A BUSINESS MODEL ENABLING A PASSENGER-DISTANCE-IMPROVED LONG-HAUL NETWORK TO DECREASE TRANSPORT INEFFICIENCIES

Dominik STEINWEG [ID] *, Kai-Daniel BÜCHTER [ID], Marc ENGELMANN [ID],
Antoine HABERSETZER [ID], Ulrike SCHMALZ [ID], Annika PAUL [ID]

Bauhaus Luftfahrt e. V., Willy-Messerschmitt-Str. 1, 82024 Taufkirchen, Germany

Abstract. The air transport system faces pressing challenges arising from CO_2-emission reduction targets, fragmented passenger needs, and a highly competitive market environment. Aiming for a reduction of CO_2-emissions in the long-haul sector, a holistic solution is suggested incorporating both operational and technological innovations in three areas: (1) changes in the air transport network structure, (2) (liquid) hydrogen as energy carrier, and (3) new aircraft and cabin design. To these ends, this paper focuses on the implications resulting from a passenger-distance improved air transport network. Demand pooling is proposed to enable higher load factors, offer more point-to-point connections for passengers, and generate new revenue sources for airlines. Based on a discussion of traditional airline business models, a seat exchange platform named "ShAirline" is proposed, allowing multiple providers to rent out cabin space. The underlying business model is evaluated considering implications for aircraft and cabin design, new passenger services, additional revenue opportunities, passenger journey times, required aircraft, as well as implications for airports. Findings indicate that the proposed seat exchange platform in conjunction with a change in aircraft ownership structure assist in removing inefficiencies across the current long-haul network and help offset barriers connected to the use of novel eco-efficient technologies.

Keywords: airline alliances, business model innovation, cross-airline seat sharing, decreased flight speed, hydrogen aircraft, transportation system, travel time.

Introduction

Airlines operate in an environment characterized by constant change. While ever-increasing demand[1], especially for long-haul[2] travel, provides future growth perspectives, a variety of challenges needs to be managed (Airbus, 2018). With the Paris Agreement, CO_2-emission targets defined in Flightpath 2050 and the environmental goals of ICAO, aviation has moved to the center of attention in the societal debate on climate change (United Nations Treaty, 2016; European Commission, 2011; ICAO, 2010). Furthermore, competition and the need for flexibility is increasing, leading to an ongoing market consolidation. Simultaneously, passenger needs are becoming increasingly diverse, making their satisfaction more challenging (Kluge et al., 2018).

While long-haul travel accounts for only 10 percent of global aviation passengers, it is responsible for more than 30 percent of aviation fuel burn, and hence CO_2-emissions (OAG, 2018; BADA, 2019)[3]. Therefore, this market exhibits a significant lever to introduce operational as well as

---

[1] While demand plummeted by over 90 percent during the COVID-19 pandemic, it is currently estimated that economic growth in developing countries will likely support long term growth scenarios (IATA, 2020).

[2] In this study, flights over 4,000 km are classified as long-haul.

[3] It is important to note that aviation has an effect on climate change not only through CO_2-emissions, but through a variety of other processes, summarized under the term non-CO_2-effects (for a comprehensive overview, see (Lee et al., 2020)). We chose to solely focus on CO_2-emissions in this work because the specific influence of hydrogen combustion during high-altitude aircraft movement on non-CO_2-effects is largely unknown: On the one hand, the exact influence of non-CO_2-effect of aviation on atmospheric temperature change is still characterized by substantial uncertainties (Lee et al., 2020). On the other hand, both the exhaust composition and its influence on atmospheric physical properties and chemistry is currently debated in academia (McKinsey & Company, 2020). It would thus be out of the scope of this work to evaluate the environmental benefits of a hydrogen powered aircraft from a non-CO_2 perspective.

---

*Corresponding author. E-mail: Dominik.Steinweg@bauhaus-luftfahrt.net

technological innovations to reduce CO_2-emissions in the aviation sector. This paper focuses on network optimization through operational improvements and addresses the associated challenges connected to their implementation. The fundamental motivation for these operational improvements is the societal challenge to mitigate the effects of anthropogenic climate change. Yet, there is also an economic rationale to reduce airline operating cost by increasing fuel efficiency and thus CO_2-emissions produced by aviation as much as possible. This motivation is both rooted in the societal challenge to mitigate the effects of climate change and the economic rationale to reduce airline operating costs in light of rising prices for CO_2-emissions. The approach to reduce fuel burn, and thus CO_2-emissions is enabled through operational adaptations by using hydrogen as energy source for propulsion, improving passenger routing, utilizing aircraft more efficiently, and reducing flight speed. In order to achieve these improvements, a new business model is suggested to counteract the efforts of transitioning to a new energy source. Consequently, three pivotal elements – effective passenger routing, passenger pooling and lower flight speed – in combination with a hydrogen-powered aircraft are brought together in a holistic framework called HyShAir.

The focus here is on the development and assessment of a conceptual future business model ("ShAirline"), which supports the implementation of a passenger-distance-optimized network structure. Additionally, the introduction of hydrogen-powered long range aircraft catering to the requirements of long-haul passengers is covered, which is illustrated in (Troeltsch et al., 2020). Rather than implementing only incremental changes, it demonstrates how synergies can be achieved by simultaneously managing the introduction of hydrogen-powered aircraft, passenger-distance-optimized networks, and slow flight speed. In line with this, policymakers, managers, researches, and planners are addressed with the aim to develop feasible eco-efficient air transport where stakeholder interests are aligned. The paper is structured as follows: Chapter one introduces the HyShAir concept and discusses the major aspects of the aviation system which it seeks to address. Chapter two describes the materials and methods used for developing a suited business model and for analyzing potential network effects induced by the HyShAir concept. Chapter three presents the results regarding business model set-up and network effects, while Chapter four puts them into a larger discussion context. The paper is finalized with a short conclusion section.

1. Addressing long range aviation challenges with the HyShAir concept

To meet future challenges faced by the air transport sector, a holistic approach enabling the implementation of operational and technological innovations is presented. The HyShAir concept addresses three main questions that define the global long range air transport system with regard to the following:

1. Air transport network: How can the eco-efficiency of the long-distance network be increased by changing the operating structure in the airline industry?
2. Energy supply scenario: How can the introduction of alternative energy sources be fostered to reduce the environmental impact?
3. Aircraft and cabin design: How should new vehicles be designed to integrate new fuel options, operational requirements, and future passenger needs?

In line with these questions, operational measures promise reduced environmental impacts using currently available technology. For example, fuel savings can be achieved by making intermediate stops on long-range flights (Linke et al., 2017). However, the examination of climate impacts in the form of non-CO_2 effects shows that intermediate stops, while saving fuel, can have adverse effects on local air pollution and the global climate (Grewe et al., 2017). Replacing transfer connections with more point-to-point routing, especially in the long-haul market, may contribute to a more eco-efficient transport network by reducing the detour factor from the optimal route.

In addition, significant improvements in eco-efficiency require additional radical changes. A viable path being to shift from fossil fuels to hydrogen, offering an energy carrier that mitigates CO_2-emissions if produced with renewable electricity and sustainable sources (Grewe et al., 2017). A concept for a hydrogen-powered aircraft was already proposed two decades ago by Klug and Faass (2001), but several factors, including investment costs, infrastructure requirements and aircraft design, have halted a potential market uptake in the aviation sector.

While a new operational structure, including the airline network, may favor specific aircraft types in terms of distances flown, passenger seating capacities and turnaround processes at the airport based on economic considerations, climate impact reduction would call for different requirements. Therefore, to propel the aviation sector towards reaching challenging CO_2-emission-reduction goals, different challenges in the aviation system have to be considered in combination. The analysis in this paper therefore focuses on future business model innovations in the air transport industry, highlighting the interlinkages between future long-haul air transport network, aircraft and cabin design as well as a hydrogen energy supply scenario.

1.1. Air transport network

Improved load factors and increased operational efficiency both offer opportunities for reducing relative fuel burn and CO_2-emissions at the fleet and passenger level. Today, more than 60 percent of long-haul passengers travel via indirect connections, i.e. making at least one stop between their origin and destination airports. These multi-stop journeys have an average detour from the optimal route of about 8 percent, and increase overall travel times for passengers. Furthermore, on average, 20 percent of seats on long-haul flights remain empty across all airlines, creating unused capacities across the network (SABRE, 2017).

We suggest mitigating these inefficiencies by introducing a new long-haul network structure and new business model. This may involve a shift from today's airlines' asset ownership models towards a novel aircraft sharing platform that pools demand across many airlines. Bundling demand between two airports across airlines and alliances reduces surplus capacity and enables additional direct connections, representing an expansion of the currently used code sharing between individual airlines to the entire network. On the passenger level, the expansion of the code sharing concept is reflected in an adaptable cabin design facilitating the introduction of individually branded sections on a single aircraft. First, an increased load factor on long-haul flights translates to decreased fuel burn per passenger-kilometer and potential reductions in overall movements. Second, omitted stopovers can be translated into lower flight speeds without negatively affecting the passengers' overall travel time. For 60 percent of today's long-haul passengers, this implies more comfort and convenience by eliminating one or more intermediate stops along the journey. For a new aircraft to operate economically, necessary requirements include maintaining current aircraft productivity as well as a comparable level of frequencies for passengers to choose from.

1.2. Aircraft design and cabin design

As a result of reduced travel speeds envisaged, aircraft productivity, measured in seat kilometers flown per day per aircraft, is reduced at a given seat count. Thus, the productivity of individual aircraft can be maintained by transporting more passengers per flight by improving either the load factor or by adding seats. On the fleet level, productivity can be maintained by increasing flight frequencies. The proposed ShAirline concept provides an approach towards achieving higher load factors, while the tradeoffs between aircraft speed, flight distance, cabin size, and flight frequencies with regard to aircraft productivity will be discussed next.

Reduced flight speeds decrease aircraft productivity, ceteris paribus. The most profitable flight speed from airline perspective can be found using a cost index, between the speed for minimum fuel consumption for maximum range and maximum speed for minimum time, which is around Mach 0.82 in current aircraft. Figure 1a shows modeled aircraft productivity, measured in seat kilometers per day, over flight distance and assuming a Mach 0.85 reference cruise speed. A ground time of 90 minutes per flight is assumed, with an additional 7.2 hours of daily ground time due to maintenance, repair and overhaul (MRO) processes, delays and unutilized time (Randt, 2016). Reducing flight speed from today's Mach 0.85 to Mach 0.7 requires a 17% increase either in passengers per flight or in flight frequency in order to maintain the same level of long-haul productivity. In the case of the average wide-body aircraft, this corresponds to a capacity increase from 300 to about 350 seats, as illustrated in Figure 1b. A reduction of average ground time (i.e. all ground handling activities including turnaround, MRO, taxiing, as well as time not utilized) by approximately 2.5 hours per day, for example through operational improvements and flight scheduling optimized for slower flights, can also mitigate the lower productivity by increased utilization (Figure 1b). Moreover, a given number of passengers on a route can be transported either with smaller aircraft and a larger fleet, or vice versa. Therefore, an assumed long-term growth in air transport demand can either be absorbed by offering more frequencies or increasing the size of aircraft, or a combination of both.

2. Materials and methods

Radical shifts to new network topologies and eco-efficient aircraft are difficult to implement in the current airline business model structure. Due to small profit margins and high capital requirements, airlines focus on incremental improvements rather than on radical operational and technological changes to increase their competitiveness.
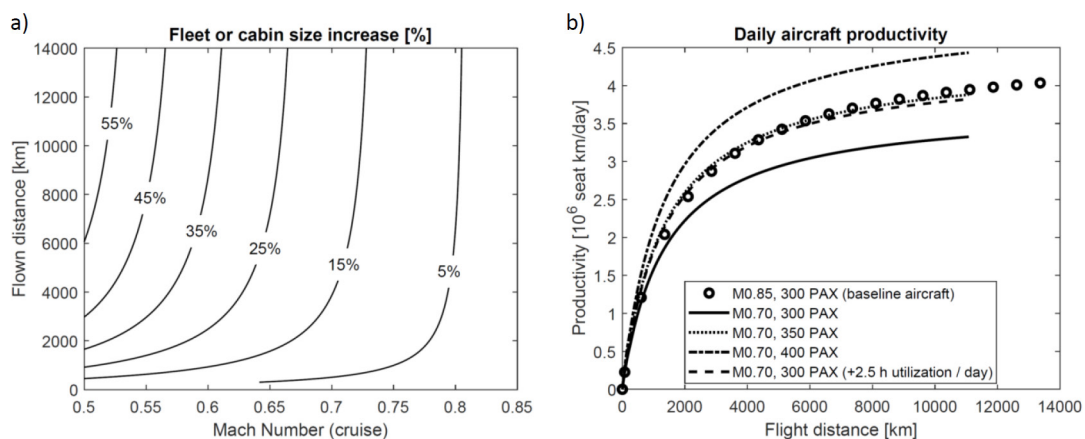

Figure 1. Aircraft productivy depending on flight speed, flight distance, and cabin size. a) The relative required increase in cabin size or fleet is shown as a function of flight distance and cruise Mach number. At short distances, productivity is predominantly limited by ground time, rather than flight speed. b) Daily aircraft productivity as measured in seat kilometers is shown as a function of flight distance, considering variations in flight speed, ground time, and seating

This paper therefore focuses on the proposition of a new business model approach aiming at the implementation of a passenger-distance-optimized long-haul network structure as well as a respective hydrogen-powered aircraft design. The lack of competitiveness of previous hydrogen-powered aircraft concepts is countered by the increased transport efficiency in the network enabled by the proposed business model and anticipated CO_2-emission pricing schemes that will make the operation of fossil fuel powered aircraft more expensive in the future.

The core of the business model is the seat exchange platform, facilitating a passenger-distance-optimized long-haul air transport network while simultaneously distributing energy supply infrastructure investments among platform participants. In this regard, the number of passengers transported as well as travel times are two important characteristics that influence the different elements of the proposed business model innovation in the air transport sector. Section 2.1 outlines prior work on business models from the literature including the utilized business model framework (Section 2.1.1) and an overview of current airline business models (Section 2.1.2). Furthermore, a methodology to evaluate the impact of the proposed business model using selected performance metrics is described in Section 2.2. The results are then presented in Section 3 and discussed in Section 4. The last section concludes this paper.

2.1. Overview of business model frameworks

Business models describe how companies generate value (Wirtz et al., 2016). Different definitions of the term "Business Model" (BM) exist, along with several proposed business model frameworks containing various components[4] (Daft & Albers, 2013; Gassmann et al., 2014; Mason & Morrison, 2008; Osterwalder & Pigneur, 2010; Wirtz et al., 2016; Wirtz & Daiser, 2018). Some frameworks are more general and not specific to any industry. The framework proposed by Daft and Albers (2013) is applied to measure the convergence of airline business models empirically, as was done in a case study by Daft and Albers (2015). The frameworks proposed by Wirtz et al. (2016) and Osterwalder and Pigeneur (2019) present generalized frameworks that are not specific to one industry, that integrate all essential business model functions and require an already fully developed, detailed idea in order to use them. This also applies to the framework provided by Mason and Morrison (2008), which has the advantage of being airline-specific. Due to the scope of this study and its aim to develop a novel, innovative business model, the St. Gallen Business Model Navigator is considered to be the most suitable framework for this analysis (Gassmann et al., 2014).

2.1.1. Business model navigator

The Business Model Navigator framework has already been proven to accurately describe business model innovation stories and to identify success factors in a comprehensive way (Gassmann et al., 2014). Furthermore, customers are not just considered as mere sources of revenue, but as stakeholder with individual needs and requirements (Gassmann et al., 2014). They (the "Who") become one of the four key dimensions of the "magic triangle", illustrated in Figure 2, which describes the overall framework for innovating business models. The importance for a business to target main customer groups, to know the trends driving these groups, and to understand how they will develop in the future, is seen as a crucial and fundamental activity at the heart of the magic triangle. Another key component is the value proposition for the customers (the "What"), defining the products and services that a company offers to target customers. The third dimension is the value chain itself (the "How"), describing the process of how products and services are generated. The fourth dimension is the profit mechanism (the "Why"), which describes how profit (including costs and revenue) is generated for an organization (Gassmann et al., 2014).

2.1.2. Current airline business models

While the core product of airlines is the provision of a transport service from origin to destination, airlines differ in their business models (Wittmer & Hinnen, 2016). The classification between the two well-established airline business models – Low-Cost Carrier (LCC) and Full-Service Network Carrier (FSNC) – seems outdated. Soyk et al. (2017) analyzes the emerging concept of long-haul LCCs by investigating their business model characteristics and cost advantages. Accordingly, long-haul low-cost carriers operate with 20 to 30 percent lower operating costs than legacy hub carriers (Soyk et al., 2017). Furthermore, other studies propose additional business model categories that exist in the market, such as global hybrid carrier, global niche market carrier, and large-size network carrier (Urban et al., 2018). Applying the business model canvas model from Osterwalder and Pigneurs (2010), a trend
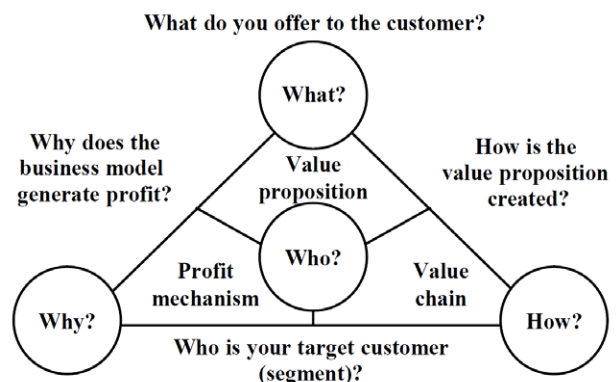

Figure 2. Business model innovation – the magic triangle
(Gassmann et al., 2014)

---

[4] E.g. customer centricity, customer intelligence acquisition, customer-oriented BM change, and BM evolution (Wirtz & Daiser, 2018) or customer segments, value proposition, channels, customer relationship, revenue streams, key resources, key activities, key partners, and cost structure (Osterwalder & Pigneur, 2010).

towards an increased convergence between LCCs and FSNCs is revealed. This hybrid model trend, manifested by combining characteristics from LCC and FSNC, is also confirmed by Daft and Albers (2015).

2.2. Methodology for evaluating the proposed business model on the network level

In the following section, a methodology is introduced which evaluates the efficiency gains of the business model approach. It describes how the supply of air transport capacity is affected by the ShAirline concept. In order to forecast the resulting effects on the global air transport system, both the supply and demand side are investigated.

2.2.1. Analysis data

For this analysis, we used connectivity data provided by the Sabre Corporation for the entire year of 2017, covering worldwide direct and indirect connections. A total number of 3.448 billion passenger journeys covering all intermediate stops are covered, including 5,689 airports. The dataset used in this study covers 90.2 percent of passengers in 2017 (SABRE, 2017). An overview of the data format is provided in Table 1. Itineraries include the number and location of stops along the journey. For each leg, the operating airline is provided. Furthermore, the annual total number of passengers traveling on this unique itinerary is shown.

2.2.2. Approach for passenger demand pooling

To capture the effects of ShAirline on the network level, the original data is transformed to reflect the new business model. Four possible scenarios, summarized in Table 2, are considered, reflecting traditional and new business models as well as current and proposed slow-flying aircraft. The resulting air transport system is subsequently described by selected key performance indicators described in 2.2.3. The strategic goal of the ShAirline concept is the accommodation of more direct connections in the network. The following three steps, illustrated in Figure 3, are performed, representing the necessary modifications of the current air transport network:

1. **Airline-independent demand for itinerary:** in the first step, all possible routing connections were combined, independent of the operating airline.
2. **Rerouting:** in the second step, passengers were rerouted on already existing but shorter routes if there was no existing direct flight, or on direct flights if direct flights already existed.
3. **Introduction of new flights:** in the last step, all combined connections were re-evaluated to identify the potential of introducing new direct connections. A new direct flight is introduced for routes with a maximum great circle distance of 15,350 km and an annual aggregated number of 1,200 passengers.

Table 1. Travel data format

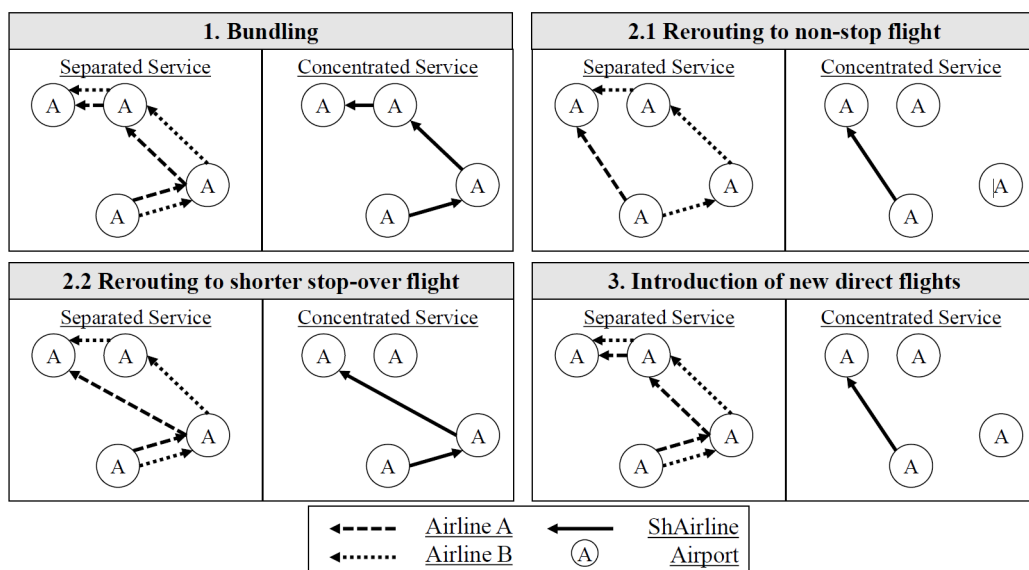| Itinerary	Origin	Destination	Layover	Operating Airlines	Total Passengers[5]
NON-STOP	AAA	AAB		SU	1919.07
THREE-STOP	BLL	PMR	CPH-PVG-AKL	EE-SK-NZ-NZ	2.55
...	...	...	...	...	...

Figure 3. Methodological approach representing the introduction of ShAirline by bundling, rerouting and introducing direct flights

---

5 Decimal numbers result from the regression model used by Sabre˙ to derive global route traffic.

Table 2. Investigated scenarios

Flight Speed	Regular Airline	ShAirline
Regular flight speed	Reference case	ShAirline using regular aircraft
Decreased flight speed	Introduction of new aircraft	ShAirline using slow-flying aircraft

2.2.3. Key performance indicators

The performance of the resulting air transport system can be described by the following four key performance indicators (KPIs) to capture the effects of ShAirline and the introduction of new aircraft technologies in the overall Hy-ShAir concept. The *(1) average deviation from great circle distance* for an individual passenger can serve as a proxy for operational and ecological efficiency. The effects of reduced flight speed can be evaluated in terms of travel time. Since airlines operating under today's business models are also at liberty to introduce hydrogen-powered-slow-flying aircraft, the effects on *(2) passenger journey times* for varying flight speeds are evaluated for both business model scenarios. In addition, the *(3) number of required aircraft* to operate the described air transport network is estimated. An average seat load factor of 85 percent is assumed in all scenarios. The average utilization of the aircraft is estimated at 50 percent, based on data reported by major American carriers to the U.S. Department of Transportation for wide-body aircraft of (MIT, 2020). Furthermore, it is assumed that aircraft operating at regular speed as well as slow-flying aircraft have a maximum capacity of 400 passengers. The theoretical operating time of the aircraft is assumed to be 24 hours, over 365 days a year, neglecting airport night flying restrictions. Maintenance and turnaround times, as well as inefficiencies due to scheduling are considered in the average utilization. Finally, the change in *(4) airport passenger traffic* provides additional insight into the impact of the ShAirline business model.

2.2.4. Modelling the ShAirline network

Based on the data provided by Sabre, all annual passenger itineraries $I_{S,L}$ for a specific routing S and airline L are represented by

$$I_{S,L} = (a_i)_{i=1,...,n}, \tag{1}$$

being a sequence of airports $a_1 \in A$, where A includes all airports covered in the data set. For every airport, the latitude ϕ_a and longitude λ_a are known. Additionally, for every $I_{S,L}$ the number of annual passengers on a specific itinerary $q_{I_{S,L}}$ are known. The distance of a single flight $d_{f_{a_1,a_2}}$ between two airports $a_1 \in A$ and $a_2 \in A$ is given by the haversine formula

$$d_{f_{a_1,a_2}} = 2r \arcsin\left(\sqrt{\sin^2\left(\frac{\phi_{a_2}-\phi_{a_1}}{2}\right)+\cos\left(\phi_{a_1}\right)\cos\left(\phi_{a_2}\right)\sin^2\left(\frac{\lambda_{a_2}-\lambda_{a_1}}{2}\right)}\right). \tag{2}$$

Thus, the flight distance of a multi stop itinerary d_I is given by

$$d_I = \sum_{n=1}^{F+1} d_{f_{a_n,a_{n+1}}}, \tag{3}$$

with F being the number of flights in I. The additional travel distance of a multi stop itinerary Δd_{orth} of a multi stop itinerary compared to the orthodrome between the first airport in the itinerary a_1 and the last airport in the itinerary a_n is given by

$$\Delta d_{orth} = -d_{a_1,a_n} + d_I. \tag{4}$$

The transport inefficiency μ_I of the investigated itinerary is defined as the amount of passenger kilometers μ_I deviating from the orthodrome between origin and destination and is given by

$$\mu_I = \Delta d_{orth,I} \cdot q_I, \tag{5}$$

with q_I being the annual number of passengers traveling on itinerary I. For the entire network, the transport inefficiency μ_N becomes

$$\mu_N = \sum_{n=1}^{N} \mu_{I_n}. \tag{6}$$

To represent the introduction of ShAirline, the provided Sabre dataset is reorganized to represent aircraft sharing, as following: In the first step, referred to as bundling in Figure 3, identical itineraries operated by different airlines are combined. Therefore, it holds that

$$I_{S,L} = I_{S,L+1}, \tag{7}$$

which results in

$$q_I = \sum_{l=1}^{L} q_{I_{S,l}}. \tag{8}$$

In the second step, itineraries are reorganized to replace every itinerary I_S, for which an itinerary I_X with a shorter total flight distance exists, without changing the first and last airport of the itinerary. Therefore,

$$I_S = \begin{cases} I_X & \Delta d_{orth,X} < \Delta d_{orth,i} \wedge a_{1_X} = a_{1_i} \wedge a_{n_X} = a_{n_i} \\ I_S & \Delta d_{orth,X} \geq \Delta d_{orth,i} \wedge a_{1_X} = a_{1_i} \wedge a_{n_X} = a_{n_i} \end{cases} \tag{9}$$

is applied. The execution of this step results in multi-stop itineraries being changed to itineraries with a smaller or no deviation from orthodrome distance compared to the initial itinerary. In the third step, new direct flights are introduced for multi-stop itineraries where the annual number of passengers is greater than 1200, thus that

$$I_S = \begin{cases} a_O, a_2, ..., a_D & q_{I_i} < 1200 \\ a_O, a_D & q_{I_i} \geq 1200 \wedge d_I \leq r_{AC} \end{cases}, \tag{10}$$

with r_{AC} being the maximum range of the aircraft, which is assumed at 15,350 km. The resulting itineraries provide the potential savings of deviation from the orthodrome distance leading to the requirement of additional energy. The implementation into a feasible flight schedule as part of the aircraft routing problem is not considered here. The duration of a single journey is calculated as following

$$t_I = \frac{v_{AC}}{d_I} + t_{TO} \cdot N_{TO,I} + t_L \cdot N_{L,I}, \tag{11}$$

with t_I being the required flight time for a given itinerary and v_{AC} the velocity of the aircraft. Additional time for takeoff t_{TO} and landing t_L is considered with 18 minutes each. Passenger transfer time between connecting flights is not considered for the itinerary. v_{AC} is assumed at 917 km/h for regular flight speeds and 746 km/h for reduced flight speeds. The number of required aircraft on airline and network level is estimated by

$$N_{AC} = \frac{\sum_1^N t_I \cdot q_I}{\mu_{SLF} \cdot \mu_{AC} \cdot q_{AC} \cdot 24 \cdot 365}, \tag{12}$$

with t_I being the trip time of an itinerary, q_I number of passengers traveling this itinerary μ_{SLF} being the average seat load factor of the aircraft, μ_{AC} being the average daily utilization of the aircraft, q_{AC} the maximum number of passengers on board.

3. Results

Following a detailed qualitative description of the ShAirline business model enabling the implementation of a passenger-distance-optimized air transport network structure as well as a slow-flying hydrogen aircraft in Sections 3.1, its impact on the four main pillars of the business model are outlined in Section 3.2. Subsequently, the defined KPIs for the investigated scenarios are presented in Section 3.3.

3.1. Propositions of ShAirline

The new business model approach in this paper is based on the following key propositions:

1. Proposition on airlines' fleet management: airlines move away from the traditional aircraft ownership and leasing principle to a fleet management approach, where aircraft can be partially leased, covering only a fraction of seats on specific routes. With 20 percent of scheduled seats remaining empty, passenger pooling and aircraft sharing via a seat exchange platform has the potential to increase utilization on long-haul routes. Pooling demand across multiple providers enables higher seat load factors and additional direct connections on an airport pair. Aircraft are no longer assigned on an airline-route basis, but by overall demand per route, facilitating a better allocation of the long-haul fleet across the network.
2. Proposition on airlines' profit mechanism: in terms of rethinking the ownership principle and bundling passengers using the sharing concept, an innovative cabin design with branded add-on services is conducive. Passenger comfort and ancillary revenues from add-on services take on more importance, since passengers are on board for longer times due to slower flight speeds. Improved comfort and convenience on long-haul flights could eventually lead to a higher acceptance of longer travel times.
3. Proposition on network topology: in the current long-haul network, layover passengers travel on routes an average of 8 percent longer than the direct distance between origin and destination. The longer trip distance stems from layovers at airports not located on the orthodrome between origin and final destination. By bundling demand, ShAirline aims at providing more direct connections and thus decreasing the necessary passenger seat kilometers to meet the required transport requirements, thus exhibiting the potential to reduce the environmental impact.

3.2. Implementation of ShAirline

The outline of this section follows the structure of the magic triangle (Gassmann et al., 2014). Based on the key propositions of ShAirline, customer demands, value proposition, system and cabin design, as well as potential revenue streams and cost savings are described.

3.2.1. Meeting customer demands ("Who")

Passengers are the first main stakeholder in the aviation system, since they generate the demand for air transport. In a liberalized market, they have a certain buying power: several airlines and routes (e.g. point-to-point vs. self-hubbing for a price-conscious, long-distance alternative) are available for travel. Six individual customer segments can be considered; (1) cultural seeker, (2) family and vacation traveler, (3) single traveler, (4) best ager, (5) environmental traveler, and (6) digital native business traveler, each with individual needs along the travel chain (Kluge et al., 2018). In addition, future customers might demand that long-haul journeys shall be tailored to personal preferences and providing an environment allowing for a value-adding use of their travel time, including comfort and convenience (Kluge et al., 2020).

Airlines are the second main stakeholder within the aviation system. They provide the air-transport service, both to passengers and cargo customers, currently applying various business models. Next to ticket sales, ancillary revenues are an essential income stream for airlines, with LCCs relying heavily on them. To increase profitability, airlines aim for the optimal balance between supply and demand to maximize the utilization of their fleet (currently measured by a high passenger load factor). Due to the large capacity of long-range aircraft, the introduction of new routes and satisfaction of fluctuating demand is challenging, since transport capacities cannot be split between different destinations. Moreover, maintaining customer satisfaction, loyalty and brand recognition is becoming challenging for airlines due to increasingly diverse passenger profiles. Accordingly, travel products need to be tailored on a more granular level to address customer needs. At the same time, airlines are challenged in light of recent political advances to provide environmentally-friendly air transport in order to meet CO_2-emission targets (European Commission, 2011). Conversely, radically

new aircraft technologies could be a solution, but require a large investment, especially if technology is novel and requires additional investments in new ground infrastructure and scaling up also considering the costs incurred during the entire life cycle, from manufacturing, operations and out of service.

Third parties outside the aviation industry can profit by providing additional by-products and services to passengers during their comparatively long travel time. An opportunity is presented by introducing individually customizable containers in the aircraft cargo hold that can be accessed by passengers. As an example, this may include hotel brands providing amenities before customers even reach their destination (e.g. by furnishing one of the containers with beds). Further benefits of these containers include a potential increase in sales for retailers, as they can get in touch with customers during the flight for an extended period, and thus may have a willingness to shop. Additionally, customers might also get in contact with retailers they did not know before, turning the container spaces into areas for discovering and experiencing unknown brands, similar to a fair. Lastly, these proposed container applications may include food vending, an activity and exercise area as well as sleeping compartments.

3.2.2. The value propositions ("What")

As a service, ShAirline offers air-transport capacity between a specific origin-destination pair. Within the proposed model, a centralized aircraft operator in charge of providing, maintaining, and managing the aircraft and its required infrastructure offers white label transport capacity to airlines and other interested parties. Individual areas within the aircraft can be configured to individual airline needs and brand requirements. Further, configurable cargo containers with access to the passenger deck allow airlines to provide additional services to customers, including beds, food services and entertainment.

Quite noticeably, certain similarities to the concept of point-to-point code-sharing exist, most notably, the use of aircraft seats by an airline not owning said aircraft. The current sharing of seats between airlines ranges from interlining, in which airlines mutually accept tickets issued by a partner, to code sharing, in which an airline blocks fixed spaces for a partner airline on specific flights (Nugraha, 2018). However, ShAirline expands this code-sharing practice by extending the possibility to rent out seating areas within a shared aircraft to every business, and not only airlines or alliance members, and hence introducing more flexibility in regard to participating partners per flight. This increases the potential for higher seat load factors. Further, the possibility to rent a larger section allows for better branding opportunities, enabling a single aircraft cabin being branded in different ways. While with code-sharing, passengers are confronted with the branding of a different airline, the HyShAir concept gives the possibility for a seamless branding along the whole trip, disregarding

the ultimate owner of the aircraft. Lastly, there is no need for an operating carrier. The shared aircraft can also be operated by third parties, which do not need to be airlines, or centralized aircraft management entity.

Third parties: Currently not represented in the aviation industry, these have the option to lease a presence within an aircraft, similar to any other real estate location. Depending on the route and preference of the passengers traveling, this can include but is not limited to branded food, shopping and personal services. Unlike in brick and mortar stores, business success will likely depend on the space and weight needed for the products themselves or the equipment needed.

For passengers: The comfort level on long-haul flights varies among the different flight phases and has its low peak while stowing luggage in the overhead bin and during the cruise time. Sleeping is the preferred activity of passengers on long-haul flights (Bouwens et al., 2017). Hence, space is a general issue, including knee space (seat pitch), comfortable sleeping options, and moving around. However, the goal of airlines is to provide the best cost-benefit ratio for passengers, instead of maximizing comfort. As such, the aim of airlines is not to increase comfort as a general rule rather than perfectly addressing the passenger need. While most travelers prefer additional personal space, the utility function of price-sensitive passengers does not reward additional room over fares. With the ShAirline concept, an increased variety of options becomes available to passengers to accommodate their needs. For exceptionally long flights, passenger health requirements with regard to space have to be considered as well.

Journeys tailored to personal preferences: Targeted customer segments have different profiles with respective requirements. To personalize the long-haul flight, the in-flight entertainment (IFE) system is replaced by bring your own device (BYOD) entertainment. Using advances in technological developments, virtual reality headsets allow visual experiences decoupled from the physical space in the cabin. Such experiences can be highly personalized, too. For example adding child-friendly content (for family and vacation travelers), concerts and destination information, and meeting or e-learning options (for digital native business travelers). To increase the entire door-to-door air travel experience and provide maximum personalization, mobility service integrators on personal devices could possibly be included within the overall concept (Höser & Schmalz, 2021).

Value-adding use of travel time: Longer travel time due to slower flight speeds should not be lost time, but should rather be spent in a value-adding way. Personal preferences of targeted customer segments can be met in dedicated areas within the aircraft cabin. These can include providing a family area, a separate space for toddlers and small children, a working and meeting area for business travelers, as well as a general lounge area for all passengers.

3.2.3. New cabin design ("How")

The cabin design: The slow-flying hydrogen-powered aircraft (Hyliner 2.0) in this study possesses two spherical hydrogen tanks in the front and rear of the cabin, leading to a fuselage with an almost circular diameter of 8.46 m. The resulting cabin, illustrated in Figure 4, is therefore much wider, but also shorter compared to current aircraft. In addition to two passenger decks, a third enhanced cargo deck can be included inside the fuselage. Classes and seat types can be introduced at the liberty of airlines, where each airline may provide a specific seat. The upper deck contains the central meeting and lounge areas, which are accessible from both the upper and the main deck via a staircase. Furthermore, a dedicated area in the upper deck consists of seat groups located around tables, enabling easy interaction between passengers. Due to the large cabin width and the fact that a single excuse cabin design (maximum of one person to pass when standing up) increases passenger comfort, a three-aisle configuration is used. In the aft of the main passenger deck, grouped seats and open spaces provide leisure room for families and playing children. In the center of the main deck, a staircase connecting the upper deck, a lounge area as well as a meeting space complete the enhanced passenger experience on the decks. In effect, increased space, movement options as well as a variety of offers on-board is seen as a way to mitigate the negative effects of prolonged travel times on the passengers' health. Furthermore, these measures increase comfort for the majority of the passengers.

Integrating the business model: Since the cabin is split into several separate areas, different seat vendors can operate in the aircraft at the same time. The consequent BYOD strategy lowers the aircraft's weight and facilitates the re-branding of the travel experience, e.g. via airline specific ticketing and entertainment apps. The lower container deck can be accessed via a staircase in the aft of the cabin. Containers can be loaded into the aircraft during longer turnarounds or minor checks depending on the routes the aircraft is serving. Hence, services can be adapted to passenger demand, region, season and airline generating additional revenue on the aircraft. Different to the already established concepts of swappable containers which are often considered for the whole cabin, these containers are independent of the cabin itself. They represent an opportunity to repurpose redundant cargo space and increase the space accessible by passengers during a flight. The business model is schematically illustrated in Figure 5.

3.2.4. Revenue streams and efficiency improvements ("Why")

The economic viability of ShAirline is based on four key assumptions.

1. Tailored products increase passengers' willingness to pay.
2. Additional service opportunities aboard the aircraft, enabled through adaptable containers accessible to passengers.
3. Higher load factors through the improved match of supply and demand.
4. Mitigation of high capital requirements needed for the introduction of eco-efficient aircraft in order to fulfil long-term regulatory requirements.

Under these assumptions, the concept leads to more revenues and increased profitability as compared to today's business models.

Passengers' willingness to pay: As already mentioned above, one core proposition of ShAirline is a travel experience individually tailored to passenger needs. With increased flexibility due to the containers, more diverse services can be offered on-board to cater to a wider array of demands. Taking away the burden of operating the aircraft allows airlines and service providers to focus more on the travel experience aboard, thereby increasing the journey value for the passenger. While this can include amenities,
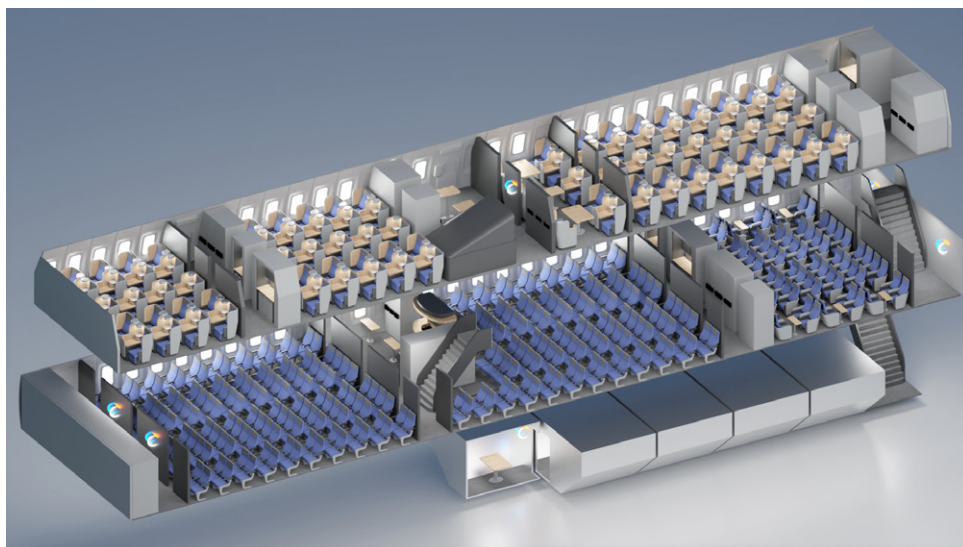

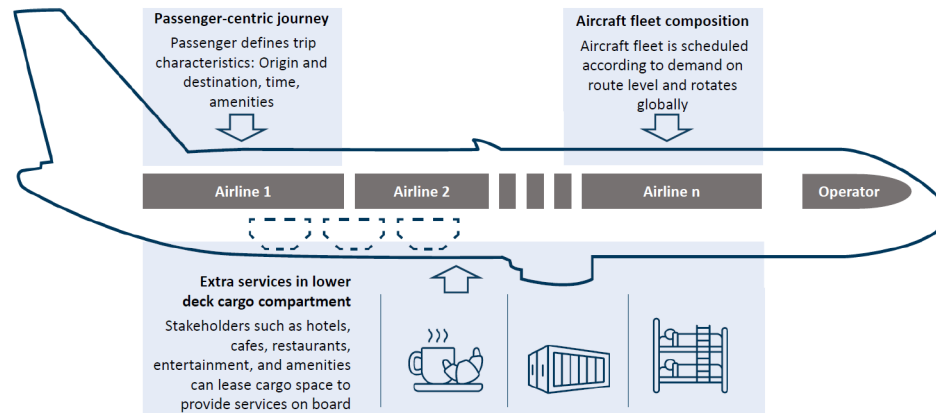Figure 4. Illustration of three-deck cabin layout (Engelmann et al., 2020)

Figure 5. Conceptual representation of the Seat sharing concept proving transport capacity to
multiple airlines on the same aircraft

it can also extend to low cost, last minute tickets targeting price conscious travelers. In general, specifically tailoring services to customer needs increases spending willingness and thus revenue (Franke et al., 2009).

Additional services opportunities: The introduction of exchangeable containers provides additional flexibility to the operator of the aircraft, airlines and third parties, allowing them to increase revenue in two ways. As with traditional airlines, the space in the belly of the aircraft can be monetized by transporting cargo. However, unlike with traditional aircraft, where an average of 40 percent of the belly cargo capacity remains empty, this space can be used for accessible containers used to provide services to passengers (Raja, 2015). The containers increase revenue opportunities for service providers by offering the unique option to follow passengers around the world. Their dynamic adjustment allows adaptions depending on the region, flight duration, or time of day. Containers with sleeping compartments may be used on long overnight flights, whereas entertainment providers might provide a space for social activities on typical tourist routes. Depending on the region and passenger segments on board, food and beverage vendors might accompany the journey. Additionally, tailored by-products may improve passengers' willingness to pay.

Increased load factor: One proposition of the seat exchange platform is to achieve high load factors while enabling more point-to-point connections, thus improving efficiency. The flight network is optimized towards bundling passengers in order to offer a larger number of route-specific seat contingents. With this approach, airlines are able to better match the expected demand with the available supply. New routes within their network can be established without the need to allocate an entire aircraft. Furthermore, as a cost reduction strategy, airlines currently bundle passengers in a hub-and-spoke network structure (Kahn, 1993). With ShAirline, this approach evolves into bundling demand between particular airport pairs to decrease the cost connected with passenger detours. This concept relies on changing the ownership structure of aircraft, as already been discussed in the literature (Plötner

et al., 2017). Hence, aircraft are no longer owned and operated by individual airlines[6], but rather by a centralized aircraft management entity or third parties, which sells seat contingents over a single exchange platform. Through this system, demand can be better allocated to aircraft, thus avoiding unutilized capacities on large aircraft or an insufficient number of seats on too small ones.

Mitigation of capital-intensive environmental regulation: The seat sharing platform also facilitates the introduction of new aircraft technologies connected to large infrastructure investments. While individual airlines may adopt new technologies, their incentive is the increase of either revenue, profitability, or both. However, in the current system, eco-efficiency does not impact or does only marginally impact airline profits, with the exception of fuel costs. Investments in new aircraft technologies and clean energy sources bear the risk of not boosting competitiveness, thus effectively impeding the airline business. Providing airlines with access to flexible shares of eco-efficient air transport capacity gives them the opportunity to move to cleaner technologies with less financial risk.

3.3. Quantitative evaluation of passenger-distance-improved long-haul network

The scenarios described in Table 2, influencing selected key performance indicators, are summarized in the following chapter. The ShAirline model reduces kilometers flown that deviate from the orthodrome distance by 90 percent. The worldwide long-haul detour traffic decreases from 4.87 percent to 0.48 percent of flown long-haul passenger kilometers. When considering only multi-stop long-range flights, the worldwide long-haul detour traffic amounts to 8.02 percent. In Figure 6, the deviation from the direct route between origin and destination weighted by passengers is illustrated for long-haul, multi-stop connections. The deviation is provided for today's network with regular airlines and a network operated by the

---

6 Or operating carrier, as for instance seen in the code-sharing concept.

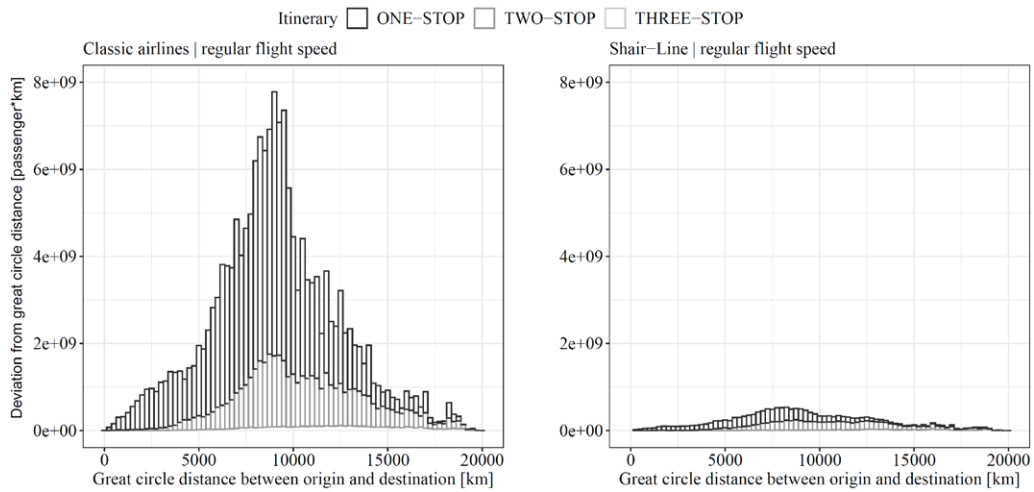Itinerary ☐ ONE–STOP ☐ TWO–STOP ☐ THREE–STOP

Figure 6. Deviation from orthodrome distances for passenger itineraries over a combined length of 4,000 km

ShAirline. If detours are considered as inefficiencies, it can be seen that ShAirline significantly reduces the amount of additionally flown distances in the network.

The variation in flight speeds directly influences the average travel time of passengers. Figure 7 illustrates the average travel time over great circle distance between origin and destination for the investigated scenarios. Comparing the current business model at regular flight speeds with the ShAirline concept operating at regular flight speed shows, that the average travel time over all distances can be reduced, along with the trip-time standard deviation. The proposed reduction in flight speed by 17 percent generally yields a 20 percent increase in average travel time over all distances.

However, the adverse effects of slower flight speeds can be partially compensated by the ShAirline business model. Considering a regular airline that limits flight speed to Mach 0.7, the resulting increase in average travel time can be reduced by 25 percent through the decrease in flight distance enabled by ShAirline. Further time savings gained by avoiding the latency and boarding processes involved in a layover are not considered in this study.

With regard to the number of aircraft required to operate within the network, ShAirline can eliminate inefficiencies, especially for smaller airlines. This is attributed to routing inefficiencies that typically decrease with increasing network size. Depending on the flight speed, the proposed business model can reduce the fleet size by 20 percent as illustrated in Figure 8. Further, abandoning layovers at hubs in exchange for more direct flights also impacts airports. Figure 9 illustrates the change in the number of layover passengers at airports for the fifteen airports gaining and losing the most. The loss of layover passengers at big hubs primarily served by long-range flights is especially apparent. While this effect may not be desirable from the standpoint of the airport operator, ShAirline offers a solution to decrease the traffic near big hubs located close to cities in order to reduce local

CO_2-emissions and noise, or to free up valuable slots for new destinations and growth. While more than 60 percent of long-haul passengers travel on indirect connections, the overall share of layovers in the entire air transport network is below 10 percent. Thus, on the global air transport network level, ShAirline reduces the number of passenger departures by 5.13 percent.
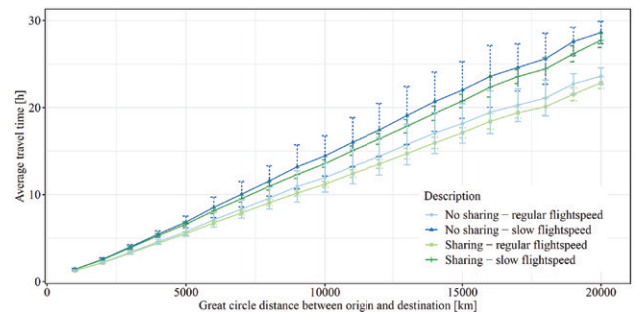

Figure 7. Influence of business model and flight speed on average travel time of the itinerary
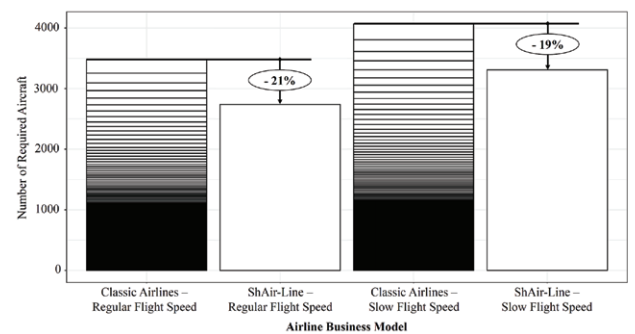

Figure 8. Required aircraft within the long-haul air transport network depending on the airline business model and aircraft flight speed
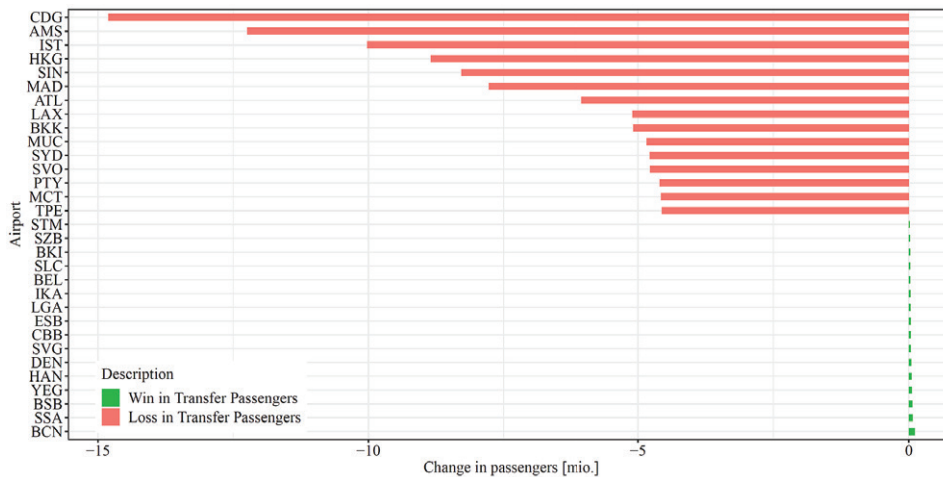
Figure 9. Top 15 decrease and increase in passenger numbers at worldwide airports
through ShAirline.

4. Discussion

In the present study, three interrelated challenges to decrease the climate impact of long-haul aviation are addressed, including the air transport network structure, hydrogen as an energy carrier as well as aircraft and cabin design. To meet these challenges, the innovative business model of the ShAirline is proposed that mitigates obstacles on the path toward environmentally-friendly aviation. The core idea is the introduction of a seat sharing platform that enables airlines to better match their supply and demand. A single transport capacity provider offers white label seats to airlines, with multiple airlines serving passengers on a single aircraft. To counter the effect of lost productivity due to reduced flight speeds, slightly larger aircraft are used. In contrast to existing alliances, pooling the entire capacity supply in a single organization enables improved aircraft routing and thus increases efficiency.

Key stakeholder are described along with the corresponding value propositions offered to them, including their realization and assumptions leading to financial viability. It is shown that the proposed concept is capable of reducing passenger kilometers resulting from layovers by 90 percent. Together with efficient aircraft routing, these performance improvements can be used to partially compensate for the drawbacks of slower flights and high investment costs of the hydrogen infrastructure. The number of required aircraft for the entire long-haul air transport network can be reduced by about 20 percent, along with a 5 percent decrease in travel times. However, the study presented here only constitutes an initial concept rather than a final solution.

This study should be considered as a first exploratory approach. Further investigations are required with regard to technological requirements for the containers and flexibility of aircraft interior. While the use of flexible containers enables the provision of additional passenger and cargo services, the introduction of such a system increases structural weight and thus fuel burn, while at the same time decreasing the maximum useful payload. As seen in the described business model frameworks, a strong customer orientation is essential. The next steps can include the integration of the customer demand side into the concept development. In line with this, the assessment of the concept in this paper focuses on network effects that are quantifiable with existing data. Further studies may also address the financial feasibility of introducing larger aircraft and the associated customer behavior. As seen with the retirement of the Airbus A380, despite its relative young age, airlines are not able to fully exploit the potential efficiency of larger aircraft in terms of fuel burn per passenger kilometer, since their maximum seating capacities are typically not fully utilized. Other aspects not addressed here include the exact extent to which larger networks improve efficiency when solving the aircraft routing problem. Finally, the specific effects of a sharing platform on airline differentiation and airline marketing would also be worth investigating.

As outlined in the introduction, the long-haul network accounts for more than 30 percent of aviation fuel burn and thus CO_2 emissions, making it challenging for airlines to meet CO_2-emission targets and offer environmentally-friendly transport in the near future. While alternative modes of transportation including trains and fully electric aircraft offer environmentally friendly solutions on short-haul routes, they are not suitable for long-haul transport either because of travel time or engineering constraints. Within the HyShAir project, we argue that liquid hydrogen, in conjunction to operational network optimization, presents a feasible solution to reduce fuel burn and CO_2-emissions caused by long-haul flights. The climate effects of implementing this proposed new network structure as well as the introduction of a slow-flying hydrogen-powered long-haul aircraft are not the subject of

this paper. Further research needs to focus on the assessment of these effects.

In addition, to offset the significant upfront investment costs associated with introducing hydrogen as an alternative aviation fuel that airlines as well as other stakeholder in this industry would be subject to, the ShAirline concept also offers the potential to bundle the demand for eco-efficient technologies. The airline-specific first-mover penalty can be mitigated, and investment and infrastructure efforts can be distributed between multiple stakeholder, thereby reducing the entry barrier for individual airlines. Further research in this area is required to evaluate the costs and benefits of such a concept, and thus the potential for a market uptake.

Finally, a major challenge arises particularly in the early phase of implementation and transition, where technological risks and financial investments are high. Especially for airlines operating in highly competitive markets, high costs and deficits related to the introduction of new technologies and business models can become a heavy liability. Consequently, it seems reasonable to first introduce the HyShAir concept on individual high-demand routes. This would have the advantage that a large number of individual airlines are already present on these routes, where the sharing concept seems particularly promising. Further, high passenger demand would ensure a good saturation of increased capacities. Finally, initial investment costs in infrastructure and systemic components could be kept relatively low due to scaling effects. Public support in the early phase of market diffusion seems reasonable to partly mitigate investment risks, and to ensure high standards for safety and security.

Conclusions

This paper proposed the HyShAir concept whose ultimate goal is to reduce CO_2-emissions on the long-haul aviation market by altering the air transport network structure, introducing liquid hydrogen as a new energy carrier, and by proposing a new aircraft and cabin design. This enables operational improvements with regard to passenger routing, passenger pooling, and flight speed adaptation. The results of the paper indicate that these improvements can be achieved with a new business model and a hydrogen-powered aircraft optimized for lower flight speeds. The business model proposes to open up aircraft cabins to third parties by using a seat sharing platform provided by a single aircraft operator. It is suggested that a seat sharing platform can improve the match of supply and demand in the air transport system and thus increase load factors as well as reduce the number of required aircraft in the future. Furthermore, the seat sharing platform motivates the feasibility of pooling passengers, thus reducing unnecessary passenger kilometers caused by layovers. Efficiency gains can subsequently be used to promote the introduction of new, eco-efficient hydrogen-powered aircraft, which requires substantial financial investments. In the context of introducing passenger-distance-optimized air transport network structures, new aircraft technologies and energy sources, innovative business models can provide significant leverage for facilitating radical changes to the air transport system. Future research is needed in order to better understand the complex and dynamic interplay between these elements of the aviation industry. Specifically, the impact of extending code sharing through the proposed seat sharing platform on airline strategy and competition is still ambiguous. Further, the feasibility of the "ShAirline" flight schedule with regard to aircraft routings has to be further investigated. Together with the presented research, this would give the opportunity to substantially reduce CO_2-emissions of the aviation sector.

Disclosure statement

The authors declare that there is no conflict of interest.

References

Airbus. (2018). *Global market forecast 2018–2037*. Airbus. https://www.airbus.com/content/dam/corporate-topics/publications/media-day/GMF-2018-2037.pdf

BADA. (2019). *Base of aircraft data*. https://badaext.eurocontrol.fr/

Bouwens, J., Tsay, W-J. J., & Vink, P. (2017). The high and low comfort peaks in passengers' flight. *Work, 58*(4), 579–584. https://doi.org/10.3233/WOR-172637

Daft, J., & Albers, S. (2013). A conceptual framework for measuring airline business model convergence. *Journal of Air Transport Management, 28*, 47–54. https://doi.org/10.1016/j.jairtraman.2012.12.010

Daft, J., & Albers, S. (2015). An empirical analysis of airline business model convergence. *Journal of Air Transport Management, 46*, 3–11. https://doi.org/10.1016/j.jairtraman.2015.03.008

Engelmann, M., Drust, D., & Hornung, M. (2020). Automated 3D cabin generation with PAXelerate and Blender using the CPACS file format. In *Deutscher Luft- und Raumfahrtkongress, 2020*. Virtual. https://doi.org/10.25967/530014

European Commission. (2011). *Flightpath 2050 Europe's vision for aviation – report of the high level group on aviation research*. European Commission. https://doi.org/10.2777/50266

Franke, N., Keinz, P., & Steger, C. J. (2009).Testing the value of customization: when do customers really prefer products tailored to their preferences? *Journal of Marketing, 73*(5), 103–121. https://doi.org/10.1509/jmkg.73.5.103

Gassmann, O., Frankenberger, K., & Csik, M. (2014). *The business model navigator: 55 models that will revolutionise your business*. Pearson. https://doi.org/10.3139/9783446437654.003

Grewe, V., Dahlmann, K., Flink, J., Frömming, C., Ghosh, R., Gierens, K., Heller, R., Hendricks, J., Jöckel, P., & Kaufmann, S. (2017). Mitigating the climate impact from aviation: achievements and results of the dlr wecare project. *Aerospace, 4*(3), 34. https://doi.org/10.3390/aerospace4030034

Höser, M., & Schmalz, U. (2021). *Supporting door-to-door air travel: Towards a privacy preserving virtual assistant for passengers.* Accepted for publication in Journal of Air Transport Studies.

International Air Transport Association (IATA). (2020). *Recovery delayed as international travel remains locked down.* IATA. https://www.iata.org/en/pressroom/pr/2020-07-28-02/

International Civil Aviation Organization (ICAO). (2010). *Environmental report 2010.* ICAO. https://www.icao.int/environmental-protection/Documents/Publications/ENV_Report_2010.pdf

Kahn, A. E. (1993). The competitive consequences of hub dominance: A case study. *Review of Industrial Organization, 8*(4), 381–405. https://doi.org/10.1007/BF01024277

Klug, H. G., & Faass, R. (2001). Cryoplane: hydrogen fuelled aircraft – status and challenges. *Air & Space Europe, 3*(3–4), 252–254. https://doi.org/10.1016/S1290-0958(01)90110-8

Kluge, U., Paul, A., Ureta, H., & Ploetner, K. O. (2018, 16–19 April). Profiling future air transport passengers in Europe. In *Proceedings of 7th Transport Research Arena (TRA) 2018.* Vienna, Austria. https://doi.org/10.5281/zenodo.1446080

Kluge, U., Ringbeck, J., & Spinler, S. (2020) Door-to-door travel in 2035 – a Delphi study. *Technological Forecasting and Social Change, 157*(August). https://doi.org/10.1016/j.techfore.2020.120096

Lee, D. S., Fahey, D. W., Skowron, A., Allen, M. R., Burkhardt, U., Chen, W., Doherty, S. J., Freeman, S., Forster, P. M., Fuglestvedt, J., Gettelman, A., León, R. R., Lim, L. L., Lund, M. T., Millar, R. J., Owen, B., Penner, J. E., Pitari, G., Prather, M. J., Sausen, R., & Wilcox, L. J. (2020). The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric Environment, 244*, 117834. https://doi.org/10.1016/j.atmosenv.2020.117834

Linke, F., Grewe, V., & Gollnick, V. (2017). The implications of intermediate stop operations on aviation emissions and climate. *Meteorologische Zeitschrift, 26*(6). https://doi.org/10.1127/metz/2017/0763

Mason, K. J., & Morrison, W. G. (2008). Towards a means of consistently comparing airline business models with an application to the "low cost" airline sector. *Research in Transportation Economics, 24*(1), 75–84. https://doi.org/10.1016/j.retrec.2009.01.006

Massachusetts Institute of Technology (MIT). (2018). *Traveler numbers reach new heights.* Airline data project, 2020. http://web.mit.edu/airlinedata/www/default.html

McKinsey & Company. (2020). *Hydrogen-powered aviation: A fact-based study of the hydrogen technology, economics, and climate impact by 2050.* Publications Office of the European Union. https://doi.org/10.2843/471510

Nugraha, R. A. (2018). Legal issues surrounding airline alliances and codeshare arrangements: insights for the Indonesian and asean airline industries. *Indonesian Law Review, 1*, 37–62. https://doi.org/10.15742/ilrev.v8n1.382

OAG. (2018). *Official airline guide 2018.*

Osterwalder, A., & Pigneur, Y. (2010). *Business model generation: A handbook for visionaries, game changers, and challengers.* Wiley & Sons. ISBN 9780470876411.

Plötner, K., Urban, M., & Hornung, M. (2017). *Potential of aircraft on-demand sharing model for large commercial aircraft* [Conference presentation]. Air Transport Research Society, 21st ATRS World Conference.

Raja, P. (2015). World airlines cargo report. *Cargo Airports & Airline Services*, Spring Issue.

Randt, N. P. (2016). *Aircraft technology assessment using fleet-level metrics.* Technische Universität München.

SABRE. (2017). *Sabre Market Intelligence.* Proprietary data access.

Soyk, C., Ringbeck, J., & Spinler, S. (2017). Long-haul low cost airlines: Characteristics of the business model and sustainability of its cost advantages. *Transportation Research Part A: Policy and Practice*, 106, 215–234. https://doi.org/10.1016/j.tra.2017.09.023

Troeltsch, F. M., Engelmann, M., Scholz, A. E., Peter, F., Kaiser, J., & Hornung, M. (2020, 15–19 June). Hydrogen powered long haul aircraft with minimized climate impact. In *AIAA Aviation 2020 Forum*, virtual event. https://doi.org/10.2514/6.2020-2660

United Nations Treaty. (2016). *Paris agreement. United Nations.* https://unfccc.int/sites/default/files/english_paris_agreement.pdf

Urban, M., Klemm, M., Ploetner, K. O., & Hornung, M. (2018). Airline categorisation by applying the business model canvas and clustering algorithms. *Journal of Air Transport Management, 71*, 175–192. https://doi.org/10.1016/j.jairtraman.2018.04.005

Wirtz, B. W., Pistoia, A., Ullrich, S., & Göttel, V. (2016). Business models: Origin, development and future research perspectives. *Long Range Planning, 49*(1), 36–54. https://doi.org/10.1016/j.lrp.2015.04.001

Wirtz, B. W., & Daiser, P. (2018). Business model development: a customer-oriented perspective. *Journal of Business Models, 6*(3), 24–44.

Wittmer, A., & Hinnen, G. (2016). Airline passengers. In L. Budd & Ison S., *Air transport management – an international perspective* (pp. 139–150). Routledge.

Notations

Symbol	Description	Unit
a	Airport	–
A	Set of all airports	–
$d_{f_{a_1,a_2}}$	Distance between two airports	km
d_I	Distance of all flights in itinerary	km
Δd_{orth}	Additional travel distance of multi stop itinerary compared to orthodrome	km
q	Number of passengers	–
q_{I_S}	Annual number of passengers travelling on itinerary I_S	–
$q_{I_{S,L}}$	Annual number of passengers travelling on itinerary $I_{S,L}$	–

Symbol	Description	Unit
I_S	Annual passenger itineraries for a specific routing S	–
$I_{S,L}$	Annual passenger itineraries for a specific routing S and airline L	–
F	Number of flights in itinerary	–
N_{AC}	Number of required aircraft	–
$N_{TO,I}$	Number of take-offs in itinerary	–
$N_{L,I}$	Number of landings in itinerary	–
t_I	Duration of entire itinerary I	min
t_L	Duration of landing	min
t_{TO}	Duration of take-off until cruise speed	min
μ_I	Transport inefficiency of itinerary	km
μ_N	Transport inefficiency of network	km
r_{AC}	Range of aircraft	km
v_{AC}	Cruise speed of aircraft	km/h
ϕ_a	Latitude of airport	rad
λ_a	Longitude of airport	rad