capacity aims to optimize the capacity of airports as nodes in the network and the use of air space for air traffic that delivers the connections between the nodes.

In March 2017, the International Transport Forum (ITF) organized a round table on optimizing airport capacity for existing airports. Together with UNAQ University in Mexico, the Aviation Capacity research unit prepared a paper on aviation capacity with a focus on the factors of airport capacity and the added value of simulation to optimize airport capacity based on a comparison between Amsterdam Airport Schiphol and Mexico City Airport (Mota, Boosten, & Zuniga, 2017b); both Schiphol and Mexico City airports are capacity constrained, but for different reasons. The next part is based on the findings of this research.

What is Airport Capacity?

In practice, airport capacity is an airport's capability to accommodate the airlines' demand for facilities to handle the scheduled and unscheduled flights according airlines and international quality and safety standards at any given moment in time. As long as the airport is capable of meeting this demand, capacity is not an issue. As soon as one or more facilities become a limiting factor for airport capacity, the airlines can no longer plan their flights unconditionally, and the airport enters into a new operating phase. Planning, scheduling rules, and agreements among airports, airlines, and ATC are needed to allocate the available capacity to the demand. The limiting factor will dictate what options are available. For instance, a shortage of runway and/or air space capacity at the airport could result in slot coordination, while a shortage of terminal facilities can be handled by reducing the international quality standards (service-level agreements); the new allocation mechanism of counters, gates, or baggage systems; or the introduction of new technology, like self-service check-in and baggage drop-off. Airport capacity is a container filled with different capacities, each of which can be a different cause for airport capacity shortages; thus, many different options should exist to optimize airport capacity.

In the literature, various approaches and definitions can be found, but none of these result in a clear and objective definition due to the many dimensions of airport capacity:

- Airport capacity is related to the capability of a facility to handle people, freight, and vehicles (Reichmuth, Berster, & Gelhausen, 2011)
- Airport capacity is the number of (air traffic) movements per hour (Barnhart, Fearing, Odoni, & Vaze, 2012)
- Airport capacity is a function of operational and environmental constraints (Graham & Guyer, 1999; Upham, Thomas, Gillingwater, & Raper, 2003)
- Airport operations focus on the relationship among flight schedules, (available) airport capacity, and how to mitigate delays (Jacquillat & Odoni, 2015)
- Airport capacity and airport development are the interaction of four main factors: (1) operational, sizing, and design of airside and landside infrastructure, (2) economics, (3) environmental restrictions and regulations, and (4) social perception toward airport infrastructures (Janic, 2008)
- Airport capacity is constrained by many factors, such as noise, emission reduction, airport slots, separation intervals for landing and departures, meteorological conditions, aerodrome design, runway configuration, arrival/departure ratio, air traffic flow type, aircraft characteristics, and demand-

related issues such as fleet mix, runway occupancy time, and average ground speed on final approach (FAA, 2015).

Other relevant factors determining airport capacity are land use at and around the airport and the available size of airport land (Janic, 2016), the role and contribution of stakeholders for defining environmental capacity and the demand for air traffic (Upham et al., 2004), and the relationship between airports and airlines and their respective business models (D'Alfonso & Nastasi, 2014).

The literature demonstrates that many factors determine airport capacity; some are static, like available runways, but most are dynamic and linked to how airport facilities are used and operated given the environmental, economic, social, and business constraints. Therefore, a definition of airport capacity should incorporate different factors to express the dynamics and the impact of deliberate choices made by the community and aviation business on how to operate within defined constraints and performance levels.

> Airport capacity is a multifunction of airline and airport business model, airport infrastructure, regulations, and capacity caps imposed by the government for environmental or society-related reasons. Defining airport capacity as a multifactor function leaves open the exact relationships between the factors but stresses that all factors are relevant to assess an airport capacity. The definition of capacity should take into account some factors as it illustrates the following formula (Mota, Boosten, et al., 2017b, p. 2):
>
> *Airport capacity=f(Factor 1,Factor 2,Factor 3…Factor n)'*

Defining airport capacity as an open multifactor function implies that the actual definition of airport capacity can differ by airport and is dynamic instead of static. Each airport is different and unique on many aspects related to available infrastructure; regulations; relationship with airport/airline/region; economic, social, or environmental constraints; or air space limitations or performance levels. Therefore, the capacity of a specific airport can be defined as the unique set of parameters that will apply to this airport. However, the set of parameters or factors that define the specific airport's capacity is limited and can, in general, be applied for all airports. Table 1 provides an overview of the identified factors used to define an airport's capacity. The limitations of airport capacity are linked to three main capacity categories: technical, social, and business. Identifying and – if possible – quantifying the origin of a specific airport's capacity is the first step; the second step is to define the possible solutions to optimize the airport's capacity and/or mitigate the impact of unintended constraining factors. Constraining factors can and, in many instances, will influence each other, so removing one constraint will automatically introduce a new limiting factor. Defining and optimizing airport capacity require a series of iterations before a new optimum is reached. This process becomes even more complex when realizing that the airport is a node in a network and that network dynamics will influence the airport's operations as well.

Table 1. Factors Defining Airport Capacity

Capacity Category	Limiting Factor	Item
Technical oriented	Operational	Runways Terminal buildings Taxiways Technology on board/airport
	Physical boundaries	Available land on and off airport
Society oriented	Environmental constraints	Noise emissions Pollution Weather
	Relationship region–airport	National economy, demand for connectivity, triple helix Business/development models of government
	Governmental regulations	Security regulations Night curfew Land-use planning
	Societal behavior	Human behavior inside and outside the airport New technology influencing passenger choice Accessibility to airport
Business model driven	Airline business models	Hub-and-spoke/point-to-point Connectivity Frequency
	Airport business models	Aeronautical business Non-aeronautical businesses
	Relationship airport–airline	Low-cost carriers/Full service carriers Minimum connection times Position of dominant airline

Note. All airports have a unique set of parameters that define their capacity; the factors itself can be identified and categorized. The result is a dynamic definition of capacity as factors might and will influence each other (Mota, Boosten, et al., 2017b).

As each airport has a unique set of parameters and values that define its capacity, by definition the solutions per airport will differ; therefore, there is no "one-size-fits-all" solution to optimize capacity at airports worldwide. However, airports can of course learn how to optimize capacity or mitigate the impact of constraints from each other.

Mota, Boosten, et al. (2017b) sub-divided the three capacity categories into the building blocks of aviation capacity:

> The "technically oriented" blocks are considered *inflexible-technical* barriers for capacity; these define the maximum capacity limits of what is technically possible to handle at an airport within generally accepted safety limits.
>
> The "society-oriented" blocks represent one of the elements of *flexible constraints* which determine the maximum throughput at an airport which do not correspond the physical limitations of the system. This parameter refers to imposed limitations due to the relationship of stakeholders beyond the technical limits of the infrastructure. For this reason, stakeholders' interests should be considered for releasing potential capacity. If not, the government either pushed by society or by other entities can limit the capacity growth by using curfews or artificial caps which might change during seasons and even during the day.
>
> The "business model-driven" blocks are also flexible limitations since they do not use the infrastructure at its maximum capacity, but their operational paradigm influences directly the capacity of the system. For instance, regarding airline business model, change from frequency competition to maximization of [workload unit] per slot can have a significant impact on the airports' capacity to handle passengers or cargo. In addition, the airline and airport relationships affect directly the peak hour operational capacity; airlines often compete with frequencies between destinations, thus increasing the number of movements. In addition, connectivity also has downsides for this model; the delays in one airport might be exported and sometimes amplified in another one due to the connectivity. Regarding the airport model, for some airports, the decision to make deals to use their available space for alternative business that provide revenue instead of use it for expand its capacity; this is a particular case of terminal buildings on the landside and real state close to the airside. The relationship between these two entities might create more or less competition which in turn increases or reduces capacity.

> Understanding airport capacity and what drives the capacity usage at airports will provide an insight in the set of instruments that can be used to optimise the use of capacity. In other words, every existing airport will have a different (*unique*) set of constraining factors and possible solutions to increase the capacity. Since airports are part of a worldwide aviation network they are vulnerable for developments within the network and they can import or export problems from other airports in the network. Understanding network dependency requires insight in the position and capacity of an airport in the network. (Mota, Boosten, et al., 2017b, p. 4)

The definition and building blocks are still abstract. A first step for further research is to build a database with relevant capacity data for all major airports worldwide to gain insights into each airport's capacity challenges and the network consequences. By doing so, we get local, continental, and global insights into the true airport capacity available.

Aviation Capacity Factors Applied to Amsterdam Schiphol Airport

Mota, Boosten et al. 2017 applied the factors defined in Table 1 to both the Schiphol Airport and Mexico City Airport at a qualitative level. This provided insights into the capacity constraints of each airport and the dynamics involved to make optimal usage of the available capacity. For this lecture, we concentrate on Schiphol only. Although many factors determine Schiphol's capacity, we concentrate on the most relevant factors.

Technical oriented. Figure 9 shows the complex airport layout of Schiphol Airport, with five main runways and a so-called one terminal/one roof concept. The declared runway capacity varies between 110 ATM during peak hours[9] and an average of 76 ATM in off-peak hours; the airport capacity is fully available during the day, but limited/restricted in the evening and at night (SACN, 2016). The overall punctuality performance measured as 15-minute tolerance was 81.15% in 2015 (OAG, 2016). Although the strict technical runway movement limit has not been defined, Schiphol has to operate with a maximum number of 500,000 ATM annually until 2020 as an outcome of the Alderstafel (Alders, 2013). Other limiting operational factors for Schiphol Airport are the taxiway system, air space (terminal maneuvering area), and airspace/airside operating procedures in runway usage (Veiligheid, 2017). The capacity of terminal facilities is at its limit, resulting in a strong reduction of quality standards during peak hours, as demonstrated by the long queues for departing and arriving passengers in 2017 and a standard recommended arrival time of three hours before departure. The airport is currently expanding its terminal and apron facilities (Schiphol, 2016). Yet the question remains: Is the expansion of terminal facilities sufficient? If a crucial facility at an airport (e.g., runways) is operating at maximum capacity for most of the day (over 80% capacity), normal operating rules and principles will no longer apply, nor will operators know how to deal with the impact of disruptions in those systems (Thacker, Pant, & Hall, 2017). Further research is needed to investigate the implications of constantly running an infrastructure system at maximum capacity, where aviation can learn from other transportation modes (e.g., rail) and how they deal with cascading failures (Dueñas-Osorio & Vemuru, 2009). In other words, the assumption here is that a critical system operating in a network at maximum capacity can be far more vulnerable for disruptions and that systems risks will be bigger than anticipated (and regulated) for normal infrastructure use or a single flight or event because of the cascading effect. Further research, incorporating system dynamics and resilience, is needed to understand if anticipated measures really contribute to increased capacity, operations control, and safety or will potentially disrupt the entire system.

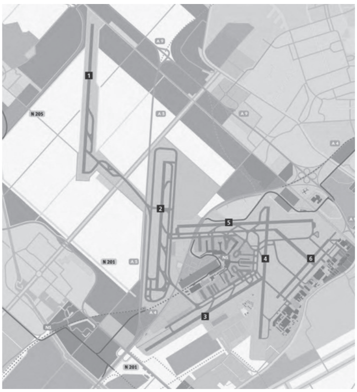

Figure 9. **Layout of Schiphol Airport. (Source: https://www.researchgate.net/publication/315753002_Coordination_of_scheduling_decisions_in_the_management_of_airport_airspace_and_taxiway_operations/figures?lo=1 Accessed on August 7, 2017).**

The available land on and off airport is by definition a limiting factor. For Schiphol, the most limiting factor is the pressure by neighboring communities to expand and develop land around the airport for housing and business areas. This is partly due to the success of the airport in attracting traffic and many businesses to the

Netherlands that wish to settle close to the airport. It results in the so-called Schiphol paradox that airport success contributes to the regional economy and thus results in additional constraints for airport expansion due to increased land use demand by local communities (Boosten, 2008). The pressure on land use will not directly influence the airport land itself. Permanent conflicts exist concerning the use of land around the airport allocated for noise and safety zones. The airport's maximum ATM growth is based on the assumption of the optimal use of the contours. In reality, both the development of local communities closing in on the contours and the rapid growth of ATM result in increased tensions among stakeholders and a constant effort to shrink the land surface occupied by the noise contours.

Society oriented. The society-oriented factors have the greatest influence on Schiphol's capacity. Schiphol has a long-standing history of environmental constraints. Since 1967, Schiphol has been noise constrained, although the noise limitations have changed over time (van Deventer, 2010). These changes reflect the major achievements by aviation to reduce noise due to aircraft performance, operating procedures, limitations of operating times, and the societal debate on the balance between the economic advantages of airport development versus quality of living in the neighboring communities. Consequently, the airport has realized very rapid growth in terms of ATM, passengers, and cargo while the number of noise-affected houses has dropped dramatically. The current noise policy is based on two principles: containing the noise pollution around Schiphol and creating an overflow option to non-mainport-related traffic to designated airports. The rules for containing noise around Schiphol are as follows:

- Limitation of 500,000 ATM per annum
- Rules for airspace usage (minimum flight levels, strict standard arrival and departure routes)
- Rules for runway system availability and runway usage at various times of the day (day, evening, night)
- Rules about noise-preferential runway usage
- Minimization of the number of noise-affected houses, seriously affected persons, and persons with disturbed sleep patterns

The overflow options within the Dutch airport system are shown in Figure 10. The airports of Lelystad, Eindhoven, and Rotterdam are part of the airport capacity offered by Schiphol, and some airlines like LCC or charters will be stimulated to use the other airports in the system instead of Schiphol (Alders, 2013; van Deventer, 2010).

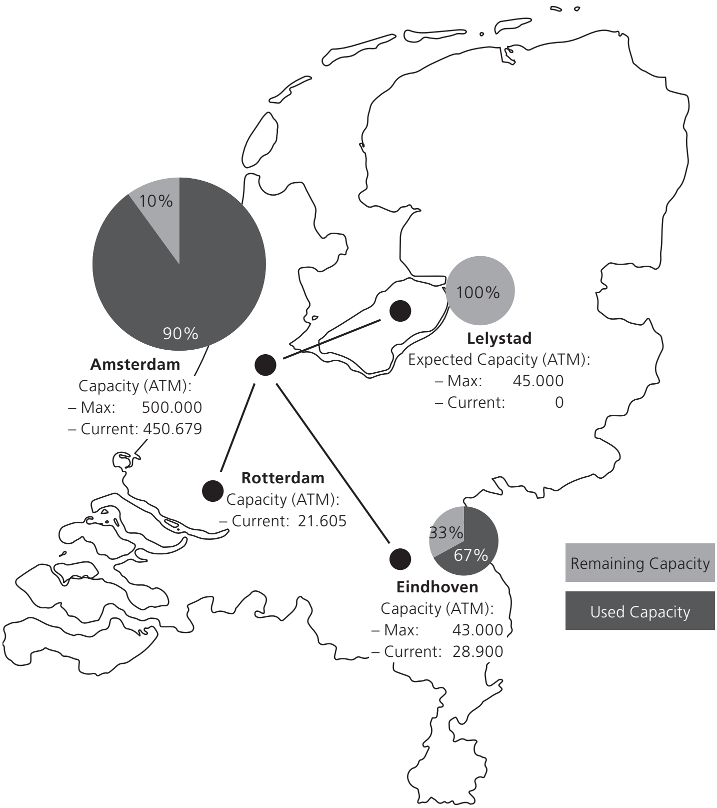

Figure 10. Dutch airport system combining the capacities of Schiphol Airport with Rotterdam, Lelystand, and Eindhoven Airport (Mota, Boosten, et al., 2017b).

The recent strong ATM and passenger growth at Schiphol disrupted the Alderstafel system to contain noise while the anticipated coherent system of measures obviously does not seem to function as foreseen. In other words, these are not robust solutions. The relationship among the government, airline, and airport (a triple helix) has long been an asset for Schiphol's development (van der Veer & Bertnsen, 2016). The airport and airlines deliver the connectivity for the Netherlands and generate many economic activities in the airport region. The three parties have long had congruent goals and strategies to support and strengthen the Dutch economy, which is very open and dependent on connectivity to many parts of the world. The Alderstafel tried to maintain the principle of the airport as an engine for the Dutch economy (the mainport) (Alders, 2013) and ensure that the hub, which is perceived to be the most critical for the contribution to the Dutch economy, can continue to grow in the future. The current situation, in which maximum capacity was reached in 2017, puts a high burden on the triple helix; the public signals are that the parties are no longer collaborating in a constructive manner (Cohen, 2017c), while other new entrants, like Ryanair, put pressure on the incumbents to change their policy (Zakennieuws, 2017).

Government rules and regulations have significantly influenced the airport's operations and capacity. The noise regulations can be seen as a license to produce a maximum amount of noise annually, and operating standards provide procedures to maintain these standards. Even more constraining are hard limitations on night flights and the total number of ATM annually. There is no way to overcome these limitations on short notice. Safety regulations, especially in airspace, limit capacity for aircraft to approach or depart. Due to recent attacks at airports abroad, security is expected to become even tighter and move from the border between air- and landside toward the perimeters of the airport. Indirectly, government policies could have a serious impact on operational capacity as well; budget cuts on border control and security or governmental dividend policy for government-owned companies will reduce the airport's operational capability to carry out or invest in optimization measures. Future infrastructure expansions depend on Schiphol investments. Schiphol is a separate legal entity and has to finance its investments based on the company's results. Therefore, the non-aeronautical activities of the airport are crucial for maintaining its function as a mainport.

Finally, societal behavior and developments will influence the way passengers behave, travel patterns and the use of airport facilities, and the influence of new technologies like social media and the use of dedicated apps. For infrastructure development at Schiphol, scalability and human scale are important issues. Airport facility expansion because of air traffic growth is technically feasible, but it may not be beneficial to airport operations. Departing passengers at Schiphol are already asked to arrive three hours before departure, and it takes significant time to walk from the landside to the gate or to transfer between gates, suggesting that there might be a limit to the physical size and, thus, capacity of an airport site. Passengers feel lost in the large facilities and become uncomfortable. Therefore, the current and future expansion of facilities might discourage passengers from using Schiphol and cause them to seek other routes via regional airports.

Social and technological developments have a direct impact on airline and airport operations and influence passengers' behavior inside the airport. The impact it is not fully clear yet. Travelers already use smart technology to make well-informed decisions in preparation for their travel and while travelling. This could impact the time spent at the airport and the use of the shopping center. On the other hand, technological developments pertaining to communications also change the way in which individuals and businesses decide whether to travel or communicate from home or the workplace before travelling. The use of easier ways of communicating may indeed intensify air travel by fostering connections that have not previously been possible (Mota, Boosten, et al., 2017b). Furthermore, airport congestion could result in changes in passengers' preferred travel patterns, so that passengers and airlines will start using less preferred hours of the day, thereby making optimum use of available capacity.

Business model driven. The airline and airport business models significantly influence how airport capacity is developed and used. The impact of the business models on the use of airport capacity is not always clearly recognized; changes in operating procedures can result in a big change in capacity needed. The airport's core beneficiaries are the passengers and goods transferred, the generic product that includes the airline and airport services, the expected product including multi-modal services to and from the airport, and the wide product including logistical, commercial, consulting, and real estate services, among others (Jarag, 2005). The airport business model is geared to generate revenues from accommodating airline traffic (aeronautical activities) as well as all kinds of non-aeronautical activities, including retail, real estate, and investments in other airports. The latter provide most of the profit because aeronautical fees and charges are regulated. This is also the case for Schiphol Airport; indeed, Schiphol constantly has to decide where to invest – in increasing traffic and/or in additional non-aeronautical activities. Schiphol's business model is based on the airport–city growth cycle shown in Figure 11.

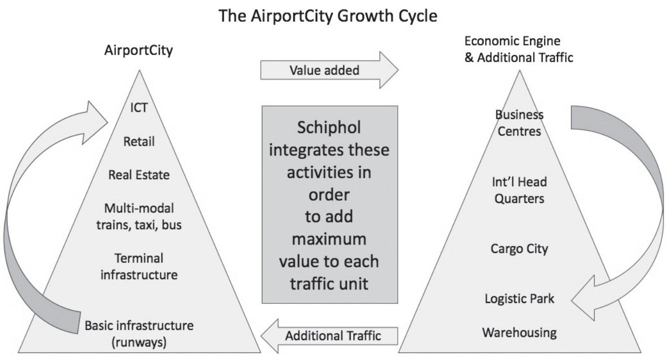

Figure 11. The airport–city growth cycle of Schiphol (Schiphol Roadshow, 2003).

The timely expansion of airport infrastructure is crucial for Schiphol to accommodate expected air traffic growth and to maintain quality standards and on-time performance levels. But given Schiphol's relationship and lack of contracts with airlines, investments in airport expansion like the new A-pier are fully at risk for Schiphol. Thus far, Schiphol has been able to invest in new capacity in a timely manner and generate a positive return on its investments. But any investment risk has to be constantly and carefully evaluated to avoid potential problems in economic downturns. This in turn may cause investments in airport capacity expansion to be delayed or limited, making that new capacity available at a later stage. In addition, Schiphol's bottom line result can be optimized by delaying investments in operational capacity. This concept, sometimes referred to as "sweating your assets," is beneficial in the short run, especially if very costly operational investments can be delayed and/or investments in profitable non-aeronautical business can be done earlier (with the risk of attracting additional traffic and activities landside). An example of the impact of delayed investments is described in the Dutch Safety Board report, where Schiphol's delayed investments in taxiways to and from the Polderbaan caused today's operational and capacity problems (Veiligheid, 2017).

Airline business models in turn have an impact on how and to what extent the capacity is used. At Schiphol Airport, the home carrier (i.e., KLM) and its alliance partners account for approximately 70% of the traffic and most of the transfer traffic. KLM and partners operate a hub concept at Schiphol, resulting in high operational peak demand and the need for flights in the restricted evening, night, and early morning. Just like many carriers, KLM's business model is based on frequency competition using smaller aircraft to operate high daily frequencies to the same destination. This principle demands much more peak capacity than the situation of an airline maximizing the number of passengers or cargo per movement (D'Alfonso & Nastasi, 2014). At Heathrow, due to severe capacity constraints, British Airways makes a different choice by using larger aircraft with less frequent flights than Schiphol, making a far more efficient use of the workload units per movement[10] (D'Alfonso & Nastasi, 2014).

The second group of big users at Schiphol are LCC, which typically operate A320 or B737 family-type of aircraft in a point-to-point network. The LCC business model is based on maximum daily aircraft productivity, resulting in many flights and short turnarounds each day. To ensure maximum productivity out of an aircraft based at Schiphol, it is crucial to allow the airline to optimize the aircraft scheduling in the early morning and late evening. Between these times, the connecting peaks for the hub will often coincide with return flights from LCC to

Schiphol, putting high pressure on the peak hour slots, while the facilities are less utilized in other times of the day. The LCC short turnaround demand is supported by a dedicated terminal and apron facilities. Developments of passenger self-transfer and further integration between FSC and LCC transfer will put additional pressure on the peak moments at Schiphol.

Schiphol competes with the other major hubs in Europe; therefore, high peak-capacity and reliable, short minimum connection times (MCT) are big assets as they allow the hub carrier to offer high connectivity with short transfer times at the airport. The overall capacity and efficiency of the hub can be defined by its maximum declared peak hour capacity (measured in ATM), which has a direct relation with the number of connections on offer from the hub and by its ability to transfer passengers and baggage between flights within the requested MCT. The terminal design and automated baggage handling system support this capacity demand. At Schiphol, both the one roof/one terminal concept and the massive investments in automated baggage handling systems are designed to support the traditional peak hour transfer capacity demand. The potential introduction of long-haul-low-cost (LHLC) operations at Schiphol might change the system by introducing passenger self-transfer. The passenger books two connecting flights at his own risk and ensures the connection of the baggage. Today, airports like London Stansted and Milano have started facilitating this type of transfer, which will require new infrastructure at the airport and will result in changes in facilities at the baggage claim areas and transfer lounges, among others (de Lange & Gordijn, 2017).

Both the special features to support transfer traffic and the facilities to support LCC traffic make Schiphol very attractive for a hub airline and LCC. However, the consequence is that Schiphol ATM grew very rapidly, with strong pressure on early morning, evening, and night flights. Consequently, further growth of both models at Schiphol is only possible if the overall annual ATM and peak hour capacity also grow. Today, the successful growth of both airline business models at Schiphol is a major source of conflict. The ATM-capacity shortage influences both operating models, and neither of them is willing to reduce their capacity claim on the other's behavior. The Alderstafel solutions do not fit within the business model of LCC airlines like EasyJet, which refuse to go to Lelystad Airport; the ministry and Schiphol lack successful instruments to incentivize airlines to change such behavior (Alders, 2013; Cohen, 2017d; Luchtvaartnieuws, 2017).

In addition, traffic flows are shifting worldwide; for instance, the airports in the Middle East nowadays connect Asia, Australia, and the Americas. For Schiphol

Airport, these trends could have a major impact on the demand for and the type of airport facilities needed. It is possible that the existing capacity and business models will be completely restructured. Due to these situations, continuing to optimize the current capacity and operations might not be possible. System thinking (Meadows, 2008) and scenarios support the evaluation of the proposed measures in terms of how the aviation system would respond to policy proposals and assess the intended and unintended impact of the proposals themselves and as part of an overall system. Future research is needed to understand system dynamics within the multiple factors that compose the aviation capacity to determine how proposed measures optimize aviation capacity within socially acceptable constraints that work within the system. Reliable simulation models that incorporate all factors need to be developed to evaluate the scenarios and validate the options suggested.

To conclude, Schiphol's actual airport capacity is a construct of many factors. Most constraining is the society-oriented capacity, where the real operating limits for Schiphol are formulated in hard, non-changeable constraints and operating procedures. These constraints and procedures reflect how society's interest in excellent connectivity is balanced with a social license to operate in terms of allowance to produce a limited amount of pollution while preserving a certain level of quality of life. The society-oriented constraints are part of the societal design criteria used to govern aviation capacity. The airport and airline business models are the second most constraining factors for airport capacity. The need for aircraft productivity and hub competition boils down to high frequency operations, high transfer peaks at the hubs, and maximum usage of available operating times and conditions. The airline business models at Schiphol are all geared for growth; no equilibrium has yet been reached with sufficient connections for the city and sufficient traffic for optimal aircraft productivity. The technical-oriented capacity is in principle capable of accommodating the requested airline demand, but is limited by the society-oriented capacity. Underlying this, we see that the combination of a complex airfield and air space because of 5+1 runways and society conditions on runway usage hits the safety limits and might become an unstable operating system.

The upfront agreed-upon solutions between society-oriented and business model-driven capacities on how to act when the airline production will hit the ceiling have obviously failed to work and have resulted in a very complex situation. There are no easy solutions available because the drivers and incentives of both society oriented and business model capacity are contradictory and hardly leave room for new approaches or design criteria on short notice.

The Schiphol capacity discussion does not consider the impact of developments at other hub airports in the worldwide aviation network. Capacity expansion and operating decisions elsewhere (at airports, in regulations, or from technical issues) could have a significant impact on the capacity usage and possible operating concepts at Schiphol; these are considered externalities, but within the network these are real parameters that should be part of the decision-making framework. What is the role of legacy here? Legacy plays an important role in all three aspects of the capacity of Schiphol Airport. The technical-oriented capacity was designed in the 1950s based on the best insights in available technology and aviation growth at the time. Today, the airfield is a very complex set of runways that is difficult the operate; it would have never been designed this way today. The terminal complex is an extension of the unique one-terminal concept, but is now reaching its limits in terms of human scale and quality levels. The position of the hub activities in the center of the terminal is a historic decision and also defines the operating boundaries and transfer offerings of hub and non-hub carriers. The physical boundaries and contours are the result of 50 years of public debate and decision making and are hard to move. Most communities have used these contours as the basis for their decision making and plan new developments on or over the contour limits.

The society-oriented capacity is legacy driven; the regulations and environmental constraints are the 50 years of decision making and how the government, society, and aviation have used and maintained these standards in the past. The mainport concept still acts as an important mental framework for aviation development; indeed, the mainport drivers are still the focal points in capacity evaluations, public policy, and decision-making criteria on how to allocate capacity. The underlying concept of the triple helix between airline, airport, and government is falling apart, but there is still no good alternative available.

The business model-driven capacity is also determined by legacy. The current economic relationship and pricing models (including underlying incentives on how to use capacity) between airport and airlines are driven by legacy. These dictate airports' and airlines' investment decisions, risk perceptions, and the like. Changes in social behavior and worldwide trends can result in dramatic changes in aviation and could seriously harm the fundamentals of the business models: reduced passenger dwelling time at airports harm the airport model to generate non aeronautical revenues, and increased connectivity at all airports offering so many different options to passengers harms the added value of the hub in the network.

In other words, in the current debate on Schiphol's capacity, legacy is an important factor. Legacy is a known blocker for innovation and efforts to implement changes to optimize business and aviation contributions to society (Bonvillian & Weiss, 2015). It is also the inequality of risk taking (Lazonick & Mazzucato, 2013). Making the impact of legacy and risk taking on the debate explicit through research will help reevaluate the societal and business design criteria for aviation capacity. This will create a new arena for the debate and decision making on airport capacity. Incorporating system dynamics and scenarios in the debate will produce additional insights if the proposed solutions generate the desired situation in reality. Checks on robustness and resilience should be part of the process to validate the proposed criteria to control aviation capacity.

Cooperation: Simulation/optimization within 24-hour aviation operations

The review and governance of airport capacity are relevant exercises to explore the complexity of airport capacity and determine what factors should be considered when dealing with airport capacity issues at large. These steps are necessary to produce the best workable solutions for aviation operations; this is crucial input for aviation professionals employed by airlines, airports, ATC, handlers, or maintenance. At the bottom of the pyramid, these aviation professionals have to solve airport capacity limitations daily within the framework of the Alderstafel agreements, international operating procedures and standards, business model constraints of their companies and passengers' quality, and safety and security expectations. The Dutch Safety Board report offers some excellent examples on the complexity these professionals have to solve, even more if we realize that the actual operations are very vulnerable because of delays and disruptions. The public disgrace stemming from the long waiting times at Schiphol in April are another example of the pressure on the daily operations and the complexity professionals have to deal with in terms of capacity problems.

The first and final objective of the Aviation Management research unit (Lectoraat) is to support these professionals in finding sustainable solutions for their daily capacity optimization quest. Understanding the airport capacity factors provides insights into what the relevant building blocks and variables are for steering daily operations. The production of a flight is a chain of events involving many parties; most parties are independent and make their decisions based on their own role and responsibility for their events in the chain. For instance, border control and security are public tasks, and the government decides what the level of control is, irrespective of the business motives of the airline or airport. Therefore, each party can and will influence the productivity and optimization of the entire chain to produce one flight, let alone a series of 100 or more flights simultaneously, which is the case at airports like Schiphol during peak hours. Each flight and operational day are carefully prepared, planned, and scheduled in advance. But on the actual day, delays, disruptions, or adverse weather demand constant changes to the schedule. The adaptability and flexibility of the process should be massive. At the research unit, we focus on both the preparation for the operational day and efforts to contain disruptions when (or even before) these occur. Simulation and optimization techniques are already introduced in the preparation of the operational day and prove to be very powerful tools for gaining insights into the potential capacity of the airport facility, but also the most influential parameters for the final capacity allocation and usage. Simulation investigates the entire process and generates options for operations, regardless of the role of parties involved in the aviation chain, thereby offering the opportunity to focus on the entire process, from landing to take-off. The simulation process itself is structured as shown in Figure 12. The process allows for a thorough analysis of the actual process (i.e., as it is actually realized); the findings are input for the model that can be used to generate and analyze various options. The options will be verified and analyzed. The outcome will provide all parties in the aviation chain with insights into the optimization of the overall process and, subsequently, the role and contribution of each party in the chain.

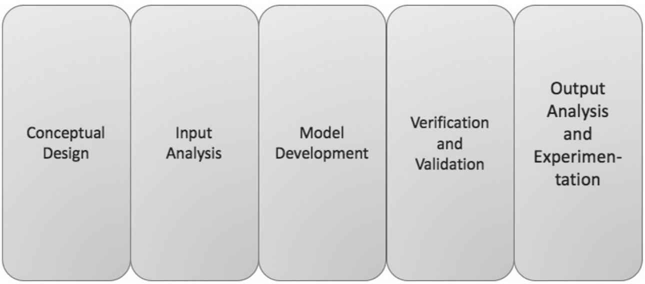

Figure 12. Overview of various steps used in an airport simulation process (Mota, Boosten, & Zuniga, 2017a).

An advantage of simulation is that it does not interfere with the day-to-day operations; various options and possible solutions can be analyzed without disturbing the daily operations, and only the best results can be implemented later on. In research projects for future capacity optimization, simulation is often the first step in the analysis aimed at the different levels of details aligned with the objectives pursued. For instance, simulation is used in the design of operational facilities like the apron and airspace usage of the new Lelystad Airport (Mota, Boosten, De

Bock, Jimenez, & de Sousa, 2017). The analysis of the options provides insights into the optimal design and operations of the apron in Lelystad Airport in case operation standards concerning turnaround times, costs, and safety are applied. When comparing the capacity constraints at Schiphol Airport and Mexico City Airport, the simulation of the operational process of Mexico City Airport supported efforts to find the best moments of the day to add additional ATM to the daily operations without massive disruptions (Mota, Boosten, et al., 2017b).

Simulation is a tool that has been introduced at airports over the last decade and is in practice most often used in airport master planning (infrastructure development), scheduling, and planning of operations. Simulation and optimization tools are used in the Singe European Sky ATM Research (SESAR) to find and validate possible options to accommodate further growth. However, one of the biggest challenges is not to build and use simulation models, but to empower professionals in 24-hour operations to use insights from simulation and optimization tools to steer the actual operational process. This requires aviation professionals in operations to be able to foresee or predict the next developments, from 1 hour to 48 hours in advance. The ideal situation is that possible disruptions are recognized and mitigated before they happen. To achieve this, a massive change in cooperation among parties in the chain is required to exchange sensitive information in advance and share crucial information systems. Currently, Eurocontrol is working on the Airport Operations Centre (APOC) project to design a common operations center at airports, where ATC, airport, and airline staff cooperate to optimize the capacity available and reduce the impact of (possible) operational disturbances (Eurocontrol, 2017b).

Using simulation and optimization techniques within 24-hour operations is not just a matter of developing and applying new techniques and solutions. The main issue is translating the insights gained from these techniques to operational procedures and standards that fit within the international framework, safety criteria, and company policies. Aviation professionals should be duly trained to use the insights from the new tools and know what options are available in specific situations. The exchange of sensitive information in a competitive situation and determining how to divide potential costs and empower professionals to make decisions are some of the major hurdles to be overcome. Therefore, future research should focus not only on the new tools and techniques, but also on what knowledge and competences are needed, how to train the professionals, and the development of new operating procedures and standards. The Aviation Management research unit focuses on how to apply simulation and optimization techniques within the actual operations in order to ensure that available aviation capacity can be optimally used at all times, even when disruptions in terms of delays, adverse weather, and other sources occur. In the future, the network component, taking into account the airport's role in the aviation network, should also be part of the research objectives.

When operational insights are gained, an efficient feedback loop can be made for the capacity procedures and limitations at the higher level, thereby allowing decision makers and professionals in 24-hour operations scope to assess the added value or effectiveness of the set of measures to control the operational process, the capacity available, and the generation of input for a dynamic update of the criteria to control aviation capacity.

City–Connectivity–Connections–Capacity–Control–Cooperation–Transformation

Aviation is facing an enormous challenge to create sufficient capacity to accommodate up to 46,000 aircraft in commercial aviation within the next 15 to 20 years; meanwhile, many old aircraft will be replaced as well. A new generation of aircraft will be used with different operating profiles, and airlines, airports, passengers, and cargo forwarders will behave differently while using new technologies and social media. In addition, airlines will continue to develop and change their operating and business models. The aviation industry has started impressive programs like SESAR (Europe) and NextGen (USA) to find technical and operational solutions for the challenges ahead. Such projects focus on innovation through new technology, information analysis, and/or procedures. Often these programs focus on defining the final solution that should solve the problems we are facing today. The transition to the new situation is often neglected or not the major subject of studies. The transition is of major importance as, for example, shown with the introduction of a relatively simple information exchange procedure geared toward improving the predicted actual time of departure of a flight at an airport called airport collaborative decision making (CDM). CDM was introduced in 1998 and, by 2016 CDM, had been fully implemented at 22 airports (Eurocontrol, 2017a). The pace of change is very slow, and all new technology, procedures, and alignment among actors in the aviation chain should ultimately land at the workplace with 24-hour operations.

Therefore, applied research on aviation capacity cannot neglect the transformation needed to implement innovation and changes in operations. The image of the future represents both the worldwide changes and trends as well internal ambitions. The transition path envisions how the present is connected to the future via multiple crossings and complex business dilemmas. As shown in Figure 13, the road to the future is not a direct line, but a path with dead ends and side streets. A successful innovation is not a one-way pipeline, but a system of interlocking cycles with feed-forward and feedback connections. It should incorporate the quality of the process and the company's capabilities to execute the process (Berkhout, Duin, Hartmann, & Ortt, 2007).

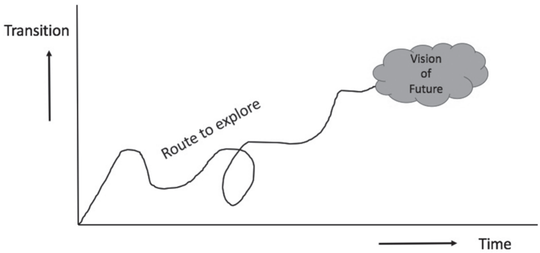

Figure 13. Route to explore is not linear, but will be cyclical and based on multiple iterations.

In the case of aviation, a global system, the transition does not affect one single company, but the entire sector; thus, affiliated businesses and society need to change simultaneously. In other words, we run into a complex technical and social system. The change of the entire sector has specific characteristics where the focus is not only on the economic potential of the innovation for a company or economy, but also the societal changes induced by the innovation and the consequences for environment and sustainability (Smith, Voß, & Grin, 2010). More radical innovations, for instance fundamental changes in ATC and control of an aircraft, may require substantial changes in the old regime's fundamental architecture; transitions can be caused by a sequence of multiple component innovations instead of just a breakthrough in one technology, resulting in a new architecture and linkages in the networks (Geels & Schot, 2007). The transition is more than the collection of technical developments, and it is often difficult to identify the specific technical developments that serve the desired development of the sector (Langeveld, Sanders, & Meeusen, 2010). Managing the transition process is as important as finding technical solutions for the challenges ahead. In the literature, relevant factors for the transition process include the following:

– A solid vision for the future is needed to provide a common focus by target-setting and monitoring processes, providing a metaphor for building actor networks and a narrative for allocating capital and other resources (Smith, Stirling, & Berkhout, 2005).

- Managing the expectations of actors involved toward the future; changing the focus from looking into to looking at the future. This helps understand how the future is mobilized in real time to allocate resources, coordinate activities, and manage uncertainty (Brown & Michael, 2003). Expectations are an important factor in innovation management because they influence processes of strategy building, resource allocation, and efforts to look at capabilities and firm culture. Initial promises of expectations can be very high and result in a hype cycle and/or lock-ins in "expectation trajectories" (Borup, Brown, Konrad, & Van Lente, 2006).
- Path dependency of innovations and transitions. Existing systems are bound by existing infrastructure, regulations, market mechanisms, and social conventions. These will influence the transition pathways at different levels. In particular, changes at regime and innovation landscape levels will take a long time, even up to a generation, to change (Geels & Schot, 2007).
- Learning is an important part of the transition. Learning is a key concept to better understand the nature of the technological change and the dilemmas that might occur. Learning will occur at different levels. First-order learning involves learning how to improve the design of a technological innovation, which features are acceptable for users, and ways to create policy incentives to facilitate the adoption of the technology. Second-order learning is related to the establishment of the regime shift based on a niche development. Here, concepts about technology, users, demands, and regulations are questioned and explored instead of tested (Hommels, Peters, & Bijker, 2007).
- Governance of societal change and balance of power. Societal change does not happen independently, but rather requires steering. Governance is needed to set the agenda and societal (self) steering and to collectively define and redefine the objectives. Steering societal processes comes with power and power balances between different groups in society. Power is not evenly distributed, and parties with different – often opposing – interests will try to influence, steer, or even destabilize developments. The role of the government to maintain or shift the power balance in order to realize the societal objective is crucial. The government has several techniques to intervene to shift the balance of power between actors, varying from adjusting legal rights and responsibilities to creating new institutional actors, establishing new centers of economic power, or encouraging inter-organizational collaboration (Meadowcroft, 2007).

Managing the transition requires the management of change within the parties that jointly form the aviation chain as well as the incorporation of the societal boundary conditions for the transition. The cyclical governance model for aviation capacity already referred to the importance of both industry and society in controlling aviation capacity and finding robust and resilient solutions. With reference to A.J. Berkhout, the transition for the aviation sector is constructed as shown in Figure 14. Applied technology and business developments are linked to the governance and power balance within society. Future business models in aviation are driven by technology and business development options on the one hand and societal boundaries on the other hand. The transition process itself should be driven by the factors mentioned before including system dynamics; the role of legacy as a blocking factor will increase the complexity of this transition process dramatically.

A major challenge for aviation is that the transition path has to be invented while in full production; each day, more and more flights have to take off and land safely while many airports have already hit their capacity ceiling. Safety is a cornerstone of all operational processes in aviation; therefore, processes should be resilient so that, when a disturbance to the processes occur, they can automatically bounce back to safe operations. The transition process toward doubling the size of aviation requires the constant and deliberate disturbance of our processes into unbalanced situations for many years in order to ensure that they stabilize at another level without hampering safety and security or efficiency and effectiveness. The transition will be a step-by-step process because measures taken at one node in the network often require follow-up at other nodes.

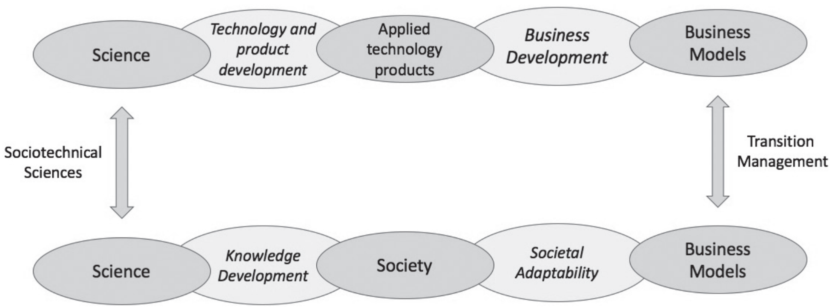

Figure 14. Sectoral transitions where applied technology and business are linked to governance and power balance in society (Berkhout, 2010; Boosten, 2017).

Changing the aviation process requires input and commitment from many parties within and outside the aviation chain. The exchange of information, learning curves, mutual trust, willingness to experiment, creation of a common ground, vision, and language as well as an increasing adaptability or flexibility of all stakeholders involved are prerequisites for a robust system for change. The ultimate challenge is for professionals within 24-hour operations, who have to execute all plans on a daily basis within the turmoil of the daily operations. As we have seen, optimizing aviation capacity is a complex matter, and there are no easy solutions left. If these professional are not able to manage the transitions and implement the required changes in a step-by-step approach, aviation will soon run out of options to increase the daily capacity at airports and in the air. Supporting these professionals in developing knowledge and insights for managing the transition and enhancing their own adaptability to change is part of the research agenda. Stakeholders should dedicate sufficient (human) resources to this process because no party can independently manage the transition process at one node or in the network.

To conclude, aviation capacity research starts with a good understanding of the aviation industry's contribution to cities and regional economies. The growth forecasts of aviation are based on globalization and worldwide trends, but accommodating aviation growth, especially airport capacity, is a regional decision and should be incorporated into and balanced with regional developments and design criteria defined by a city or a regional community. Airport capacity itself is a complex matter; many factors together construct the actual capacity available for aviation. The factors are determined by the aviation business and the city's demand for connectivity within a framework of the socially acceptable contribution of aviation. The available capacity and boundary conditions are the basis for the aviation professionals in the aviation chain for airlines' networks, scheduling, planning, and managing the actual operations in the 24-hour scope. The failure to develop well-defined constraints will hamper the operations and have an adverse impact on the socially acceptable contributions of aviation. Legacy, being the infrastructure, systems, procedures, standards, pricing models, mental framework, and habits that we have developed in the past, has a major influence on how we envision today's operations and options for change. Legacy might be a major invisible blocker for our vision of the future and the changes that are required.

Ultimately, aviation capacity on a day-to-day basis is the optimal use of existing capacity. Simulation and optimization tools can be used to gain insights into how to optimize planning and execution in operations as well as how to handle disturbances at one airport and in the network of airports – preferably before these occur. The ultimate goal is to empower the aviation professional within the

24-hour scope to use the insights from simulation and optimization so that the optimal capacity usage is constantly secured.

Planning for the future and finding technical and procedural solutions for the expected growth is not sufficient for coping with the change. The changes will not take place overnight, but are long-lasting transition processes that are often not well recognized or defined compared to the attention paid to new technology, systems, or procedures. A well-designed and managed transition process that incorporates both the business and societal aspects of aviation is needed to secure a safe and successful process toward our image of the future.

Aviation capacity is a challenging research area consisting of complex relationships and dynamics in the system. Aviation capacity consists of many factors (building blocks), many of which exceed the level of daily operations. Yet it is crucial to understand the dynamics between the city and aviation because many relevant factors, constraints, and operating standards are defined in this arena. The applied research agenda of the Aviation Management research unit is designed to focus primarily on the operational aspects and the needs of the aviation professionals in the scheduling and planning of 24-hour operations to deal with the aviation capacity challenges ahead. The use of simulation, optimization, and transition management will have a central position; the cyclical governance model for aviation capacity is a prerequisite for understanding the societal dynamics in the region. Both legacy and transition management support the understanding of the degrees of freedom in changing aviation capacity and the speed of change possible.

Acknowledgments

This paper primarily reflects the ideas and insights gained over almost 30 years in various aspects of aviation, varying from airport operations and strategy at Schiphol to consulting and applied research. During this period, aviation capacity in many shapes or forms has always been a focal point of interest and study.

I would first like to thank the Executive Board of the HvA for providing the opportunity to start the Lectoraat Aviation Management with a special focus on aviation capacity. Together with the Lectoraat Aviation Engineering, the Lectoraat Aviation Management supports the development of the Aviation Academy and its relationships within the field of aviation in the Netherlands and abroad. The international position is also reflected in the composition of the staff of the Aviation Academy and the international network that the Aviation Academy has developed over the years. The research on aviation capacity fits very well within this framework as one of the cornerstones, along with MRO, human factors, and health monitoring of new materials. From an industry standpoint, these cornerstones are closely linked, and I am convinced that in the future we will further increase the synergy between the various research topics and our education in order to provide optimal support for the aviation industry.

Lectoraat Aviation Management has also developed close relationships to parts of the urban technology field. I highly appreciate the cooperation and collaboration with our colleagues from logistics and am looking forward to further joint projects in the near future.

The Lectoraat Aviation Management could not have been established without the support of many persons. The Dean of the School of Technology, Gerard van Haarlem Msc, supported the research area and the Lectoraat from the start. My many colleagues within the Aviation Academy provided their meaningful support and contributions. Within the Lectoraat, our associate professors Dr. Miguel Mujica Mota and Dr. Daniel Guimarans Serano and our junior researcher Nico de Bock have made – and continue to make – major contributions to the outcomes, results, academic and industry network development, and feedback for the educational field. A special word of thanks for Miguel, who has been working within the Lectoraat from the start and has played an important role as a sparring partner and a co-producer of the research agenda. I have enjoyed the research projects we have done so far, and they served as an important foundation for this lecture. I would also like to thank my colleague Dr. Dick van Damme for his support and contribution to the framework of this lecture and Professor John Stoop for his unconventional feedback and support. Last but not least, I would like to thank Els for her continuous support over the years and her understanding for missing a summer holiday to write this lecture.

Curriculum Vitae

Geert Boosten has more than 29 years of experience in the airport business. Following his studies in the Netherlands and four years working at a large publishing company, he started working at Schiphol Airport in 1988 (where he stayed until 1999). Working in various positions, Geert gained experience and expertise in all aspects of airport (operations and commercial) management, business development, and strategy. As a director of corporate strategy, he was responsible for Schiphol's master planning, long-term airport development (i.e., airport in the sea concept), and international development (i.e., strategic alliance with Vienna International Airport and acquisition of Brisbane's airport in Australia) as well as airport privatization, the regulation of fees and charges, and new business development using ICT (including a project with BIAC/Switch). Geert is an all-round airport expert with special interest in airport strategy, development, positioning of the airport in the local community (optimizing the added value of the airport), and master planning.

As a consultant, Geert was involved in the strategy and/or masterplan development of Toronto International Airport (Canada), JFK Airport in New York (USA), Brisbane International Airport (Australia), Vienna International Airport (Austria), Brussels Airport BIAC (Belgium), Maastricht-Aachen Airport (Netherlands), Eindhoven Airport (Netherlands), Oostende-Brugge Airport (Belgium) , Airport of Kortrijk-Wevelgem (Belgium), Abidjan Airport (Ivory Coast), Lima Airport Partners (Peru), Rotterdam Airport and Bohol Airport (Philippines), and the port of Rotterdam (Netherlands).

Geert has been a board member of two publicly/privately founded Dutch centers of expertise in transport and infrastructure in addition to chains and networks/

logistics. As an aviation expert, he defined the curriculum of the Bachelor's Honors Aviation Management course at the Professional University of Amsterdam, School of Technology Amsterdam, where he also lectures. Geert is currently the head of the Aviation Department (1500 students and 85 staff) and a professor of aviation management. The Aviation Management research unit focuses on applied research on airport capacity optimization.

Bibliography

ACI. (2017). *Airport industry connectivity report 2017*. Retrieved from http://mailing.aci-europe.org/ACI E Airport Industry Connectivity Report 2017_web version.pdf

Addie, J.-P. D. (2014). Flying high (in the competitive sky): Conceptualizing the role of airports in global city-regions through "aero-regionalism". *Geoforum, 55*, 87–99. doi:https://doi.org/10.1016/j.geoforum.2014.05.006

Airbus. (2016). Global market forecast. Retrieved from http://www.airbus.com.cn/fileadmin/media_gallery/files/brochures_publications/GMF/Global_Market_Forecast_2016-2035.pdf

Alders, H. (2013). *Eindavies Alderstafel-Schiphol*. Retrieved from https://www.rijksoverheid.nl/...alderstafel-schiphol/eindadvies-alderstafel-schiphol.pdf

Appold, S. J., & Kasarda, J. D. (2011). Seeding growth at airports and airport cities: Insights from the two-sided market literature. *Research in Transportation Business & Management, 1*(1), 91–100. doi:http://dx.doi.org/10.1016/j.rtbm.2011.06.011

Barnhart, C., Fearing, D., Odoni, A., & Vaze, V. (2012). Demand and capacity management in air transportation. *EURO Journal on Transportation and Logistics, 1*(1), 135–155. doi:10.1007/s13676-012-0006-9

BBC. (2015). Grounded: The chequered history of UK airport expansion.

Berkhout, A. J. (2010). *New Solutions for A better World*. Presentation at TU Delft for CIM Team.

Berkhout, G., van der Duin, P., Hartmann, D., & Ortt, R. (2007). *The cyclic nature of innovation: connecting hard sciences with soft values* (Vol. 17). Amsterdam: JAI Press, Elsvier.

Blonigen, B. A., & Cristea, A. D. (2015). Air service and urban growth: Evidence from a quasi-natural policy experiment. *Journal of Urban Economics, 86*, 128–146. doi:https://doi.org/10.1016/j.jue.2015.02.001

Boeing. (2017a). Traffic and market outlook. Retrieved from http://www.boeing.com/commercial/market/long-term-market/traffic-and-market-outlook/

Boeing. (2017b). Current market outlook 2017–2036. Retrieved from http://www.boeing.com/resources/boeingdotcom/commercial/market/current-market-outlook-2017/assets/downloads/2017-cmo-7-05.pdf

Bonvillian, W. B., & Weiss, C. (2015). *Technological innovation in legacy sectors*. New York, USA: Oxford Univeristy Press.

Boosten, G. (2008). The importance of Schiphol Mainport for the northern part of the Randstad region: The Schiphol paradox. In D. de Jong, B. Kaashoek, & W.-J. Zondag (Eds.), *Blue skies or storm clouds* (pp. 117–122). ISBN 9789051795844. Science Guide

Boosten, G. (2017). *Innovation in legacy sectors, a hollistic approach* (Unpublished work).

Borup, M., Brown, N., Konrad, K., & Van Lente, H. (2006). The sociology of expectations in science and technology. *Technology Analysis & Strategic Management, 18*(3–4), 285–298. doi:10.1080/09537320600777002

Brown, N., & Michael, M. (2003). A sociology of expectations: Retrospecting prospects and prospecting retrospects. *Technology Analysis & Strategic Management, 15*(1), 3–18. doi:10.1080/0953732032000046024

Castells, M. (2010). *The rise of the network society* (2nd ed.). Malden, MA: Blackwell.

Cohen, R. (2017a). Nu de schaarste op Schiphol toeneemt, krijgen we meer vragen over onze keuzes. *Financieel Dagblad*. Retrieved from https://fd.nl/ondernemen/1187780/nu-de-schaarste-op-schiphol-toeneemt-krijgen-we-meer-vragen-over-onze-keuzes

Cohen, R. (2017b). Opstellen verdelingsregels voor luchtvaart stelt ministerie voor hoofdbrekens. *Financieel Dagblad*. Retrieved from https://fd.nl/ondernemen/1187335/opstellen-verkeersverdelingsregels-luchtvaart-stelt-ministerie-voor-hoofdbrekens

Cohen, R. (2017c). Schiphol zwicht voor druk en neemt meer maatregelen om rijen te voorkomen. *Financieel Dagblad*. Retrieved from https://fd.nl/economie-politiek/1201093/schiphol-opent-beveiliging-verder-om-rijen-te-voorkomen

Cohen, R. (2017d). Staatssecretaris DIjksma: Schiphol groeit volgens afspraak. *Financieel Dagblad*. Retrieved from https://fd.nl/ondernemen/1201142/staatssecretaris-dijksma-schiphol-groeit-volgens-afspraak

Cohen, R. (2017e). We zouden arrogant zijn als we Norwegian niet serieus namen. *Financieel Dagblad*. Retrieved from https://fd.nl/ondernemen/1187875/we-zouden-arrogant-zijn-als-we-norwegian-niet-serieus-namen

D'Alfonso, T., & Nastasi, A. (2014). Airport–airline interaction: some food for thought. *Transport Reviews, 34*(6), 730–748. doi:10.1080/01441647.2014.971470

de Lange, M., & Gordijn, H. (2017). The potential of the long-haul low-cost business model and its impact on the Netherlands. Retrieved from https://www.kimnet.nl/actueel/nieuws/2017/02/09/the-potential-of-the-long-haul-low-cost-business-model-and-its-impact-on-the-netherlands

de Wit, J. G., & Burghouwt, G. (2017). Hoe moet de steeds schaarsere capaciteit van Schiphol worden verdeeld? *Tijdschrift voor Ververoswetenschap TVW*(juni 2017).

Debyser, A. (2016). *Airports in the EU. Challenges ahead*. Retrieved from http://www.europarl.europa.eu/RegData/etudes/IDAN/2016/583820/EPRS_IDA%282016%29583820_EN.pdf

Derudder, B. (2008). Mapping global urban networks: A decade of empirical world cities research. *Geography Compass, 2*(2), 559–574. doi:10.1111/j.1749-8198.2008.00102.x

Dijksma, S. (2017). *Voortgang routes luchthaven Lelystad*. *Den Haag*. Retrieved from https://www.rijksoverheid.nl/documenten/kamerstukken/2017/06/26/voortgang-routes-luchthaven-lelystad

Doganis, R. S. (2010). *Flying off course : airline economics and marketing* (4th ed.). London: Routledge.

Dueñas-Osorio, L., & Vemuru, S. M. (2009). Cascading failures in complex infrastructure systems. *Structural Safety, 31*(2), 157–167. doi:http://dx.doi.org/10.1016/j.strusafe.2008.06.007

Eldering, P., & de Jong, Y. (2017). Wachtrijen op Schiphol niet opgelost. *De Telegraaf*. Retrieved from http://www.telegraaf.nl/binnenland/28096969/__Wachtrijen_Schiphol_niet_opgelost__.html

Eurocontrol. (2017a). Airport collaborative decision making (A-CDM). Retrieved from http://www.eurocontrol.int/articles/airport-collaborative-decision-making-cdm

Eurocontrol. (2017b). Airport Operations Centre (APOC). Retrieved from http://www.eurocontrol.int/articles/airport-operations-centre-apoc

FAA. (2015). *FACT3: Airport capacity needs in the National Airspace System*. Retrieved from https://www.faa.gov/airports/planning_capacity/media/FACT3-Airport-Capacity-Needs-in-the-NAS.pdf

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy, 36*(3), 399–417. doi:http://doi.org/10.1016/j.respol.2007.01.003

Gelhausen, M. C., Berster, P., & Wilken, D. (2013). Do airport capacity constraints have a serious impact on the future development of air traffic? *Journal of Air Transport Management, 28*, 3–13. doi:http://dx.doi.org/10.1016/j.jairtraman.2012.12.004

Graham, B., & Guyer, C. (1999). Environmental sustainability, airport capacity and European air transport liberalization: irreconcilable goals? *Journal of Transport Geography, 7*(3), 165–180. doi:http://dx.doi.org/10.1016/S0966-6923(99)00005-8

Hommels, A., Peters, P., & Bijker, W. E. (2007). Techno therapy or nurtured niches? Technology studies and the evaluation of radical innovations. *Research Policy, 36*(7), 1088–1099. doi:http://doi.org/10.1016/j.respol.2007.04.002

ICAO. (2010). ICAO environmental report: Chapter 2 Aircraft technology improvements Retrieved from https://www.icao.int/environmental-protection/Documents/EnvironmentReport-2010/ICAO_EnvReport10-Ch2_en.pdf

ICAO. (2017a). About ICAO. Retrieved from https://www.icao.int/about-icao/Pages/default.aspx

ICAO. (2017b). Strategic objectives. Retrieved from https://www.icao.int/about-icao/Council/Pages/Strategic-Objectives.aspx

Inalhan, G., & Pasaoglu, C. (2014). *Macro modelling of the European Air Traffic Network – A data analytic perspective.* Paper presented at the Resilience ATC Madrid, Spain.

Jacquillat, A., & Odoni, A. R. (2015). Endogenous control of service rates in stochastic and dynamic queuing models of airport congestion. *Transportation Research Part E: Logistics and Transportation Review, 73*, 133–151. doi:http://dx.doi.org/10.1016/j.tre.2014.10.014

Janic, M. (2008). The future development of airports: A multidimensional examination. *Transportation Planning and Technology, 31*(1), 113–134. doi:10.1080/03081060701835803

Janic, M. (2016). Analyzing, modeling, and assessing the performances of land use by airports. *International Journal of Sustainable Transportation, 10*(8), 683–702. doi:10.1080/15568318.2015.1104566

Janić, M. (2000). *Air transport system analysis and modelling: capacity, quality of services and economics*. Amsterdam: Gordon and Breach Science Publishers.

Jarag, D. (2005). *Airprot marketing. Strategies to cope with the new millenium environment*. Hampshire, UK: Ashgate Publishing.

Jorge-Calderón, D. (2014). *Aviation investment: economic appraisal for airports, air traffic management, airlines and aeronautics*. Farnham: Ashgate.

KLM. (2017). KLM on Schiphol.

Knippenberger, U. (2010). From airport city to airport region? The 1st International Colloquium on Airports and Spatial Development, Karlsruhe, 2009. *The Town Planning Review, 81*(2), 209–215.

Langeveld, H., Sanders, J., & Meeusen, M. (2010). *The biobased economy. Biofuels, materials and chemicals in the post-oil era*. London: Earthscan.

Lazonick, W., & Mazzucato, M. (2013). The risk–reward nexus in the innovation–inequality relationship: who takes the risks? Who gets the rewards? *Industrial and Corporate Change, 22*(4), 1093–1128.

Luchtvaartnieuws. (2017). EasyJet wil niet naar vliegveld Lelystad: Luchtvaartnieuws.

Macário, R., & van de Voorde, E. (2011). Critical issues in air transport economics and business.

Mazzucato, M. (2013). *The entrepreneurial state. Debunking public vs. private sector myths*. London and New York: Anthem Press.

Meadowcroft, J. (2007). Who is in charge here? Governance for sustainable development in a complex world. *Journal of Environmental Policy & Planning, 9*(3–4), 299–314. doi:10.1080/15239080701631544

Meadows, D. H. (2008). *Thinking in systems*. White River Junction, USA: Chelsea Green Publishing Company.

Mota, M. M., Boosten, G., De Bock, N., Jimenez, E., & de Sousa, J. P. (2017). Simulation-based turnaround evaluation for Lelystad Airport. *Journal of Air Transport Management*. doi:https://doi.org/10.1016/j.jairtraman.2017.06.021

Mota, M. M., Boosten, G., & Zuniga, C. (2017a). *Analyzing Mexico City airport capacity by simulation.* Paper presented at the ITF Rond Table, Queretaro, Mexico.

Mota, M. M., Boosten, G., & Zuniga, C. (2017b). *TIme to sweat the assets? The analysis of two airport cases of restricted capacity in different continents*. Paper presented at the International Transport Forum Round Table on Optimizing Airport Capacity at Existing Airports, Queretaro, Mexico.

Neal, Z. (2010). Refining the air traffic approach to city networks. *Urban Studies, 47*(10), 2195–2215. doi:10.1177/0042098009357352

Neal, Z. (2013). *The connected city. How networks are shaping the modern metropolis*. New York: Routledge.

OAG (Producer). (2016). On-time perfomance results for airlines and airports. [Report] Retrieved from https://cdn2.hubspot.net/hubfs/490937/Free_Reports/Punctuality_League_2015/PunctualityLeagueReport2015.pdf

Reichmuth, J., Berster, P., & Gelhausen, M. C. (2011). Airport capacity constraints: future avenues for growth of global traffic. *CEAS Aeronautical Journal, 2*(1–4), 21–34. doi:10.1007/s13272-011-0034-4

Schiphol. (2016). AECOM Team ontwerpt nieuwe pier Schiphol [Press release]. Retrieved from https://nieuws.schiphol.nl/aecom-team-ontwerpt-nieuwe-pier-schiphol/

Schiphol. (2017). Jaarverslag Schiphol Top connectiviteit.

SEO. (2016). *ACI Europe: Airport Industry Connectivity Report 2016*. Retrieved from http://www.seo.nl/uploads/media/2016-50_ACI_2016_Connectivity_Report.pdf

Skybrary. (2017). Operation type taxonomy. Retrieved from https://www.skybrary.aero/index.php/Operation_Type_Taxonomy

Smit, M., Koopman, M., & Faber, J. (2013). *The economics of airport expansion*. Retrieved from http://www.cedelft.eu/publicatie/the_economics_of_airport_expansion/1363

Smith, A., Stirling, A., & Berkhout, F. (2005). The governance of sustainable socio-technical transitions. *Research Policy, 34*(10), 1491–1510. doi:10.1016/j.respol.2005.07.005

Smith, A., Voß, J.-P., & Grin, J. (2010). Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. *Research Policy, 39*(4), 435–448. doi:http://doi.org/10.1016/j.respol.2010.01.023

Stichting Airport Coordination Netherlands (SACN). (2016). *Capacity declaration Amsterdam Airport Schiphol; summer 2016*. Retrieved from http://merrick.marketing-desktop.nl/files/editor/assets/Airport Coordination Netherlands/docs/DECCAP_AMS_S2016.pdf

Stoop, J. (2017). *Air saftey investigations: towards a next generation?* American Institute of Aeronautics and Astronautics.

Taylor, P. J. (2004). *World city network: a global urban analysis*. London: Routledge.

Thacker, S., Pant, R., & Hall, J. W. (2017). System-of-systems formulation and disruption analysis for multi-scale critical national infrastructures. *Reliability Engineering & System Safety, 167*, 30–41. doi:http://dx.doi.org/10.1016/j.ress.2017.04.023

The Guardian. (2017). EasyJet to set up Austrian HQ to operate EU flights after Brexit. Retrieved from https://www.theguardian.com/business/2017/jul/14/easyjet-austria-eu-flights-brexit

Upham, P., Raper, D., Thomas, C., McLellan, M., Lever, M., & Lieuwen, A. (2004). Environmental capacity and European air transport: stakeholder opinion and implications for modelling. *Journal of Air Transport Management, 10*(3), 199–205. doi:10.1016/j.jairtraman.2003.10.016

Upham, P., Thomas, C., Gillingwater, D., & Raper, D. (2003). Environmental capacity and airport operations: current issues and future prospects. *Journal of Air Transport Management, 9*(3), 145–151. doi:10.1016/s0969-6997(02)00078-9

van Deventer, F. (2010). *Geluidbeleid Schiphol, verleden, heden en toekomst. Een geschiedenis in vogelvlucht* Paper presented at the NSG De toekosmt van geluidshinderbestrijding, Utrecht, The Netherlands. https://nsg.nl/file/91/NSG_verslag_hr_100420.pdf

van der Veer, F., & Bertnsen, T. (2016). *Air service development at AMS, CPH and FRA.* City: Amsterdam; Amsterdam University of Applied Sciences

Veiligheid, O. v. (2017). Veiligheid Vliegverkeer Schiphol.

Verhallen, L., & van Dessel, G. (2014). *Brussels airport airline issues & route development breakout session 18 June.* Paper presented at the TTRA 2014, Brugge, Belgium.

World Bank. (2017). Airport transport, passengers carried. Retrieved from http://data.worldbank.org/indicator/IS.AIR.PSGR

Zakennieuws. (2017). Ryaniar heeft buik vol van Nederland en schrapt routes.

Zakenreis (Producer). (2017). Routehappy: passengier kiest comfort vaker boven prijs. Retrieved from https://www.zakenreisnieuws.nl/nieuws/categorie/2/airlines/routehappy-passagier-kiest-comfort-vaker-boven-prijs

Notes

1. City in the Sky is the title of a video series on aviation see: http://www.pbs.org/city-in-the-sky/home/ (accessed on July 25, 2017).
2. ICAO has no single definition on air connectivity and sees connectivity as an indicator of network concentration and the "ability of the network to move a passenger from one point to another with the lowest possible number of connections and without an increase in fare, focusing on, from a commercial perspective, minimum connecting times with maximum facilitation ultimately resulting in benefits to air transport users" (Debyser, 2016).
3. A system is an interconnected set of elements that is coherently organized in a way that achieves something. Therefore, a system must consist of three kinds of things: elements, interconnections, and a function or purpose (Meadows, 2008).
4. This research is not part of the focus of the Aviation Management research unit.
5. This research is not part of the prime focus of the Aviation Management research unit.
6. This research is not part of the focus of the Aviation Management research unit.
7. This research is not part of the focus of the Aviation Management research unit.
8. This research is not part of the applied research agenda of the Aviation Management research unit, but the outcomes provide highly relevant input.
9. The peak hour capacity is an indicator of the maximum number of aircraft and, thus, passengers, baggage, and cargo that can be handled in one hour of operations. The take-offs and landings related to this number of aircraft are the maximum ATM. If the runways are the limiting factor, the ATM define the peak hour capacity.
10. A workload unit (WLU) is a standard measure for a passenger or an amount of cargo.

IMAGE
BertZuiderveen.nl

9 789463 011488