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UNIVERSITY IN PRAGUE

FACULTY OF TRANSPORTATION SCIENCES

BACHELOR'S THESIS

2021

ARTEM
KAŠČEEV

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ZADÁNÍ BAKALÁŘSKÉ PRÁCE

(PROJEKTU, UMĚLECKÉHO DÍLA, UMĚLECKÉHO VÝKONU)

Jméno a příjmení studenta (včetně titulů):

Artem Kaščeev

Kód studijního programu a studijní obor studenta:

B 3710 – LED – Letecká doprava

Název tématu (česky): **Konverze osobních letadel na nákladní v souvislosti s přepravní kapacitou**

Název tématu (anglicky): Passenger to Freighter Aircraft Conversion and its Impact on Transport Capacity

Zásady pro vypracování

Při zpracování bakalářské práce se řiďte následujícími pokyny:

- Cílem práce je posoudit vhodnost přestavby osobních letadel na nákladní z kapacitního hlediska. Základem práce je analýza flotil současných osobních a nákladních dopravců a analýza možností využití přestavěných letadel na trasách s rostoucím potenciálem pro nákladní dopravu. Údaje o leteckých trasách budou získány z Eurostatu. Výsledkem práce je odhad nárůstu počtu nákladních letadel s ohledem na současnou flotilu leteckých dopravců a plánovanou výrobní kapacitu.
- Definice konceptu konverze z osobních na nákladní letadla (P2F)
- Analýza současné struktury trhu - současná flotila, plánovaná výroba nákladních letadel
- Výběr tras s potenciálem růstu nákladní letecké dopravy a odhad růstu objemu přepravy, odhad nárůstu potřeby letadel
- Posouzení vhodnosti konverze P2F z hlediska kapacity, validace metody

Rozsah grafických prací: dle pokynů vedoucího práce

Rozsah průvodní zprávy: minimálně 35 stran textu (včetně obrázků, grafů a tabulek, které jsou součástí průvodní zprávy)

Seznam odborné literatury:

J. Reichmuth, P. Berster - Past and Future Developments of the Global Air Traffic

L. Budd, S. Ison - The role of dedicated freighter aircraft in the provision of global airfreight services

I.Berlowitz - Narrow-body B737Ng passenger conversion to freighter

Vedoucí bakalářské práce: **doc. Ing. Peter Vittek, Ph.D.**

Datum zadání bakalářské práce: **9. října 2020**

(datum prvního zadání této práce, které musí být nejpozději 10 měsíců před datem prvního předpokládaného odevzdání této práce vyplývajícího ze standardní doby studia)

Datum odevzdání bakalářské práce: **9. srpna 2021**

a) datum prvního předpokládaného odevzdání práce vyplývající ze standardní doby studia a z doporučeného časového plánu studia
b) v případě odkladu odevzdání práce následující datum odevzdání práce vyplývající z doporučeného časového plánu studia

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Potvrzuji převzetí zadání bakalářské práce.

Artem Kaščeev
jméno a podpis studenta

V Praze dne.. 9. října 2020

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BACHELOR'S THESIS ASSIGNMENT

(PROJECT, WORK OF ART)

Student's name and surname (including degrees):

Artem Kaščeev

Code of study programme code and study field of the student:

B 3710 – LED – Air Transport

Theme title (in Czech): **Konverze osobních letadel na nákladní v souvislosti s přepravní kapacitou**

Theme title (in English): Passenger to Freighter Aircraft Conversion and its Impact on Transport Capacity

Guides for elaboration

During the elaboration of the bachelor's thesis follow the outline below:

- The thesis aims to conduct an appraisal of the suitability of passenger to freighter aircraft conversion from a capacity perspective. The thesis's foundation is based on an analysis of the fleets of current passenger and cargo carriers and an analysis of the possibilities of using converted aircraft on routes with a growing potential for cargo. Air routes data will be sourced from Eurostat. The thesis result estimates the increase in the number of cargo planes, taking into account the current fleet of air carriers and the planned production capacity
- Introduction of the passenger to freighter (P2F) conversion concept
- Current market structure analysis - current fleet, planned production of freighters
- Selection of routes with potential for growth of cargo air transport and estimation of the growth of the volume of transport, estimation of the increase in the need for aircraft
- Appraisal of the suitability of P2F conversions from the capacity perspective, method validation

Graphical work range: according to the instructions of the bachelor's thesis supervisor

Accompanying report length: at least 35 pages of text (including pictures, graphs and tables, which are part of the accompanying report)

Bibliography:

J. Reichmuth, P. Berster - Past and Future Developments of the Global Air Traffic

L. Budd, S. Ison - The role of dedicated freighter aircraft in the provision of global airfreight services

I.Berlowitz - Narrow-body B737Ng passenger conversion to freighter

Bachelor's thesis supervisor: **doc. Ing. Peter Vittek, Ph.D.**

Date of bachelor's thesis assignment: **October 9, 2020**
(date of the first assignment of this work, that has be minimum of 10 months before the deadline of the theses submission based on the standard duration of the study)

Date of bachelor's thesis submission: **August 9, 2021**

a) date of first anticipated submission of the thesis based on the standard study duration and the recommended study time schedule
b) in case of postponing the submission of the thesis, next submission date results from the recommended time schedule

L.S.

doc. Ing. Jakub Kraus, Ph.D.
head of the Department
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doc. Ing. Pavel Hrubeš, Ph.D.
dean of the faculty

I confirm assumption of bachelor's thesis assignment.

Artem Kaščeev
Student's name and signature

Prague .... October 9, 2020

Abstract

The subject of the bachelor thesis "Passenger to Freighter Aircraft Conversion and its Impact on Transport Capacity" is the forecast of increasing cargo volumes on selected routes, as well as the estimation of an increase in the number of cargo aircraft used on these routes from a capacity standpoint. The thesis highlights current trends in the air freight sector, current situation with historical perspective, and air cargo market forecasts. The thesis analyzes and anticipates cargo volumes for selected routes of Europe's main cargo airports. The analytical method cleanses the data for specified routes, after which the statistical significance of the cleansed data is determined using regression analysis. Following that, the cleansed data is forecasted, and the predicted numbers are compared to historical data in order to establish routes with increasing cargo potential. Based on these procedures, the number of additional airplanes required to accommodate the increased cargo volumes from a capacity point of view for each specified route is calculated. The result is the number of additional cargo aircraft necessary for each route, as well as an assessment of the suitability of P2F conversions for this purpose from a capacity point of view.

Keywords: Freighter aircraft, P2F, Conversion, Cargo Volume, Payload

Abstrakt

Předmětem bakalářské práce „Konverze osobních letadel na nákladní v souvislosti s přepravní kapacitou“ je prognóza zvyšování objemu přepravovaného nákladu na vybraných trasách a také odhad nárůstu počtu nákladních letadel používaných na těchto linkách z kapacitního hlediska. Bakalářská práce poukazuje na aktuální trendy v letecké nákladní dopravě, uvažuje současný stav s náhledem na historický vývoj a zkoumá prognózy trhu leteckého nákladu. Bakalářská práce analyzuje a předpovídá objemy nákladu pro vybrané trasy hlavních evropských nákladních letišť. Analytický postup nejprve provede čištěná data pro vybrané trasy, načež se pomocí regresní analýzy stanoví statistická významnost dat. Poté se provede předpověď objemu leteckého nákladu pro vybrané trasy. Následně, historická data se porovnají s hodnotami z předpovědi, aby se stanovily trasy se zvyšujícím se nákladovým potenciálem. Na základě těchto postupů se vypočítá počet letadel potřebných k naplnění zvýšeného objemu nákladu z kapacitního hlediska pro každou zkoumanou trať. Výsledkem práce je stanovení počtu potřebných nákladních letadel pro jednotlivé tratě a také posouzení vhodnosti použité konverzi P2F pro tento účel z hlediska kapacity.

Klíčová slova: Nákladní letadlo, P2F, Konverze, Objem nákladu, Užitečné zatížení

Declaration

I hereby declare that the presented thesis is my own work and that I have cited all sources of information in accordance with the Guideline for adhering to ethical principles when elaborating an academic final thesis.

I acknowledge that my thesis is subject to the rights and obligations stipulated by the Act No. 121/2000 Coll., the Copyright Act, as amended, in particular that the Czech Technical University in Prague has the right to conclude a license agreement on the utilization of this thesis as a school work under the provisions of Article 60 (1) of the Act.

In Prague, 05.08.2021

Signature ....

Acknowledgement

At this point, I would like to express my great gratitude to my thesis supervisor doc. Ing. Peter Vittek, Ph.D., who has led me throughout the whole thesis composing process and helped me with the elaboration. Also, I would like to thank my family and close friends who have supported me throughout my studies. Furthermore, I would like to thank Ing. Sarah Van Den Bergh for her help in the final parts of the thesis.

Contents

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List of Symbols and Abbreviations Used

ACI	Airports Council International
ACMI	Aircraft, Crew, Maintenance, and Insurance providers
ACTK	Available Cargo Tonne-Kilometers
AMS	Amsterdam Schiphol Airport
ANOVA	Analysis of Variance
ATK	Available Tonne-Kilometers
ATR	Avions de Transport Régional; Regional Transport Airplanes
AVG	Average
BCF	Boeing Converted Freighter
BDSF	Bedek Special Freighter
CAA	Civil Aviation Authority
CAAC	Civil Aviation Administration of China
CAB	US Civil Aeronautics Board
CDG	Paris Charles de Gaulle Airport
CGN	Cologne Bonn Airport
COMAC	Commercial Aircraft Corporation of China

CS	Certification Specifications
CTK	Cargo Tonne-Kilometers
EASA	European Union Aviation Safety Agency
ECS	Environmental Control System
EFW	Elbe Flugzeugwerke GmbH; Elbe Aircraft Factory
EMA	East Midlands Airport
ERSF	Extended Range Special Freighter
ETS	Exponential Smoothing
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FCV	Flow Control and Shutoff Valve
FedEX	Federal Express
FEM	Finite Element Model
FRA	Frankfurt Airport
FTK	Freight Tonne-Kilometers
GYD	Baku Airport
HAECO	Hong Kong Aircraft Engineering Company

HF	High Frequency
HKG	Hong Kong Airport
IAI	Israel Aerospace Industries
IATA	International Air Transport Association
JADC	Japan Aircraft Development Corporation
LEJ	Leipzig Halle Airport
LF	Low Frequency
LGG	Liège Airport
LUX	Luxembourg Findel Airport
MDCD	Main Deck Cargo Door
MRO	Maintenance, Repair and Overhaul
OEM	Original Equipment Manufacturer
P2F	Passenger-to-Freighter
PC	Production Certificate
PVG	Shanghai Pudong Airport
RFID	Radio Frequency Identification
RTK	Revenue Tonne-Kilometers

SARS	Severe Acute Respiratory Syndrome
SDF	Louisville Airport
STC	Supplemental Type Certificate
UHF	Ultra High Frequency
ULD	Unit Load Device

Introduction

Air cargo is an essential part of aviation. Freight transported by air plays an important role in world economics, and planes usually carry lightweight goods of high value. Last year was very hard for aviation, but the industry of air cargo managed to take advantage of the situation and increase its revenues [1]. Due to the ceased passenger operations, airlines and their customers were in a situation of air cargo capacity shortage, when demand was greater than capacity, which cargo carriers could offer. Belly cargo was significantly reduced, and dedicated cargo carriers were unable to satisfy the demand for air cargo. Boosted by growing e-Commerce even before pandemics, the air cargo market has found itself in the situation when new aircraft are needed. There are two ways to satisfy this need, factory-built freighter aircraft and converted cargo planes.

The need for the capacity and the large number of aging aircraft that are suitable for conversion being retired by passenger airlines were the two main motivations for this thesis. This thesis speaks about the history of air cargo, describes the modern air cargo industry, defines the current situation in the air cargo, describes technical process behind P2F conversions, and, most importantly, forecasts the growth of the cargo volume for selected routes and estimates the number of planes required to fill the forecast capacity.

One of the basic bases for comprehending the circumstances and motivations for this thesis is a description of the air cargo industry. Airlines, numerous aircraft types, various items transported by air, and ground infrastructures must all be explained. The knowledge and overview of the existing situation in the air cargo industry is the next crucial aspect for understanding the thesis. Trends, numbers, and continuing cargo aviation activity must be acknowledged and reported. In addition, a technical explanation of the P2F conversion must be provided in order to understand the requirements for planes, modifications, and laws in this field. The analysis and estimation will be based on data from Europe's busiest freight airports. To begin, the data will be cleansed in order to remove invalid or blank entries and identify routes with high cargo movement. The data will next be examined for statistical significance using regression analysis. This stage will be used to determine which routes are forecastable. The Forecast Sheet tool in Microsoft Excel will be used to execute the forecast, which is based on the AAA version of the Exponential Smoothing Algorithm. Next, estimated data will be compared to historical data using the variance technique, and routes with increasing average monthly cargo volume will be examined in the following phase. The additional aircraft necessary to fill missing capacity will then be estimated based on variations in average monthly cargo volume and adjusted payload of cargo aircraft. The thesis tries to predict the increase in the number of cargo planes and assesses the suitability of P2F conversions from the capacity perspective.

2. Development of Air Cargo Industry

The terms air cargo and air freight are very similar and can often be used interchangeably. According to *Budd and Ison* [2] "*air cargo is the more encompassing of the two and describes two distinct types of operation: the carriage of freight and the carriage of mail by air*." On the other hand, air freight only concerns non-human goods and does not include mail.

Air cargo and air freight can be divided into multiple categories, depending on the nature of the distribution and the desired delivery speed. These categories are express freight and mail, general freight and mail, outsized freight (heavy or bulky loads), specialist freight (temperature-sensitive, extra fragile, live animals), and humanitarian relief freight [2].

Based on these different types of operations, we can group cargo airlines into six segments, which will be discussed in Part 3.1.

2.1. History of The Air Cargo Industry

The first officially recorded freight flight occurred in the United States on 7 November 1910, when pilot Philip Barber flew a consignment of silk from Dayton to Columbus, Ohio. The flight was significant because it was the first time an aircraft was used solely to transport goods, the first time a customer chartered an aircraft for that purpose, and the first time multimodal door-to-door delivery was achieved when the cargo freight consignment was picked up from the Columbus airfield and driven by car to the stores [2]. In the late 1920s, European airlines began delivering airmail and urgent diplomatic and important freight consignments between Europe and their respective countries' overseas colonies, dominions, and mandates at a marginal cost [2].

The first regulations in the air cargo industry came with the 1929 Warsaw Convention. Section III Article 5 required consignors to complete an "air consignment note" (airway bill) detailing the date, origin and destination, personal details of the consignee, and the nature, weight, dimensions, and quantity of the goods to protect cargo consignees and determine air carrier liability in the event of loss or damage [3]. The next step in the regulations happened after World War Two when the US Civil Aeronautics Board (CAB) forbade passenger airlines from selling belly freight below the cost of transporting goods in dedicated freighters, in an attempt to safeguard young air freight carriers from harmful competition [4]. This strategy was implemented because of the opinion that the air cargo industry of the United States is developing rapidly, it requires the maximum deployment of all cargo aircraft, whose costs must be met by other carriers as well [5]. This action eliminated the economic advantages of US belly freight and fostered the growth of all cargo operators as well as the usage of specialized freighter aircraft by passenger airlines [2].

Demand for both passenger and cargo services grew steadily from 1945 to the early 1960s, then accelerated as new long-range, higher-capacity, and more fuel-efficient wide-body jet aircraft entered service, lowering flight costs, and new airline business models developed to boost revenue from transporting cargo [2]. Since the mid-1960s, dedicated freighter aircraft were deployed on the world's major commercial routes, linking Asia with Europe and North

America. These aircraft transport high-value-to-weight perishable commodities, such as consumer electronics, precision-engineered components, fast fashion items, perishable foodstuffs, and temperature-sensitive pharmaceutical products [4]. Dedicated freighter aircraft allowed carriers to transport goods a way faster and further than by road, sea, or rail. Furthermore, the volumes of goods transported were much higher than the volume of belly-hold freight. The times and destinations served by full cargo carriers favorably distinguish their cargo services from normal airlines. Figure 1 shows growth in air cargo only, Figure 2 shows growth in passenger and cargo operations.

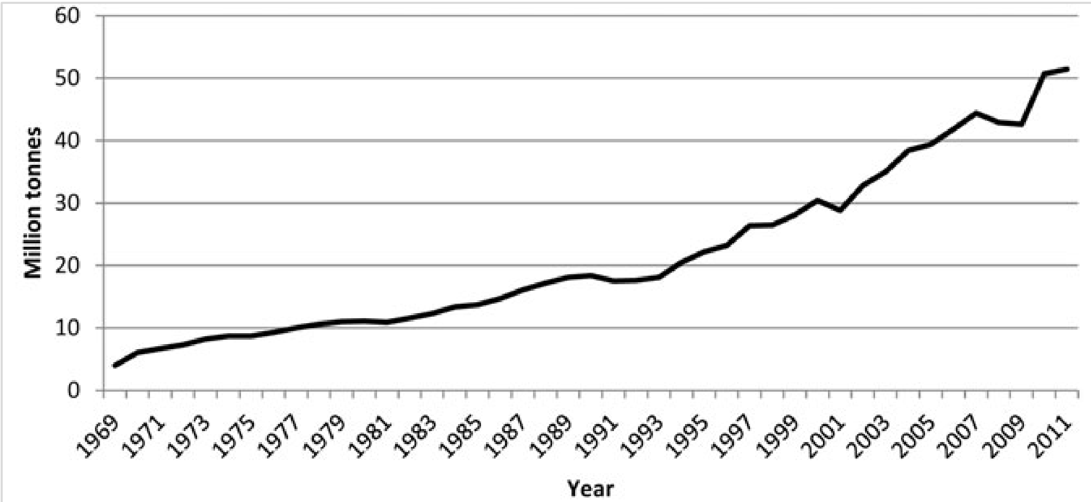

Figure 1, Growth in Global Air Cargo (Million Tonnes) 1969-2011, [2].

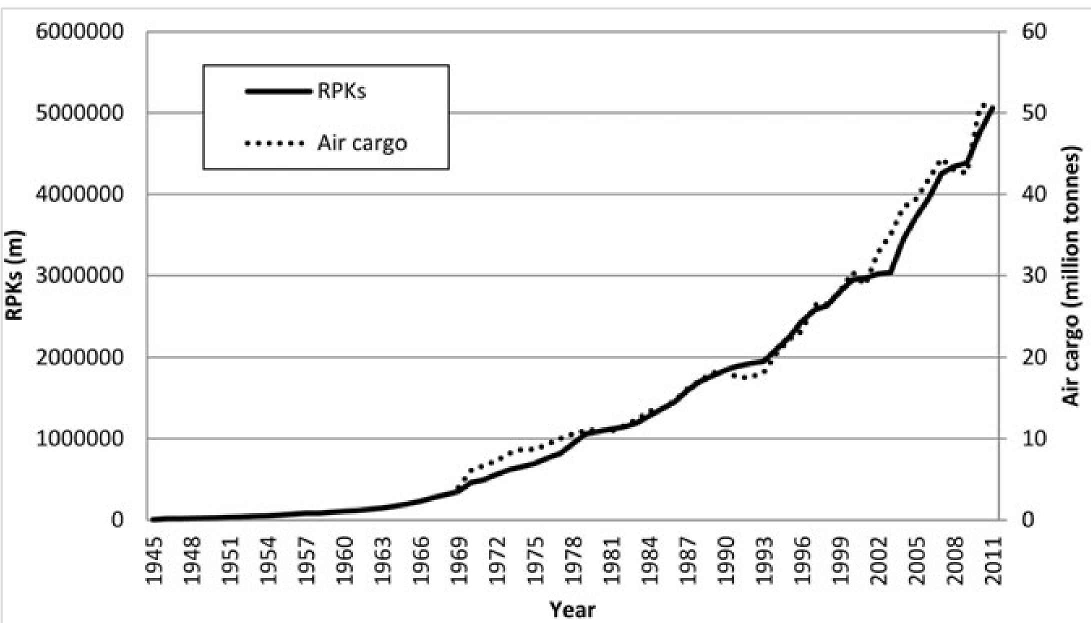

Figure 2, Growth in Global Revenue Passenger Kilometers (RPKs) and Air Cargo (Tonnes) 1945-2011, [2].

3. Air Cargo Characteristics

Following part will focus on the main characteristics of air cargo, which are cargo airlines of different types, cargo aircraft, categories of freighter aircraft and ground infrastructure.

3.1. Types of Cargo Airlines

As stated in Part 2. we can group different cargo airlines with an accent on the type of goods being carried and the way that they carry loads. Airfreight has a strong bi-modal nature because shippers and consignees typically are not located at the airport. Shipments in the 'traditional' or non-integrated air cargo market are picked up by a freight forwarder and trucked to the airport, where they are packed and loaded into the aircraft. The airline flies to the destination airport, where the goods are unloaded and transported by truck to their final destination. Trucks might be operated by the forwarder or as road feeder services on behalf of the airline under a flight number [6]. According to the 2017 IATA study, the ordinary delivery time from door to door for air cargo is 134 hours. However, the airline handles and controls the package movement for 44 hours. In the integrated air freight market, the integrator controls the entire transportation chain from pick-up to delivery, even if the part flown in the middle is not handled by its own aircraft, but by other airlines.

According to *Morell and Klein* [6], we can distinguish the following cargo airlines:

- Scheduled all-cargo carriers
- Charter cargo carriers
- Integrated carriers
- Aircraft, Crew, Maintenance, and Insurance (ACMI) providers
- Combination carriers
- Passenger carriers

Figure 3 shows examples for each type of cargo airline.

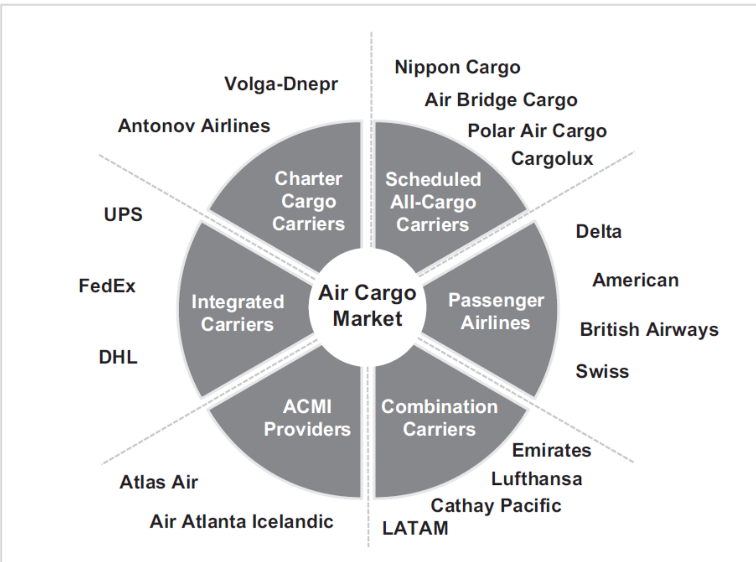

Figure 3, Examples of Carriers for Each Category, [6].

Scheduled All Cargo Carriers

Scheduled all cargo carriers, such as Cargolux or Nippon Cargo, mainly fly freighter aircraft and hence specialize in the transportation of air cargo. They construct their schedule and sell their capacity entirely on the basis of air freight demand [6]. Non-integrated scheduled all-cargo carriers are mainly active on long-haul international markets, often flying intercontinental routes. As stated by Boeing [7], these airlines have 12,5 % of the market share for international air cargo, which indicates their long-haul focus. Their share in the domestic market is lower, only 4 %. In total air cargo industry revenues, they represent 10 % of them.

The nature of their operations has a certain effect on the fleet of those airlines. Due to long-haul routes and the large volume of loads carried, scheduled all-cargo carriers commonly operate spacious aircraft, such as cargo variants of Boeing 747-400, Boeing 747-8, and Boeing 777. Examples of fleets of typical scheduled all-cargo carriers are shown in Table 1.

Table 1, Fleet examples of scheduled all-cargo carriers, [8].

AIRLINE	FLEET (FREIGHTER AIRCRAFT ONLY)
AIRBRIDGECARGO	4X BOEING 747-400, 13X BOEING 747-8, 1X BOEING 777
NIPPON CARGO	8X BOEING 747-8
KALITTA AIR	22X BOEING 747-400, 2X BOEING 767-300
CARGOLUX	16X BOEING 747-400, 14X BOEING 747-8

All-cargo carriers are more sensitive to directional imbalances since they cannot compensate for lost air freight revenues in weak sectors of passenger revenue. However, since air cargo is less sensitive to multistop routing or even deviations from the direct track between origin and destination than passengers, freighter operators frequently design their route network as "big circle routes," through one or more commercial stops in either direction to shorten the length of empty sectors [9]. Figure 4 shows a “big circle route” of Cargolux’ Boeing 747-8F [10].

Figure 4, Example of a "Big Circle Route" Operated by Cargolux' B747-8F, REG. LX-VCL, 24.06.21-26.06.21, [10].

The “big circle route” technique allows all cargo carriers to reduce the impact of directional imbalances to some extent while still achieving the breakeven load factors necessary for a successful aircraft operation. The airline can sell intermediate sectors outside of its own home country to gain additional revenue, depending on the available traffic rights available [6].

Charter Cargo Carriers

Charter cargo carriers also operate a fleet of dedicated cargo aircraft. The main difference between the two types is that charter airlines do not have any planned route network. These companies usually operate their aircraft on a specific request. The aircraft could be used for ad hoc projects, disaster relief or military charters, which frequently provide aircraft appropriate for serving distant airports without handling facilities and transporting some large loads [6].

Whatever the purpose, outsourcing cargo flight operations to a specialized business is often a more cost-effective option. This is due to the difficult and frequently expensive licensing processes for aircraft and crew, as well as the high operating expenses of small fleets of freighters [6]. Because of individual requests of each customer, most often it is not possible to operate charter flights on some defined route. For this type of carrier, the flights are scheduled based on inquiries from the clients.

Two great examples of charter cargo carriers are two eastern European cargo airlines, Volga-Dnepr of Russia and Antonov Airlines of Ukraine. Both companies operate very exceptional aircraft and usually transport oversized loads all over the world. They operate Ilyushin and Antonov aircraft that can be used in very harsh conditions. Antonov Airlines operate the only Antonov An-225 Mriya aircraft built in the world, the largest and heaviest aircraft ever built. Frequently, Mriya is used for missions in different parts of the planet, carrying a diverse variety of exclusive payloads [11]. Figure 5 show an example of the outsized load carried by Anotnov An-225 [12].

*Figure 5, Loading of the mining equipment at Paris-Vatry Airport, Antonov An-225, [12]***.**

Integrated Carriers

Companies in the integrated carriers' sector, such as UPS, FedEx, or DHL, usually evolved from parcel services and they run an all-cargo fleet with different sized aircraft, ranging from smaller turboprop feeders to wide-body dedicated freighters.

The integrated carrier model has four key elements on which it is based: door-to-door transport, fast and reliable transport services, guaranteed delivery time, and tracking systems [6]. Another specific sign of such airlines is the dependence on their hub airports. Hubs are important from the perspective of delivery of ground transport and distribution of parcels to regional airports by smaller feeder aircraft. The majority of the integrated carriers have multiple hubs on different continents (e.g., UPS - Louisville, Cologne, Shenzhen, FedEx – Memphis, Milan Malpensa, Guangzhou, Liege).

The major advantage of integrated carriers is the integration itself. The carrier manages all the steps of the door-to-door delivery process, not only the air cargo part [13]. It results in a customized supply chain, which is controlled through the company's own IT systems, handling and other equipment. The main type of load that is being transported by integrated carriers are parcels that are out for express delivery. To increase their cargo capacity, integrators purchase the free capacity of other cargo and combination carriers. Regarding their own flights, part of the space is reserved for express core business and another part of the cargo space is allocated for general cargo [14].

Integrator aircraft, especially planes that serve domestic and regional routes, which are mostly on the ground during the day, are used at much lower rates, compared to other cargo airlines. FedEx flew its Boeing 757-200F only 2:34 hours per day in 2016, Airbus A310F flew 1:52 hours and A300F 3:56 hours, respectively. The Boeing 777-200F, on the other hand, has been in the air for almost 12 hours a day, closer to the typical industry for new freight operators [15].

ACMI Providers

ACMI providers fly freighters or passenger planes on behalf of other airlines. They supply aircraft, crew, maintenance, and insurance on a per-block hour basis (wet lease) and fly under the lessor's call sign and route authorization, as well as paying for fuel, landing, handling, and overflying [6]. The most well-known ACMI providers are Atlas Air operating their aircraft for DHL, Southern Air, and others. ACMI carriers usually provide aircraft for other types of cargo airlines, and thus are used according to the business model of that exact company.

Combination Carriers

We usually refer to airlines that operate both passenger and full-cargo aircraft as combination carriers, and they sell cargo space to both types of airplane. Emirates, Qatar Airways, Korean Air, Lufthansa, or Air China can be an example of a combination carrier. Some of such companies create a cargo subsidiary (e.g., Lufthansa Cargo, Air China Cargo), others integrate dedicated freighters into their passenger fleet. According to *Boeing's World Air Cargo Forecast* [1], combination carriers have a 36 % market share in air cargo revenues, mainly operating on long-haul international routes.

Combination carriers build up their capacity on passenger aircraft routes: first, they do so to operate passenger routes with lower demand and, second, to accommodate consignments and loads that cannot be carried in the belly hold of a passenger airplane due to its size or the nature of load (e.g. dangerous goods) [6]. One of the most significant characteristics of combination carriers is their flexibility with the availability of cargo space offered. They can build up the market for belly freight and when the demand for cargo capacity will exceed the available tonne-kilometers (ATKs), they can put a dedicated freighter on the route to meet the requests. And in case the demand for air cargo drops, the combination carriers can simply pull the freighter fly [6].

Many combination carriers establish their cargo divisions as a separate business unit, or even as a dependent subsidiary, to ensure that cargo potential is fully realized and is not limited to being a by-product of passenger services. Cargo units are strategically important for major combination carriers, such as Lufthansa, Emirates, and Air China [16].

Passenger Airlines

Passenger airlines are carriers exclusively operating passenger airplanes and selling their belly cargo on passenger trips.

Almost half of the world's air cargo is carried in the belly cargo compartment of passenger planes; however, they only generate 11 % of revenue in the air cargo industry [1]. Aside from primarily European low-cost carriers and regional airlines, almost all airlines that transport passengers also transport air cargo in the lower decks of their passenger aircraft [6]. A sufficient number of passenger airlines offer cargo services on international routes, for the reason that modern long-haul aircraft have high cargo capacity, which is hardly being filled by passengers' luggage and is available for consignments. For example, the Boeing 777-300 offers almost 25 % of the revenue cargo volume of a Boeing 777F freighter [17]. Moreover, widebody is being used more due to the limited weight and space of narrowbody aircraft and due to the cheap and fast competition of ground modes of transport on short routes. However, flights carried out by narrow-body passenger aircraft, such as the Boeing B737 or Airbus A320, can feed hubs, particularly when carrying high-yielding express freight or mail, or can deliver goods to remote airports with poor ground connectivity (e.g., northern areas of Russia or Canada) [6]. Low-cost airlines do not normally carry any cargo due to the limited cargo capacity of their narrow-body aircraft and the complications of their cost-effective operations process.

According to *Morell and Klein* [6], the marginal cost of a kilogram of cargo carried on a passenger trip can be as low as one third of the fully-costed price of a comparable freighter service, depending on the route, fuel rate, and aircraft type. Furthermore, the routes and itineraries of passenger aircraft are determined by passenger demand rather than cargo demand. As a result, passenger carrier cargo departments are frequently forced to offer low prices to generate demand on underutilized freight routes. Passenger flights have lower cargo load factors than freighters. These factors together explain passenger airlines' reduced revenue contribution compared with their respective FTK shares.

3.2. Air Cargo Examples

Cargo transportation is an intermediary service that adds value to another product, but is not typically purchased separately. As a result, the demand for air freight services is determined by the underlying need for commodities that require rapid transportation, as well as the cost and benefits of air cargo compared to alternative modes of transportation [18]. While road and rail services compete with air cargo on short to medium-distance routes, sea freight is typically the only viable alternative mode on transcontinental routes [19].

Air cargo is responsible for carrying only 1 % of global cargo tonnage; however, value-wise, around 35 % of the world's trade is carried by planes [Boeing Air Cargo Forecast 2016]. That gives us a clear picture that highly valuable assets are transported by air and the value per kg of air cargo is usually higher than that of the surface cargo. International component movements are a critical component of the global supply chain economic strategy, making air cargo a perfect mode of transport of these goods [20].

The great majority of aviation cargo shipments are carried out within the Northern Hemisphere. Although the North Atlantic market dominated the air freight industry until the 1970s, the focus has switched to the Asia/Pacific region over the last three decades [6]. More than half of the worldwide freight in tonne-kilometers is being carried from, to, or within this region, with major directional asymmetries. *Zhang and Zhang* [9] specify that '*cargo tends to move from manufacturing to distribution centers or from production to consumption centers'.* Figure 6 shows main directions of air cargo movement in the world.

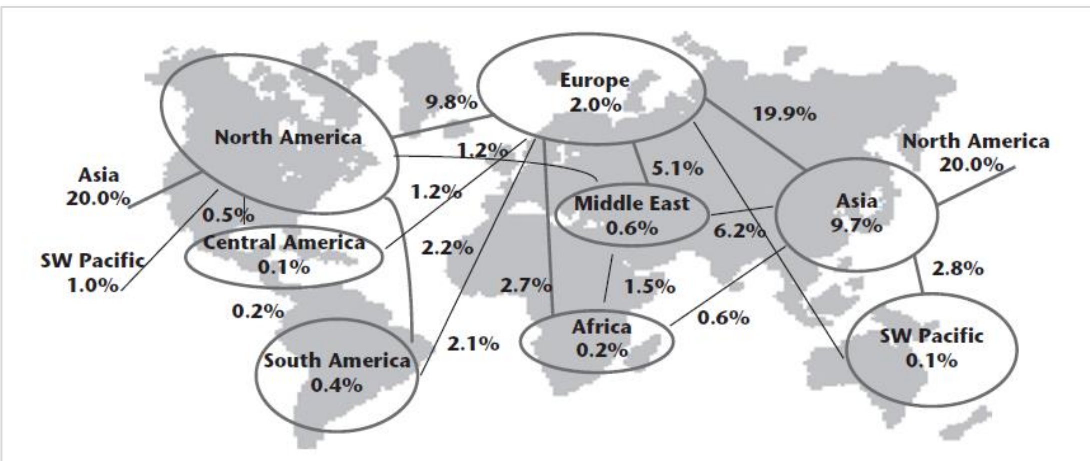

Figure 6, Main Directions of Air Cargo Movement in the World (Tonne-Kilometers), [15].

In comparison to the passenger industry, the demand for air freight is much more diverse. Air cargo shipments can be of any size or weight, ranging from small paper packets to large and bulky packages weighing several tons [6].

According to *Eurostat* (2017) [21], the most common commodities transported by air are:

- Electrical and non-electric machinery
- Clothing and footwear
- Live animals
- Vegetables and fruits (fresh or frozen)
- Flowers
- Perishables
- Chemicals

In addition to identifying individual goods types, air cargo can be subdivided into several categories based on the purpose and urgency of the shippers' mission [22; 23].

- Emergency freight
- High-value freight
- Routine perishable freight
- Routine non-perishable freight

3.3. Types of Cargo Aircraft

Due to the global need for air cargo and the various nature, weight, size and handling requirements of particular cargo consignments, the world's fleet of pure cargo aircraft includes a wide range of aircraft types [2]. The main difference from passenger planes is that cargo aircraft use both decks to carry loads.

Cargo aircraft significantly vary in size and shape, from small turboprop Cessna 208 Caravan, through military freighters such as Airbus A400M or Ilyushin Il-76, to big long-haul widebodies like Boeing 747-8F and Boeing B777F. Outsize heavy aircraft such as Antonov An-124 and An-225, Lockheed C-5 Galaxy, or specialized Airbus BelugaXL (A330-743L), and Boeing 747 Dreamlifter (747-400LCF) are all an honorable mention.

When talking about jet freighters, *Boeing* [1] separates three categories of freighters: Standard (<45 tonnes payload), Medium-widebody (40-80 tonnes payload), and Large (>80 tonnes payload). We will not focus on turboprop aircraft, because they are mainly used by regional airlines and their conversions are not so common.

Examples of aircraft of each category: Standard – Boeing 737, Airbus A320; Medium-widebody – Boeing 767, Airbus A330, Ilyushin Il-76; Large – Boeing 747 and 777, Antonov An-124.

Standard Freighters

Standard-body planes are used primarily by express carriers on local or regional routes, as well as in isolated areas [6].

Medium-Widebody Freighters

The medium-widebody freighters are used by both integrators and non-integrated cargo airlines. Although most are found on regional routes, the McDonnell-Douglas DC-10F was also deployed on long-distance routes [6].

Large Freighters

All-cargo airlines, combination carriers, and integrators fly large wide-body freighters. They often service long-distance markets, while the directional route structure requires shorter multistop flights [6]. Most freighters in this category are factory-built.

Based on the aircraft configuration, we can distinguish the following types of aircraft that carry cargo:

- Manufactured dedicated freighter
- Freighters converted from passenger aircraft (P2F)
- Combi aircraft
- Quick-change aircraft
- Passenger aircraft (lower deck cargo compartment)

Manufactured Freighters

As mentioned before, manufactured or factory-built freighters dominate in the large freighters segment. Only two models in the large segment that are still being produced are Boeing 747-8F and Boeing 777F, but the last produced B747-8F is going to be delivered to Atlas Air in 2022 [24].

In the medium segment, most of the operating aircraft are converted, as the only medium-widebody freighters produced at the time of writing are Boeing 767-300F and Airbus A330-200F [17; 25].

Speaking about the standard freighter category, neither of the aircraft manufacturers produces aircraft in this segment at the time of writing (2021). New factory-built freighters in this category are often too expensive to compete, given the abundant conversion feedstock of low-value narrow-body passenger aircraft available for the P2F conversion [6].

The main advantage of factory-built aircraft is the fact that the customer receives a new and fresh airframe that can be used for many years to come, without having to worry about some major maintenance. Another attractive factor is that factory-built freighters own specially designed elements for cargo operations, such as the Boeing B747F nose door, the Ilyushin Il-76 rear ramp. All such modifications facilitate cargo loading and unloading and shorten turnover times at airports. Among the disadvantages, the high purchase cost of the aircraft and possible waiting in the order line can be mentioned.

Figure 7 shows the nose door of a factory-built Boeing 747-8F freighter [26].

Figure 7, Nose Cargo Door of a Boeing 747-8f, Displayed at the 2011 Paris Air Show, [26].

Converted Freighters (P2F)

Approximately half of the jet freighters were originally converted from passenger planes. Speaking about jet aircraft, the proportion of conversions varies by aircraft type, but typically is the biggest for the standard freighter category and decreases with size. Not all passenger models lend themselves well to conversion: cross-sections, cabin heights, cargo door potential, and volume/payload ratio may all conspire against a successful operation [6]. Examples of successful models for the P2F conversion are B737, A320/321, B767. Examples of aircraft not suitable are A340, A319.

The process of conversion is described in Part 5.

According to *Morell and Klein* [6], the main factors that determine the extent of P2F conversion are:

- The availability and price of suitable conversion programmes
- The price of passenger aircraft suitable for conversion
- The payload/range characteristics of the conversions
- Input prices, especially for fuel and capital

The intended use of the aircraft also plays a role: a new freighter's greater range with a full payload may not be necessary for an airline that intends to consolidate loads by operating multi-sector routings. Additionally, an integrator who primarily intends to fly nightly with low daily aircraft utilization can select a converted cheap capital cost aircraft [6]. ATSG, one of the largest operators of B767 freighters, indicated that they are not interested in factory-built freighters of that type since *'the converted freighter does very much the same thing as a brand new one at about a third the cost'* [27]. In summary, converted freighters are available to carriers at a more attractive price, but require more maintenance within operations due to their age. Furthermore, the performance level of converted airframes is comparable to factory-built freighters, but P2F freighters may be missing some special design elements.

Combi Aircraft

A Combi is a multi-compartment airplane designed to transport both passengers and cargo on the main deck, divided by a bulkhead. Combi aircraft were popular on long-distance routes where passenger demand would only have justified a smaller aircraft, but cargo demand was greater than standard belly load [6].

After the SA295 South African Airways flight accident, tighter regulations on combi aircraft were implemented. Due to the significant expense of following these requirements, some airlines elected to convert their combi aircraft to all-cargo or full-passenger configurations [6]. Currently, the operation of combi aircraft is very limited; only a few operators still use them.

Quick-Change Aircraft

Like the combi and dedicated freighters, the quick-change aircraft had a reinforced main deck that could be shifted between passenger and freight roles and back. The roller bearing fitted on the main deck allowed the insertion of palletized seats and galleys, and the entire process of resuming passenger operations was anticipated to take only 30 minutes. In fact, this was perhaps overly optimistic, but it permitted the same aircraft to operate passenger flights during the day and cargo flights at night, resulting in extremely high daily utilization. For example, Martinair's MD-11CF operated in full passenger configuration in summer and all-cargo aircraft in winter thanks to various seasonal peaks for passenger and freight [6].

Passenger Aircraft

Standard-body passenger aircraft, except for the A320/321, are unable to load containerized or palletized cargo. Therefore, the belly of the cargo and the little parcels are of great interest [6]. Usually, these aircraft carry bulk cargo, which is secured by a safety net. The share of belly capacity in total air cargo capacity continues to expand, driven by passenger demand. Passenger airlines can offer space-based marginal costing, which is 60 to 70 % less than what is required to cover the full cost of a freighter [6]. However, the percentage of cargo carried on board of a passenger aircraft, as measured by the international FTK, has remained relatively steady throughout the years, hovering around 50 %, reaching 54 % in 2019 [1].

On the other hand, belly cargo has several disadvantages compared to full-cargo aircraft. *Boeing* [1] determines five of them:

- Most passenger carriers do not serve key cargo routes
- Long-haul passenger schedules do not meet shippers’ time requirements
- Freight forwarders prefer palletized capacity, which is not available on standard body aircraft
- Passenger planes cannot carry hazardous goods and project cargo
- Payload-range considerations in the passenger sector limit cargo carriage

The main asset of the passenger aircraft is that cargo can be carried to destinations with low cargo demand. Normally, a dedicated freighter would operate on such routes with a flat load factor, resulting in low or even negative yields. However, this is not an issue for passenger aircraft, as their main source of revenue is PAX transportation and they have an average load factor of 30 % [1].

3.4. Airports and Cargo Infrastructure

Airports, as the interface between land and sky, play a critical role in the delivery of safe and efficient air cargo services, and many airport operators have become increasingly aware that cargo operations can help supplement revenues derived from passenger services [2]. Historically, the first cargo airports began to grow near large manufacturing centers and large metropolitan areas. Other cargo airports, such as Anchorage, became important transit and refueling points on longer transatlantic or other major global routes. These original cargo hubs were joined by a new generation of cargo airports that were built specially to handle the big volumes of cargo frequently coming to this area [2]. The airports are a crucial element for this paper, as they are providing data about cargo flows, which will be used in the paper later to estimate and forecast the growing demand for cargo. Basing on this forecast, the estimated ATK’s will be defined.

Table 2 shows the world’s busiest cargo airports in 2020, according to *ACI* [28].

Table 2, World's Busiest Cargo Airports by Cargo Loaded and Unloaded, [28].

AIRPORT	CARGO LOADED AND UNLOADED [TONNES]
MEMPHIS (MEM)	4 613 431
HONG KONG (HKG)	4 468 089
SHANGHAI (PVG)	3 686 627
ANCHORAGE (ANC)	3 157 682
LOUISVILLE (SDF)	2 917 243
INCHEON (ICN)	2 822 370
TAIPEI (TPE)	2 342 714
LOS ANGELES (LAX)	2 229 476
DOHA (DOH)	2 175 292
MIAMI (MIA)	2 137 699

As for European hubs, which this thesis will focus mainly on, the top cargo airports in 2020 are shown in the Table 3 [29]:

Table 3, Europe's Busiest Cargo Airports by Cargo Loaded and Unloaded, Eurostat, [29].

AIRPORT	CARGO LOADED AND UNLOADED [TONNES]
PARIS (CDG)	2 049 690
FRANKFURT (FRA)	1 911 289
AMSTERDAM (AMS)	1 455 404
LEIPZIG (LEJ)	1 377 403
LIEGE (LGG)	1 026 421
LUXEMBOURG (LUX)	905 294
COLOGNE BONN (CGN)	841 694
MILAN (MXP)	516 439
BRUSSELS (BRU)	511 913
MADRID (MAD)	371 110

As can be seen from the statistics, the world's and Europe's busiest international airports are all combination carrier hubs, with most running a substantial fleet of freighters in addition to passenger flights (Paris, Frankfurt, Hong Kong), closely followed by the cargo hubs used by integrators and all-cargo carriers (Leipzig, Memphis, Liege, Louisville, Anchorage). A conclusion can be made that integrators and all-cargo carriers mainly operate from secondary airports with low passenger traffic and a smaller number of movements to minimize delays because delivery times are one of the most important factors in the air cargo industry.

Airport Infrastructure

The physical facilities or infrastructure of an airport are intended to speed up the flow of trucks, unit load devices (ULD) and their shipments, and aircraft [6].

In addition to the usual aircraft infrastructure, the terminal must be able to handle cargo carried on passenger planes, with easy access to ground infrastructure, such as roads, rail terminals, and truck parking. Sometimes, a cargo transshipment unit can be located at the terminal. The full cargo terminal requires its own aircraft parking stands, ramp handling equipment, and handling and storage facilities within the facility and must be ideally connected to ground modes of transport [6].

Cargo Terminals

Cargo terminals or warehouses serve as the link between road feeders (trucking companies) and airplanes. Shipments coming by truck or air are assembled on pallets or loaded into containers; reaching the destination of the flight, the ULDs are disassembled for further distribution. As a result, cargo terminals must include space for handling activities and, in addition, have quick landside access via truck gates. The ULDs are stacked in an automated stacker system in larger terminals and recovered when the aircraft is loaded [6]. Terminals provide distinct rooms for import and export, freight, security screening, dangerous products, temperature-controlled zones, stables for live animals, and an enclosed area for customs inspection. Cargo terminals can also provide secure storage areas for valuable shipments [6].

Usually, the cargo terminal is owned by the airport, by one of the airlines operating from the airport, or by a third-party handling provider, such as Menzies Aviation or Swissport.

Modern cargo terminals require the latest and most reliable tracking system and other measures of automatization. Barcoding and reading have been utilized for many years; however, it suffers from misreading, damaged labels, and other issues. RFID technology has the potential to solve many of these problems. RFID tags are created by attaching a computer chip to the consignment or ULD and adding a circuit that communicates data to radio antennae. These must be mounted on loaders and sorters. Passive tags do not have batteries and reflect radio signals back to the sender through the LF, HF, and UHF radio bands, thus identifying their location. Other forms of automation include combined volumetric and weight scanners, high-speed sorting, and mechanization of construction and delivery processes [6].

4.Current Situation in The Air Cargo Market

As of the moment of composition (2021), the aviation industry is still recovering from one of the biggest crises in its history, which began in late 2019 in mainland China with the outbreak of SARS-COV2 or more commonly COVID-19. The COVID-19 crisis was a severe shock to the global economy, causing havoc in practically every organization in the world.

Crises of all kinds are the most significant turning points in the world's various fields, perhaps the most well-known of which are the 1929 crisis and the 2008 crisis, both of which caused the bankruptcy of a large number of banks and included the ramifications of the world's largest economies. However, there have been health crises such as epidemics and diseases witnessed throughout the world over the previous century, such as the Spanish flu in 1920, SARS outbreak in 2002-2004, and the swine flu in 2009, and others that killed millions of people, although the economic consequences were relatively minor [30]. But COVID-19 had a devastating economic effect on many industries and, in addition, countries. Aviation was one of the industries most affected by the global pandemic. Losses in the sector have been enormous. The International Air Transport Association (IATA) expects that worldwide airlines will lose 118 billion dollars in 2020 [31]. For example, by May 2020, US airlines had cut foreign flights by 93 % and domestic flights by 74 %, and airports were processing 95 % fewer passengers than the year before [32]. Airlines around the world had to park most of their fleets and even retire some older and less efficient aircraft, such as the Airbus A340 and A380 and the Boeing 747 [33; 34] [35].

The aviation cargo business has also been hit by a capacity crisis. In April 2020, global air freight demand fell by 27.7 % compared to April 2019. To make matters worse, capacity fell at a 42 % pace. As a result, even with reduced demand, there was insufficient capacity to meet this demand, mainly due to the loss of belly cargo from the stopped passenger aircraft [36]. However, compared to passenger-carrying carriers, air cargo is regarded a "bright spot". The significant capacity shortfall, principally caused by the loss of belly cargo, resulted in a 30 % increase in fares for the year [37]. Cargo rates were rising and decreasing, depending on the pandemic situation and time of year, typically increasing during the pre-Christmas season and declining in summer, when more passenger aircraft were operated. Also, some passenger airlines have used their full passenger aircraft to operate only cargo flights, carrying loads both on the main and lower decks. Freight transportation on the main deck of a passenger airplane required certain exemptions from the regulators. For example, the FAA granted such exemption to carry cargo on the main deck without any passengers on board, which was extended until the end of July 2021 [38]. Despite price volatility, the air freight business appears to have used flexibility in transportation methods and federal rules to remain successful [39]. In general, cargo revenues are expected to remain high in 2021, with record revenues of USD 138 billion, accounting for 23 % of total global airline revenues, more than double the average share [37].

Figure 8 shows changes in traffic, capacity, yield and revenue of air cargo in 2020 [1].

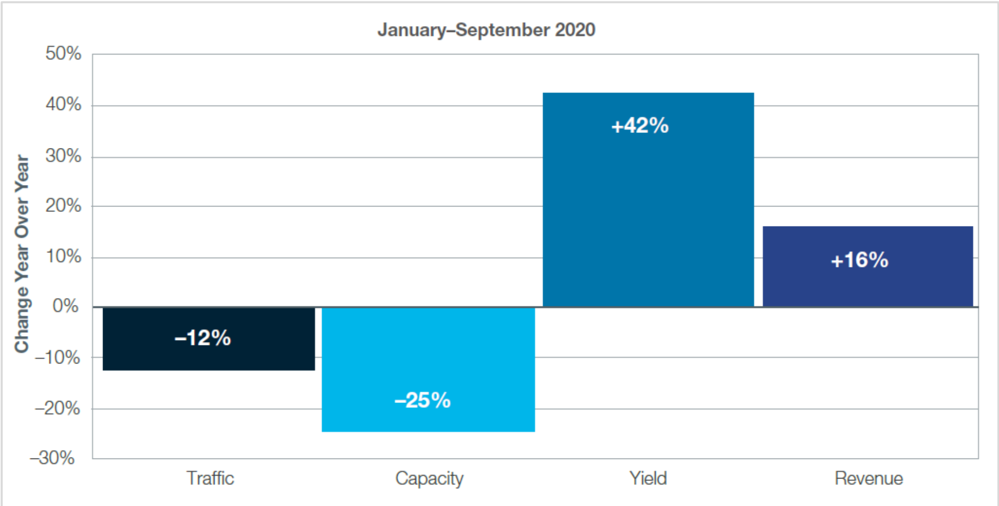

Figure 8, Traffic, Capacity, Yields and Revenue in air cargo in 2020, [1].

In 2021, air cargo continued progressing, even more, overperforming at some points. In May 2021, cargo tonne kilometers (CTKs) increased 9.4 % in May 2019 compared to precrisis levels. owever, this is a reduction from the 11.3 % growth rate witnessed in April, with the month-on-month increase in seasonally adjusted traffic (0.4%) also slowing [40]. Air cargo is now benefiting from incredibly busy container supply chains. According to Sea-Intelligence, global shipping schedule delays increased dramatically, to the level corresponding to an expected 8.6 % loss of capacity on the available fleet in April 2021. Capacity-wise, in May 2021, international ACTKs were down 11.1 % compared to precrisis levels, but on a mild increasing trend. Although international passenger traffic (bellyhold capacity) remains constrained, both passenger planes and dedicated freighters contributed to gains in May 2021 [40].

As can be seen in Figure 9 both dedicated cargo capacity and belly cargo capacity are steadily growing, but the level of total cargo capacity is still low enough. This results in high load factor, which by far exceeds prepandemic levels. The industry-wide cargo load factor was 57.2 % in May 2021, up 10.0 % in age points (ppt) from May 2019. However, the international cargo-load factor in May 2021 was record breaking – 65 %, a new high for any month of May [40]. While the epidemical situation in many parts of the world remains uncertain, with new COVID variants being discovered and new regulations being imposed, it is hard to predict when the bellyhold capacity will return to its precrisis levels. Considering that air cargo (and the air transport industry overall) was growing before the pandemic, we can conclude that the shortage of cargo capacity will continue unless more cargo aircraft are available around the world. This can be achieved by either a new factory-built freighter or by P2F conversions.

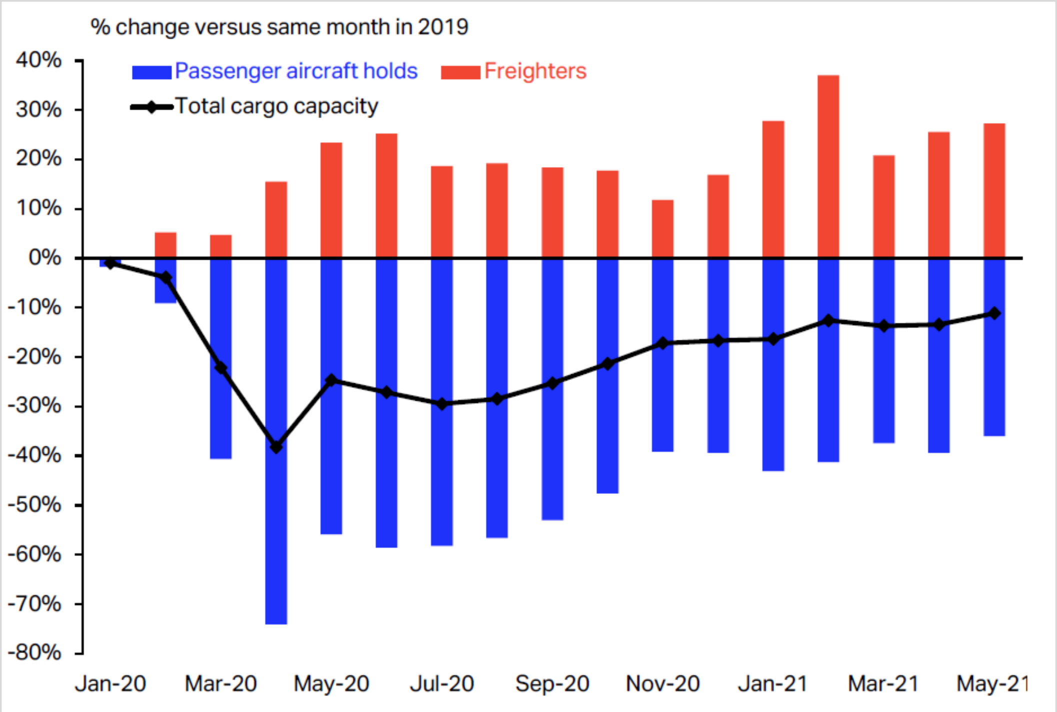

Figure 9, International freighter and bellycargo capacity growth, [40].

4.1. Production and Conversion Rates

Factory-built freighter production rates are generally lower than the number of passenger planes built. Currently, the civil freighter market segment is mainly dominated by two industry giants, Boeing and Airbus. Also, the ATR company produces its dedicated ATR 72-600F freighter with the first aircraft delivered to FedEx in December 2020 [41]. However, this aircraft is used mainly by express carriers as a 'feeder' and the production numbers are not that high now. Besides, such companies as Embraer or Antonov can be mentioned among producers of factory-built freighters, but almost all of their aircraft are used in military and other special operations. For this reason, the focus will be on Boeing and Airbus aircraft suitable for conversion.

Factory-Built Freighters

By 2020, Airbus has produced only one type of freighter, the A330-200F, as mentioned in Chapter 3.3. (Types of cargo aircraft). According to *Airbus*, there were 38 such aircraft built and all are delivered to customers [42]. However, Airbus is reportedly in talks with some potential clients over the potential launch of the A350F program [43]. By introducing and producing the cargo variant of their latest passenger jet, Airbus is hoping to compete with Boeing in the cargo segment, which is heavily dominated by the US company, namely with the very popular Boeing 777F.

Boeing, on the other hand, is certainly successful in the cargo market, producing three dedicated freighter models, 747-8F, 777F and 767-300F. Delivery and order numbers are quite high for these aircraft, as can be seen in Table 4 [44].

Table 4, Unfilled Orders and Deliveries of Boeing Cargo Aircraft, [44].

AIRCRAFT	UNFILLED ORDERS	DELIVERED*
747-8F	10	97
777F	46	209
767-300F	53	164

**delivered since the beginning of each model's production*

Converted Freighters

Because of the lower prices and long queues for new cargo aircraft, the operators often decide to use cargo airplanes converted from passengers. Definition of the P2F aircraft and the modification process are described in Part 3.3. and Part 5.

Conversion is performed by certified conversion houses and by the manufacturers themselves in collaboration with the convertors (e.g. Airbus and EFW). Boeing offers 767-300BCF and 737-800DCF converted freighters to their customers, Airbus produces A321P2F and A330P2F.

The exact numbers of how many planes are converted each year and how many orders do conversion houses receive are hard to estimate, due to the wide variety of companies that are in the P2F business. Unfortunately, these companies do not usually share their production and order numbers in open source, but according to JADC, in 2019 981 planes were converted from passenger to freighter [45]. Additionally, Boeing has reportedly received 150 commitments (orders + option orders) for its converted 737-800BCF by January 2021, and, to meet the growing demand, Boeing has added three more conversion lines – in Costa Rica, Guangzhou, and Singapore [46]. The current situation in the air cargo market is highly favorable for P2F convertors, which are getting more and more orders lately. Just in June and the first half of July 2021, lessor BBAM ordered 12 converted Boeing 737-800 [47], Aero Capital Solutions has signed up for 7 same aircraft [48], Air Transport Services Group has announced a deal to purchase two A321P2Fs [49], and Lufthansa will permanently convert its two A321s for the sake of delivery e-commerce shipments on intra-European routes [50]. One of the biggest conversion houses, Israel Aerospace Industries (IAI), is also expanding its network of conversion facilities by opening new spaces in Seoul (Boeing 777 conversion site) and their first site in Europe at the MRO center in Naples (Boeing 737 conversion site) [51; 52]. The Seoul facility is more interesting because it will serve the newly introduced Boeing 777 conversion program, 777-300ERSF. At the end of June, IAI had received three more orders for its conversion from GECAS, which now has 18 firm orders and 12 options for this aircraft [53]. The 777-300ERSF has the potential to become very popular among cargo carriers due to the aging Boeing 747-400 and MD-11 freighters, which will need to be replaced in the near future. For instance, Emirates' president Tim Clark has confirmed that the airline is 'very seriously considering' converting some of its B777–300ERs that are nearing the end of their passenger lifetimes [54].

This part can be summarized with the following points.

- Boeing still has to deliver more than 100 factory-built freighters in the near future
- 981 aircraft were converted from passenger to freighter in 2019
- Boeing has received 150 commitments for a converted 737-800BCF freighter
- Operators are actively ordering converted aircraft
- Convertors are opening new facilities in order to fulfill the demand for converted freighters
- Some carriers are considering the order of converted freighters

4.2. Future Prospects

Apart from the long-term trend of dedicated freighters carrying more than half of worldwide air cargo traffic despite the increase in widebody passenger fleets, the COVID-19 epidemic has underscored the necessity of main-deck freighters in our global air transportation system. Although increasingly capable passenger widebody planes have helped the growth of the air cargo business over the last decade, dedicated freighters are expected to continue to account for at least half of all global air cargo traffic [1]. According to *Boeing* [1] air freight (including express traffic) is projected to grow at 4.1 % per year while airmail will grow at 1.7 % per year through 2039. Over the next 20 years, global aviation cargo traffic will more than double, rising from 264 billion RTKs in 2019 to 578 billion RTKs in 2039. Airbus has a slightly more moderate forecast, predicting that air freight will grow 3.6 % per year [55].

Fleet Forecast

Freighters account for less than 8 % of the overall world's commercial jet fleet, yet carry more than 50 % of all air freight traffic. Airlines that operate dedicated freighters produce over 90 % of all air cargo revenue. Freighters complement an airline's cargo operations, allowing it to compete more successfully [1].

The fleet of dedicated freighters is expected to grow as the demand for freight transportation by air increases. *Airbus* [55] estimates that the world's freighter fleet will grow by over 50 % to more than 2 800 aircraft by 2038 from around 1 800 cargo aircraft that are currently operating. The largest freighter fleet today, and in 20 years, will be based in North America with 40 % of the aircraft and Asia-Pacific with approximately 30 % in 2038, up from 20 % in 2018. *Boeing* [1] is being more optimistic than the European company again, forecasting 3260 cargo airplanes in service by 2039, which signifies an increase of over 60 %.

Both manufacturers forecast that around 2 500 newly built and converted aircraft will be delivered to customers in the next 20 years. Roughly 60 % of these aircraft will be necessary for replacement, and the other 40 % will be required for the fleet growth. *Boeing* forecasts that 930 of these freighters will be factory built and others will be converted. *Airbus* estimates that 850 newly built freighters will be in service by 2038. Both *Boeing and Airbus* agree that production numbers of medium-widebody freighters will be slightly higher than the number of factory-built large-widebody cargo airplanes, but these numbers are comparable. Almost all aircraft in the standard-body segment are expected to be obtained through P2F conversions [1; 55].

Figures 10 and 11 demonstrate fleet forecast by Boeing and Airbus [1; 55].

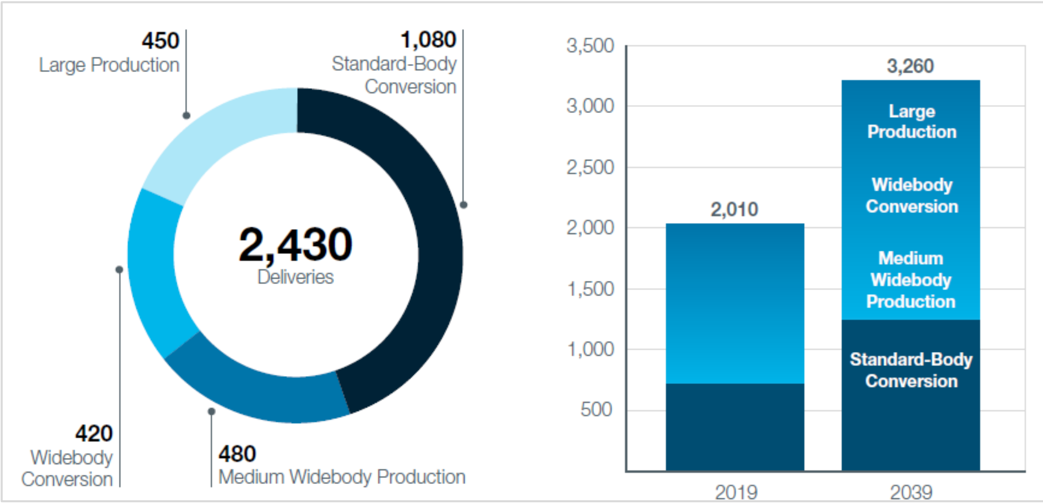

Figure 10, Boeing Fleet Forecast by 2039, [1].

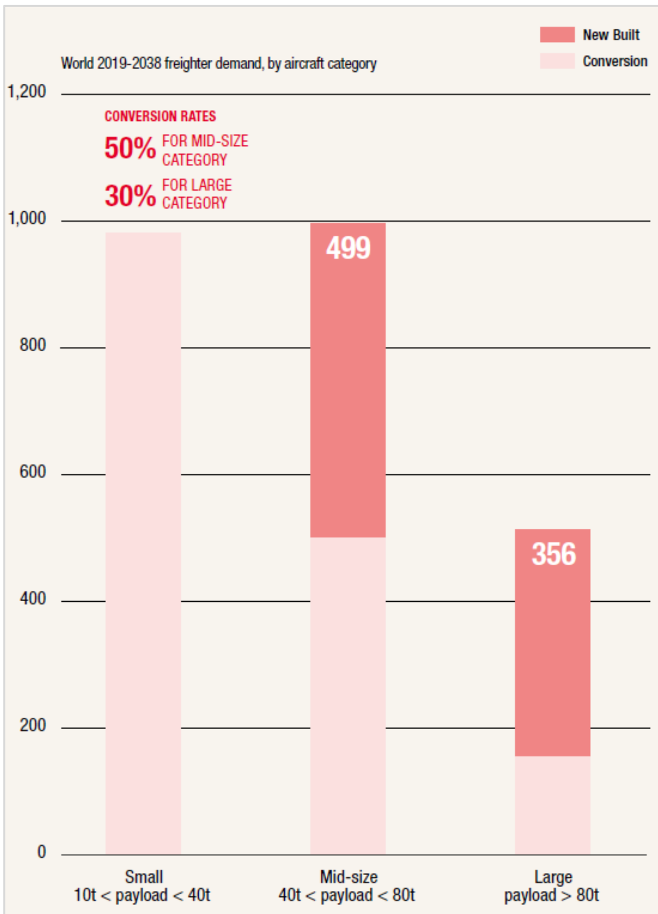

Figure 11, Airbus Fleet Forecast by 2038, [55].

Relying on all available sources, the air cargo will grow over the next two decades, mainly driven by the development of e-Commerce and global express delivery services. E-Commerce helped air cargo to grow during the COVID-19 crisis (among other transported goods, e.g., medical equipment and others). Also, both manufacturers consider that all of the delivered standard-body freighters will be converted from passengers, and this fact is really engaging. There are several reasons for this estimate, the main being the absence of the factory-built freighter among the model range of both Boeing and Airbus, plenty of feedstock available on the market (there were more than 200,000 single-aisle jets in operation by the end of 2019), and low acquisition and modifications costs (compared to medium-widebody and large-widebody freighters). It could possibly change with other manufacturers, for example COMAC, introducing brand-new standard-body freighter models, or by Boeing and Airbus doing so, but at this point, there are no exact plans about designing and introducing such airframe. For all the reasons mentioned above and because of the forecasts of the two main players, we can conclude that the conversion of P2F will become even more attractive for operators and required by the constantly growing air cargo market.

5. The Process of P2F Conversion

In the aviation industry, we usually refer to refurbishing and modifying older passenger aircraft as to a passenger-to-freighter conversion, or simply as P2F. The term P2F will be used further in the text. P2F conversion is a well-known process in the industry - the first converted airplane was operated by the American Railway Express. The company used a converted bomber manufactured by Hadley Page, as they were trying to transport freight from Washington, DC to Chicago in the United States of America [56].

A significant leap in the development of aviation took place during and after the Second World War. The progress made by military engineers in aviation has also influenced the civilian sector, and P2F conversions were no exception. After the war, there were many ex-military aircraft, such as Douglas DC-3 and Douglas DC-4, available on the market, and civil carriers have taken advantage of it [56].

Later on, the P2F market became richer and wider with new airframes that came into operation during the 20th century. The modern history of P2F conversion programs began approximately 40 years ago when one of the key players, IAI, opened its passenger-to-freighter conversion division [57]. They were followed by another major modern company, EFW, which has more than 25 years of experience in the field of aircraft conversions [58]. These two companies, mentioned in the text above, are the biggest; we will take a closer look at the conversion companies in the next part.

5.1. P2F Conversion Companies

As mentioned before, there are several companies providing solutions for P2F conversions, the largest being Israel Aerospace Industries (IAI) and Elbe Flugzeugwerke (EFW). Usually, these companies do not focus only on the P2F process. They can also provide MRO (Maintenance, Repair, and Overhaul), develop their own systems and products, perform modification and refurbishment of the aircraft's interior, etc. The next paragraphs will describe two major conversion houses.

Israel Aerospace Industries

Israel Aerospace Industries, or IAI, is a large aerospace and aviation corporation, which develops aerial and astronautic technologies for military and civilian use. As of 2019, it employs 14 922 people [59]. IAI is wholly owned by the Israeli government. Civil aircraft, drones, combat aircraft, missiles, avionics, and space-based technologies are designed, developed, produced, and maintained by IAI [60].

Although the main focus of IAI is military technologies, the company is also a very strong player in the civil sector. They specialize in converting Boeing passenger airplanes to freighter. IAI has several partner conversion sites around the world, for example, in Mexico City [61] and Seoul [51]. In 2017, IAI has delivered 22 converted airplanes to its customers [61].

At the time of composition (2021), IAI provides the following P2F conversions:

- Boeing 737-700BDSF
- Boeing 737-800BDSF
- Boeing 747-400BDSF
- Boeing 767-200/300BDSF
- Boeing 777-300ERSF

Figure 12 shows the first prototype of the Boeing 777-300ERSF in the middle of its maiden flight.

Figure 12, Maiden Flight of a Boeing 777-300ERSF Prototype by IAI, [51].

Elbe Flugzeugwerke

Elbe Flugzeugwerke GmbH (EFW) is a German aerospace company located in Dresden. EFW is a joint venture between Airbus, a European aerospace corporation, and ST Aerospace, a Singapore-based company. The company's main focus is the maintenance and conversion of aircraft into dedicated cargo and aerial refueling tanker variants. In addition, EFW supplies Airbus with fiber composite parts for the interiors of airplanes [62]. For 2019, the company had 1,800 employees and throughout its history they have delivered more than 200 converted aircraft to 40 customers worldwide [63].

At the time of composition (2021), EFW provides the following P2F conversions:

- Airbus A300/310 P2F
- Airbus A320/321 P2F
- Airbus A330 P2F

These two companies are the biggest providers of P2F converted airplanes. Among other companies, which perform services in this field, Xiamen facility of HAECO group (Boeing 747-400BCF and Boeing 757-200SF) [64], Pemco Conversions with the main base in Tampa, United States (Boeing 737-700, Boeing 737-400, Boeing 737-300) [65] and a number of other companies.

Also, Boeing provides P2F solutions using their own production capacity. American corporation provides converted Boeing 767-300BCF and Boeing 737-800BCF, these two models being very popular among cargo carriers.

5.2. Main Requirements for the Aircraft to be Converted

In view of P2F transformations, airlines tend to focus on real and direct aircraft operating costs. Including initial aircraft acquisition costs, conversion costs, leasing rates, maintenance costs, and whether the available payload of the aircraft will be suitable for the intended role of the converted cargo aircraft [66]. The cost factor is crucial, especially for the category of narrow-body P2F aircraft, which are operated not only by express carriers but also by niche regional airlines in different parts of the world [67].

Furthermore, there are two more factors that must be met in order to create an active P2F market. The first is that there must be substantial demand for air freight services, and the second is that enough appropriate aircraft (feedstock) are available at costs that are low enough to justify their transformation into a complete freight configuration [68].

The approximate age of the aircraft that is suitable for conversion is 15 to 20 years [6]. An ideal candidate for the P2F conversion should have high production rates as a passenger aircraft to provide high feedstock. An optimal number is regarded as at least 200 passenger units. The type of aircraft is also expected to lose its attractiveness to passengers, resulting in reduced residual values. Additionally, a conversion source is needed for the prospective aircraft. The conversion could be provided by the original equipment manufacturer (OEM), or, on the other hand, by a trusted and reputable third-party maintenance organization or a conversion house [66].

The most common aircraft models that are being converted from passenger to freighter are the A320/321 and A330 manufactured by Airbus and larger versions of Boeing 737 (700-, 800-, 900-), Boeing 747-400, Boeing 757, Boeing 767, and finally Boeing 777. At the time of writing, the first converted Boeing 777-300ERSF is in the middle of the testing and certification process with Israel Aerospace Industries.

5.3. Modifications during the P2F Process

Various structural changes must be performed on the aircraft in the P2F conversion. Due to the complexity of the whole procedure, these processes can be conducted by a limited number of licensed companies worldwide [2], such as those mentioned in the text above.

According to *Berlowitz* [69] every passenger-to-freighter conversion is based on four main steps:

1) Pre-conversion ground and flight tests with an aim to collect data about structural performance of the aircraft (wind deflections, fuselage pressurization, verification of the strains at critical loads and locations) and about the performance of the environmental control system.

2) Design of the forthcoming and required structural and interior modifications, determined by finite element models.

3) Mechanical, electrical and avionics system development, qualification, and certification of new and updated systems, according to the guidelines of the main aviation industry standards, such as SAE ARP 4754 (Systems), DO-254 (Hardware), DO-178C (Software), and others.

4) Post-conversion ground and flight tests in order to indicate airworthiness of the modified aircraft and meet the requirements set by FAA 14 CFR Part 25 regulations (Airworthiness standards: Transport category airplanes).

Figure 13 shows example of major conversion features on Airbus A321P2F by EFW [70].

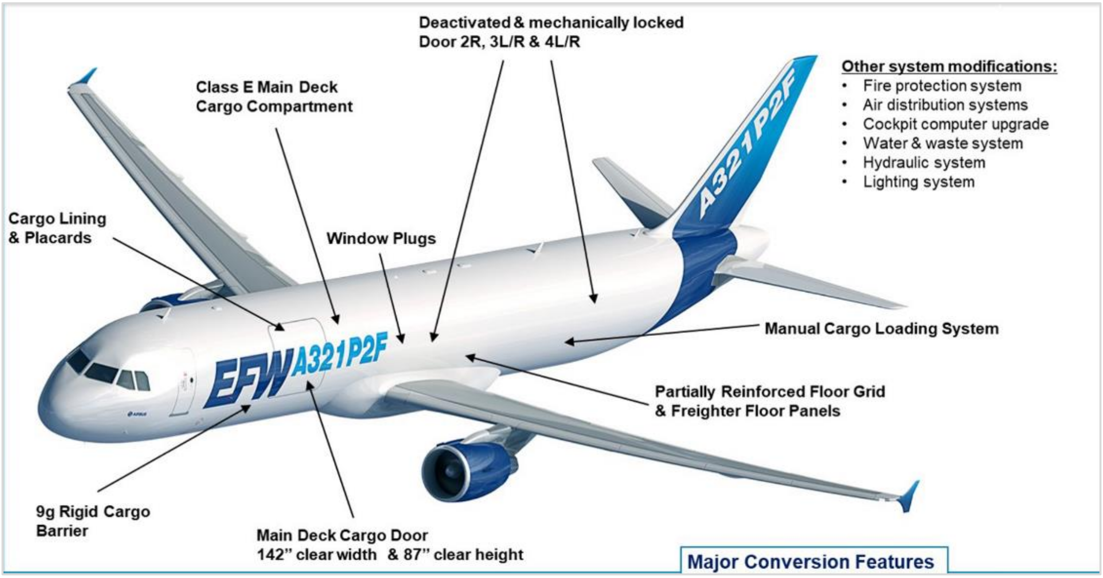

Figure 13, Major Conversion Features Shown on Airbus A321P2F Modified by EFW, [70].

5.3.1. Flight Deck Modifications

The working place of the pilots remains almost completely unchanged during the P2F conversion. Minor changes made include removal of the recirculation fan switches, added smoke detection control panel to the main deck cargo compartment, added lavatory and additional smoke detection control panel, added annunciation to the main deck cargo door [69].

5.3.2. Structure Modifications

The structure is designed to meet the increased design weights and heavy cargo loads on the main deck while preserving the exterior geometry, flying characteristics, and performance of the aircraft. The changes include replacement or reinforcement of all floor beams, posts, seat tracks, intercoastal and floor panels. Structure upgrades also include the addition of additional tension ties and frame reinforcements. To improve structural integrity, some of the new floor beams are machined from aluminum plates. The frame of the fuselage is also strengthened [6; 69].

The structural changes are supported by a number of analyses. All conversions use the same substantiation technique, which includes [69]:

- ***Load analysis*** ensures that the weight and center of gravity limitations introduced to cargo loading do not exceed the design loads of passenger aircraft.
- ***Flutter analysis*** contains a provisional dynamic analysis of the entire aircraft model before and after conversion, with the goal of demonstrating minor changes in the relevant frequencies and mode shapes.
- ***Damage Tolerance analysis*** is performed based on FAA's AC 91-56B, AC 25.571D, and the structure repair manual for the purpose of complying with FAA 14 CFR or EASA CS 25.571.
- ***Finite Element analysis*** is aimed at the establishment of the highly accurate loads distribution. This analysis uses the finite element model (FEM) and significant structural parameters (internal load, mechanical constraints, flight envelope, gear, and main deck floor loads, etc.) to validate structural changes of the aircraft.

5.3.3. Main Deck Modifications

In addition to obvious removal of all passenger amenities on the main deck (seats, overhead bins, personal airflow nozzles, reading lights, infotainment systems, etc.) and deactivation of all doors except a pair of front doors, several important modifications have to be performed on the main deck of the aircraft that is being converted.

Certain operational targets in terms of payload revenue and cargo capacity must be met. In connection to that, customers can choose between 9g safety net and 9g rigid barrier [69; 71]. Both modifications are designed to prevent movement of containers (or other cargo transport variants) during all phases of flight and to meet emergency landing requirements. Installing a 9g rigid barrier is usually performed through a wide fuselage cutout on the left-hand side of the aircraft. This cutout part is replaced by a robust surrounding structure and the main deck cargo door through the segmented hinges [69].

The main deck cargo door (MDCD) is one of the most important structural modifications. MDCD is a side door that opens outward and upward. An upward opening door provides simple access to the main deck, reduces the danger of the door or its hinges being damaged, and protects the interior from precipitation during ground operations to some extent. The door opens and closes using an independent hydroelectric circuit [69]. Another typical main deck modification, which is installed during the P2F conversion, is a loading and cargo handling system. Ball mats, roller tracks, and power handling systems are placed on the main cargo deck floor to facilitate the loading and unloading of ULD during the aircraft loading and unloading [6]. To prevent ULDs from sliding onto the flight deck, special locks are installed on the main deck of the aircraft to hold them in place [72]. For simplicity of aircraft maintenance and to minimize sun-shade cargo damage, windows are covered with protective metal coverings [6].

A new floor drain system must be installed on the main cargo deck. The existing forward and aft drain masts are connected to the floor drain. The galley drain (gray water) and forward crew lavatory are retained. To prevent water seepage, the floor of the cargo compartment of the main deck is sealed and water dams are constructed along the side walls, aft of the bulkhead, and forward of the anchor beam [69].

Among other significant modifications to the main deck, the following have to be mentioned: addition of a two-person supernumerary compartment between the flight deck and the main deck cargo compartment (including escape device for the crew); replacement of the current fluorescent lighting system with a new permanent and blinking LED lighting system; installation of a visual and auditory alarm system to allow access to the cargo compartment on the main deck; corrosion and fatigue resistance for areas sensitive to fatigue [66; 69].

Figure 14 shows the main deck of a converted Boeing 747-400BDSF [73].

Figure 14, Main Deck of a Converted Boeing B747-400BDSF, [73].

5.3.4. ECS, Ventilation, and Fire Protection Modification

Environmental Control System

The environmental control system (ECS) must be changed to suit a special cargo aircraft configuration. Passenger configuration items have to be deleted, and freighter items (fire protection related valves) have to be added. The main goal of the ECS modifications is to retain the same or better airflow rate as before conversion, temperature management, duct pressure, and noise levels and to comply with airflow and temperature control standards of FAA 14 CFR 25.831 [69].

According to *Berlowitz* [69], the ECS modifications are the following.

- Removal of sidewall ducts and outlets
- Removal of the entire main deck air distribution system and replacement by an overhead air distribution system
- Addition of main smoke mode
- Addition of a new air conditioning system with a built-in air heater

In summary, the ECS system is simplified. Its main goal in a cargo aircraft is to provide fresh air to the different compartments, and the recirculation system in the cabin is not necessary [69].

Ventilation and Fire Protection

Freighters develop a difficulty that does not exist in passenger configurations: fire and smoke in the main deck cargo compartment. FAA 14 CFR Part 25 requires "*free completion, beginning with complete pressure removal and without exceeding safety limitations*," of the smoke evacuation from the cockpit [69].

In the cabin of a passenger plane, the air flowing is a mix of the engine bleed air and the air that circulates in the aircraft ventilation system. Thus, this air contains oxygen that can be very dangerous in the event of a fire on the main cargo deck of the converted P2F aircraft. Therefore, certain modifications must be installed, allowing the airflow to be completely stopped. The modifications are the following: installation of isolation valves in each main deck duct; placing the flow control and shutoff valve (FCV) upstream of the air conditioning packs in "smoke mode" [69].

Suitable fire protection levels must be included in aircraft systems, including fire-detection, suppression, and fire-proof ceiling and sidewall liner panels [66].

The cargo aircraft fire protection system consists of [69]:

- Detection Systems
- Extinguishing Systems
- Lavatory Fire Extinguishing

5.3.5. Other Modifications

Changes in Avionics and Electrical Systems

Changes in aircraft systems affect the correspondingly changed electrical systems. The systems involved include ECS, smoke detection, communication, illumination, and indicators, among others. Components of the electrical system are removed, altered, or modified to accommodate all changes: breakers, switches, cable bundles, indicators, etc. [69].

Water Supply

The process of P2F conversion also affects the water supply system. The water and waste system mechanisms are simplified, and a large tank of potable water is replaced by a smaller one as a weight-saving measure [69]. For obvious reasons, the amount of water required for the freighter is much smaller than that for the plane carrying pax. The waste system is retained, but the connections to the removed lavatories are plugged in.

Surely, there are other minor modifications that have to be performed during the P2F conversion, but they were either mentioned in the parts above, or they are not significant for the understanding of the P2F concept.

5.3.6. Regulations

Overall, the entire aircraft industry is an area with a lot of regulations, rules, procedures, standards, and guidelines. It affects operations, manufacturing, air traffic control, maintenance, and, basically, everything connected to air transport in a great way. The most known regulators in the world are the US Federal Aviation Administration (FAA), which issues Federal Aviation Regulations (FAR), and the European Union Aviation Safety Agency, which issues Certification Specifications (CS). Normally, the majority of countries have their own aviation regulator. For example, Federal Air Transport Agency in Russia; Civil Aviation Administration (CAAC) in the People's Republic of China; National Civil Aviation Agency in Brazil; or the UK Civil Aviation Authority (CAA).

The P2F conversion changes an already certified aircraft and is considered a significant change at the product level. This means that converted aircraft does not need to acquire a new Type Certificate, but the conversion house must be given a Supplemental Type Certificate (STC) by its national civil aviation regulator [66; 69]. If the company wants to produce conversion kits, it must also obtain a Production Certificate (PC) [66]. The two most important regulations for passenger-to-freighter conversions are FAA 14 CFR and EASA CS Part 25. Both regulations contain information about airworthiness standards [69]. Many countries accept the EASA or FAA certification, but if the aircraft is being converted and operated in China, then the CAAC requires additional validation supplement type certification [66].

6. Analysis of the Effect of P2F Conversions on Transport Capacity

The methodology is the evaluation of the principles or techniques used in the research activity in a certain field. Any research requires careful selection of data, which will be used for that research and evaluated as the goal of the research.

The objective of this thesis to evaluate the suitability of P2F conversion, based on the forecast of the growth of transport volumes and the estimation of the demand for freight aircraft. The research is focused on the European airports, data are obtained through Eurostat. The analysis aims at routes with a growing cargo potential of the selected airports in the region. Figure 15 indicates thesis processing model.

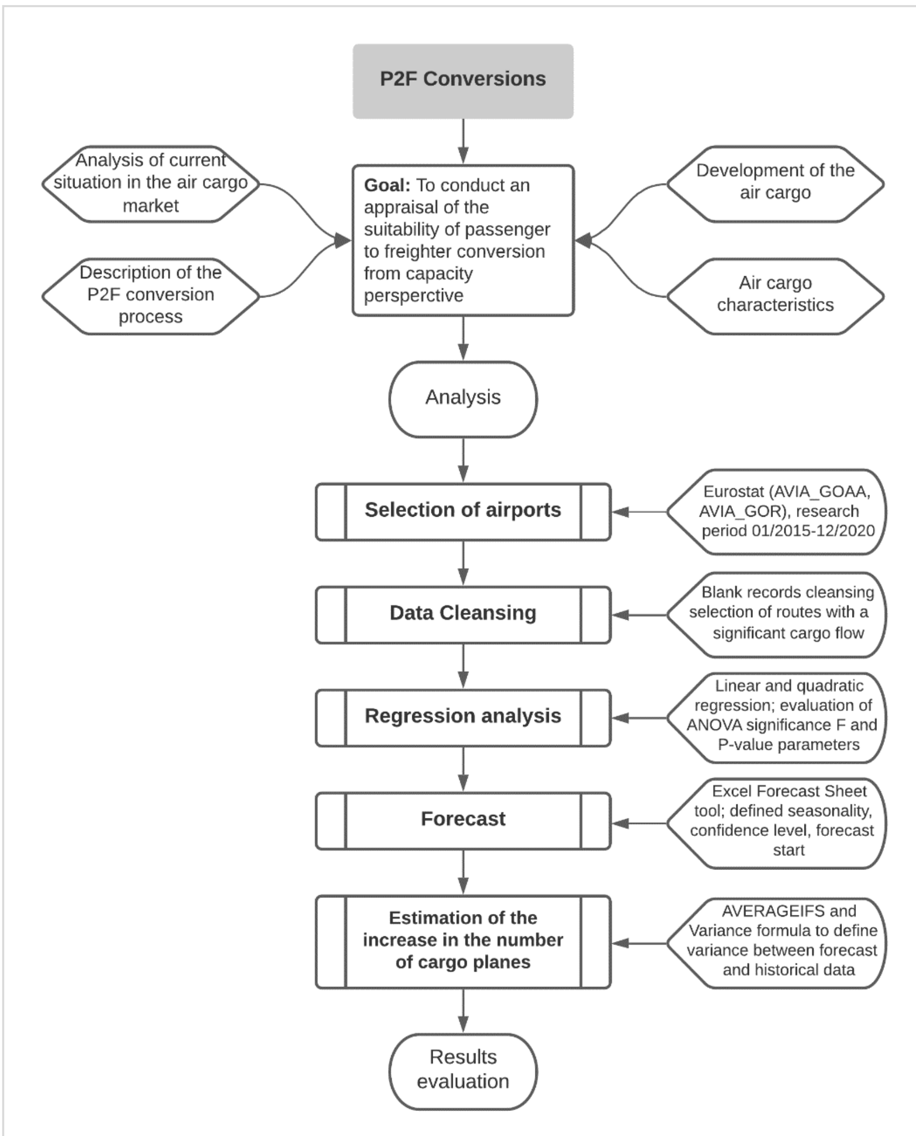

Figure 15, Thesis Processing Methodological Model.

6.1. Data Source

The analysis in this thesis requires the selection of certain airports whose data on cargo traffic will be used for the analysis. As mentioned before, the main source of data is Eurostat database, exactly speaking Air Transport data kits. Eurostat was chosen as the main source due to easy access to statistics, the wide variety of different statistics, and the reliability and relevancy of the Eurostat data [74].

6.2. Air Cargo Parameters

Main air cargo parameters are freight tonne-kilometers (FTKs), available tonne-kilometers (ATKs), revenue tonne-kilometers (RTKs), load factor, and volume of air cargo loaded and unloaded (usually measured in metric tonnes). The kilometers in the first three parameters can be changed to miles, depending on the origin of the data. FTKs, ATKs, RTKs, and load factor can show how much the freighters are used and how much revenue they generate. The volume of air cargo loaded and unloaded shows the cargo flows at airports and on individual routes.

6.3. Airports Selection

Airports were selected based on Eurostat's *Freight and mail air transport by main airports in each reporting country* (AVIA_GOOA) data set [74]. The top 15 airports by the most cargo loaded and unloaded in the year 2019 were selected primarily, then 7 airports were chosen from this list. The list of airports was chosen based on the figures for 2019 because not all airports have yet provided complete data for the year 2020. The secondary selection was defined by two factors: data completeness and airport type.

Term *data completeness* means that there were figures available for the whole research period. All airports were distinguished into three categories: big hubs, cargo hubs, minor airports. The big hubs are major European airports with high passenger flow, but they also have a large volume of cargo that is processed at those airports. Such airports usually have great cargo facilities and are the home base of combination carriers. Cargo hubs are airports with a low passenger traffic (compared to big hubs), which mainly focus on cargo operations. Such airports usually serve as base airports for all cargo carriers and integrators, which are highly dependent on the punctuality of their operations and require minimal delays. The cargo traffic of the minor airports is mainly formed by the belly cargo of the passenger airlines and by the flights of the combination carriers. Commonly, such airports lack larger cargo terminals, and some freight is handled through the passenger terminal. This analysis focuses only on the first two airport categories, i.e., big hubs and cargo hubs.

Following airports, that were selected, are either big hubs or cargo hubs: Frankfurt, Amsterdam, Leipzig, Luxembourg, Liege, Cologne-Bonn, and East Midlands. Frankfurt and Amsterdam airports can be classified as big hubs, which have large cargo facilities. Other airports are in the cargo hubs category. Only two big hubs were selected considering the fact that main cargo players (integrators and all cargo airlines) have limited operations in such airports and the main cargo routes can be defined more effectively when analyzing cargo airports. Figure 16 shows airports that were selected for the analysis.

Figure 16, Selected Airports: Big Hubs (AMS, FRA) and Cargo Hubs (CGN, EMA, LEJ, LGG, LUX), [74].

6.4. Routes Selection

For the airports mentioned above, individual routes had to be selected. In this step, the data was sourced from the Eurostat data set AVIA_GOR. This data set contains detailed statistics about freight and mail transport by reporting country and routes. Individual routes or so-called 'city pairs' are available in this data set. Data from a certain period were sourced, from January 2015 to December 2020. This timeline is conditioned by the number of records required by the regression analysis, in order to be statistically significant, and the forecast, which is 25 or more [75]. By choosing this timeline, the analysis will be performed on data from 72 months, which is a sufficient number of records for the regression analysis and forecast.

6.5. Data Cleansing

The routes for each selected airport were downloaded and, subsequently, the data were cleansed. Many routes had to be eliminated due to the lack of records; this was a limiting factor.

Following the primary cleansing of data, the routes were selected according to the average monthly cargo volume with a minimum of 2000 metric tonnes per month. After the second step of cleansing 90 routes were chosen for the regression analysis. Figure 17 shows an example of raw data.

Freight and mail air transport between the main airports of Belgium and their main partner airports (routes data)
(online data code: AVIA_GOR_BE)
Source of data: Eurostat

Table | Line | Bar | Map

TIME / AIRP_PR	5	2015-06	2015-07	2015-08	2015-09	2015-10
LIEGE airport - DUBAI INTERNATIONAL airport	381	4 197	4 372	4 200	4 396	4 088
LIEGE airport - AL MAKTOUM INTERNATIONAL airport	:	:	:	:	:	:
LIEGE airport - SHARJAH INTERNATIONAL airport	:	:	:	:	:	:
LIEGE airport - BAGRAM airport	:	:	:	:	:	:
LIEGE airport - KANDAHAR airport	:	:	:	:	:	:
LIEGE airport - KABUL ACC/FIC airport	:	:	:	:	:	:
LIEGE airport - LUANDA/4 DE FEVEREIRO airport	:	:	:	:	:	:
LIEGE airport - WIEN-SCHWECHAT airport	435	507	550	459	526	530
LIEGE airport - HEYDAR ALIYEV INTERNATIONAL airport	:	:	:	:	:	:
LIEGE airport - BRUSSELS airport	:	:	:	:	:	:
LIEGE airport - BURGAS airport	:	:	:	:	:	:
LIEGE airport - BAHRAIN INTERNATIONAL airport	:	:	:	:	:	:
LIEGE airport - HALIFAX/STANFIELD INTL, NS airport	:	:	:	:	:	:
LIEGE airport - GANDER INTL, NL airport	:	:	:	:	:	:
LIEGE airport - BANGUI/M'POKO airport	:	:	:	:	:	:
LIEGE airport - BRAZZAVILLE/MAYA-MAYA airport	:	:	:	:	:	:
LIEGE airport - GENEVA airport	:	:	:	:	:	:
LIEGE airport - DOUALA/AEROPORT airport	:	:	:	:	:	:
LIEGE airport - GUANGZHOU/BAIYUN airport	:	:	:	:	:	:
LIEGE airport - CHANGSHA/HUANGHUA airport	:	:	:	:	:	:
LIEGE airport - ZHENGZHOU/XINZHENG airport	:	:	:	:	:	:
LIEGE airport - WUHAN/TIANHE airport	:	:	:	:	:	:
LIEGE airport - NANCHANG/CHANGBEI airport	:	:	:	:	:	:

Figure 17, Example of Uncleansed Data for Liege Airport Routes, [74].

6.6. Regression analysis

Regression analysis was performed on cleansed data (e.g., individual routes or the so-called "city pairs"). The main goal of this analysis was to define the statistical significance of the data that were selected. It is important to select statistically significant data because the next step relied on the quality of the data. The regression analysis allowed to conduct whether data doesn't have any extreme values, that will influence the future forecast and make it inaccurate. The linear and quadratic regression analysis were performed for each 'city pair'. Both analyzes were carried out through the *Data analysis ToolPack* in Microsoft Excel. This tool was chosen as optimal for the research goals.

The formulas are the following:

$$y = bx + a \text{ – for linear regression}$$

$$y = b_0 + b_1x + b_2x^2 \text{ – for quadratic regression}$$

y – air cargo loaded and unloaded [metric tonnes]

x – month index number

Figure 18 shows which parameters were evaluated.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,88731058
R Square	0,787320065
Adjusted R Square	0,78428178
Standard Error	712,4011134
Observations	72

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	131514009,7	1,3E+08	259,133	3,15194E-25
Residual	70	35526074,25	507515		
Total	71	167040083,9			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	3041,399844	169,6790273	17,9244	7,3E-28	2702,985694	3379,813993	2702,985694	3379,813993
X	65,03090231	4,039786001	16,0976	3,2E-25	56,97380318	73,08800143	56,97380318	73,08800143

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,900741226
R Square	0,811334757
Adjusted R Square	0,805866199
Standard Error	675,8211113
Observations	72

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	135525425,9	6,8E+07	148,364	1,02653E-25
Residual	69	31514658,03	456734		
Total	71	167040083,9			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	3591,658283	245,7331714	14,6161	8,2E-23	3101,434019	4081,882547	3101,434019	4081,882547
X	20,41535316	15,53472953	1,31417	0,19314	-10,5755843	51,40629061	-10,5755843	51,40629061
X^2	0,611171906	0,206227356	2,96358	0,00417	0,199759588	1,022584225	0,199759588	1,022584225

Figure 18, Regression Analysis Results for LEJ-CVG Route, Evaluated Parameters Highlighted in Yellow.

The main parameters evaluated in the regression analysis were ANOVA Significance F and the P-value of the intercept. If higher than alpha level, ANOVA Significance F indicates significant differences among group means. If higher than alpha level, P-value indicates statistical insignificance [76; 77]. For data with good statistical significance and without significant differences among group means, both parameters should be lower than or equal to alpha level of 0.05. Routes with appropriate values of ANOVA Significance F and P-value were selected for the forecast.

It should be noted that not all routes have high R^2 values, which reflects that the percentage of variance in the dependent variable is explained by independent factors. However, this is not a problem in the case of this study because some fields of study have an intrinsically higher level of unexplained variance [78].

The regression analysis has defined which routes have statistically reliable data and could be used for the forecast in the next step. Results of regression analysis for each are available in the Attachment 1.

After the regression analysis, 47 routes were selected for the forecast.

6.7. Forecast

The forecast part aims to determine the future growth of cargo traffic on the routes selected in the previous steps. The forecast was carried out with the Forecast Sheet tool available in Microsoft Excel. This tool uses existing time-based data and the AAA version of the Exponential Smoothing (ETS) algorithm to predict future values [79]. The seasonal algorithm (ETS AAA) uses an equation to account for additive error, additive trend, and additive seasonality in the time data. This method is also known as the Holt-Winters algorithm. The Holt-Winters method is widely used in business, for example, to predict and plan demand [80].

The forecast table contains the following columns: historical time column, historical values column, forecasted values column (lower and upper confidence bound columns can be added by the user) [79].

As can be seen from the Figure 20, the following parameters can be defined by each user: forecast end, forecast start, confidence interval, seasonality (either automatically detected or manually set), timeline range, values range, missing points fill in method, and duplicates aggregation method. Figure 19 shows the Forecast Sheet tool interface.

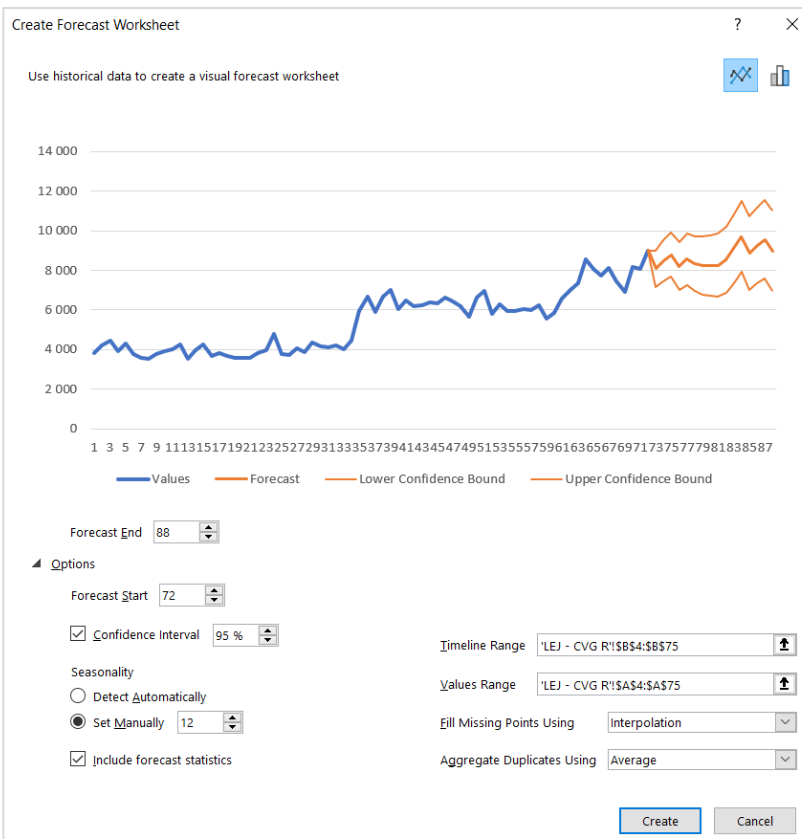

Figure 19, Forecast Sheet Interface Example.

The following parameter values were used in the forecast of this paper:

- Forecast start – x-1 (x is the last month's index number)
- Forecast end – 88
- Seasonality – 12
- Confidence interval – 95%

The forecast start value was chosen because of the forecast accuracy, which was better in cases when the forecast started one month earlier than the last available month. The forecast end was set for 88, for the reason of accuracy once again. The further the forecast end, the less accurate the prediction is. For this tool, the optimal forecast end is between 16 and 24 months from the forecast beginning, for this forecast 16 months were chosen. Seasonality was set to twelve because time values are stated in months and the standard confidence interval value was chosen for this forecast.

6.8. Estimation of the Increase in the Number of Cargo Planes

Forecast Evaluation

As mentioned in the Part 6.6., 47 routes were selected for the forecast. To evaluate whether the average monthly cargo volume will grow on the one individual route, the following actions had to be performed.

Forecasted values had to be compared to the historical data to get an overview of how much each route would grow. For this purpose, the Excel formula *AVERAGEIFS* was used. This formula, together with *SUMIFS,* can be used to determine the forecast versus actual variance based on a set of data [81]. This is a simple yet functional method, which can emphasize the variance between the forecasted and historical data. *The AVERAGEIFS* formula was used to determine the average monthly cargo volume (Freight and mail loaded and unloaded) of the forecasted data and to determine the average monthly cargo volume for the last available months. Average values were calculated over the same period of the forecasted and historical data (for German airports, LUX and AMS, the period was 17 months, for LGG 18 months, for EMA 19 months). These averages were used to calculate the variance, using the variance formula. The variance formula computes the difference between a forecast and the actual result. The variance can be stated numerically or as a percentage [82]. There are two ways to calculate variance:

$$\boldsymbol{Variance}\ [\%] = \frac{\boldsymbol{Forecast\ AVG - Data\ AVG}}{\boldsymbol{Data\ AVG}}$$

$$\boldsymbol{Variance\ [tonnes] = Forecast\ AVG - Data\ AVG}$$

Table 5 demonstrates the results of the forecast evaluation for the LEJ – CDG route.

Table 5, Forecast Evaluation for LEJ-CDG Route, Variances Highlighted in Yellow.

	Data	Forecast
AVERAGE [tonnes]	**2 646**	**2 994**
Variance [%]		**13,15%**
Variance [tonnes]		**348**

After the forecast, the evaluation routes with growing and declining average monthly cargo volumes were defined. In total, 36 routes had a growing average monthly cargo volume and 11 routes had a declining average monthly cargo volume. For the estimation of the increase of number of cargo aircraft only routes with growing average monthly cargo volume were selected. Due to the time-consuming and multistage process of the estimation (which will be described in the following paragraph) only five “city pairs” were chosen for the further analysis: CGN-SDF, LEJ-CDG, LEJ-EMA, FRA-PVG and LUX-HKG. The estimation can be performed with the other routes as well, using the same method. These particular routes were chosen because of the diversity of aircraft types operating on them and good forecasted growth of cargo volume.

Estimation of the Increase in the Number of Cargo Aircraft

The following approach was used to estimate the increase in the number of aircraft required to cover increased cargo volume on each specific route. First, the number of flights and the most common kind of aircraft utilized on a single route had to be determined. Flightradar24 provided data on flights and aircraft for this phase [83]. The website collects data from a variety of sources, including flight scheduling systems, airline booking systems, airports, airlines, and other third-party data providers. Every route required to be manually validated by detecting exact flight numbers and searching for a specific flight in the aircraft's flight history. As a result, the entire process was time-consuming. Subsequently, the number of weekly and monthly flights for each route was estimated to determine how busy the route is. Following that, the predicted growth in the number of planes for each route was calculated using the most often used aircraft types on the route. The number of planes required to meet increased cargo volumes on this route was determined as the number of additional flights required to bridge the gap between historical and forecast statistics using the same or similar types of cargo planes. The number of additional flights required was obtained by dividing the increase in cargo volume by the adjusted payload of the aircraft.

The number of additional planes required to cover the increase in cargo volume is chosen to be equal to the number of additional flights required on each specific route. This method of calculation was used because cargo planes typically have a high occupancy rate. Most cargo airlines fly on a so-called "big circle" route (common for scheduled all-cargo carriers and combination carriers) or conduct many flights from a larger significant hub to additional airports (typical for integrated carriers). Either way, cargo aircraft performs a high number of flights a week and this fact leaves almost no scope in adding new flights and routes without boosting the fleet with new aircraft. The following figures depict average flights of an aircraft that runs on each of the five previously mentioned specified routes.

Figure 20 shows the flight schedule of UPS' Boeing 747-8, which has operated flight 5X214 from CGN to SDF on 12 July 2021. The aircraft flight schedule for the 12.7-19.7 week was Louisville – Cologne – Louisville – Minneapolis - Louisville – Ontario – Honolulu – Hong Kong – Taipei Anchorage - Louisville – Portland – Anchorage - Seoul – Anchorage – Louisville, resulting in 15 flights in 7 days [84].

Figure 20, Flights of the UPS' Boeing 747-8F reg. N620UP, 12.07.21-19.07.21, [84].

Figure 21 shows the flight schedule of DHL's Boeing 757, which has operated the D01262 flight from LEJ to CDG on 17 July 2021. The aircraft flight schedule for the 12.7-19.7 week was Leipzig – Brescia – Leipzig – London – East Midlands – Leipzig – Cologne – Valencia – Cologne – Leipzig – Venice – Leipzig – London – Leipzig – Ljubljana – Milan – Leipzig – Sofia – Leipzig – Paris – Leipzig, which results in 20 flights in 7 days [85].

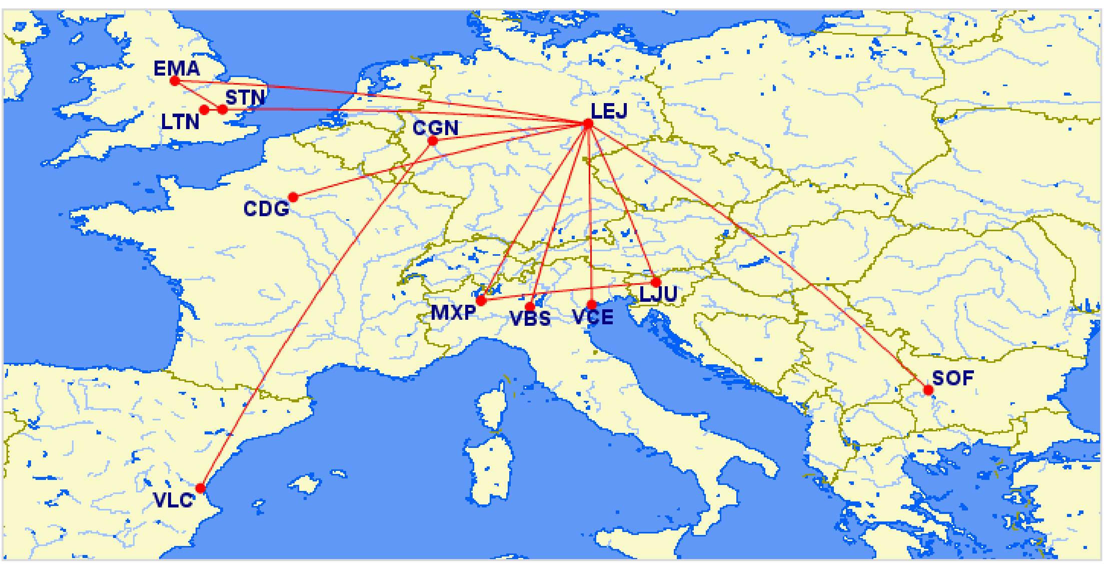

Figure 21, Flights of DHL's Boeing 757 reg. G-DHKH, 12.07.21-19.07.21, [85].

Figure 22 shows the flight schedule of DHL's Boeing 767, which has operated the flight D0108 from LEJ to EMA on 17 July 2021. The aircraft flight schedule for the 12.7-19.7 week was East Midlands – Brussels – East Midlands – Belfast – East Midlands – Brussels – East Midlands – Belfast – East Midlands – Brussels – East Midlands – Belfast – East Midlands – Brussels – East Midlands – Belfast – East Midlands - Brussels - East Midlands – Belfast – East Midlands - Brussels - East Midlands - Belfast - East Midlands - Belfast - East Midlands - Belfast - East Midlands - Leipzig - East Midlands - Belfast - East Midlands - Leipzig - East Midlands, which results in 22 flights in 7 days [86].

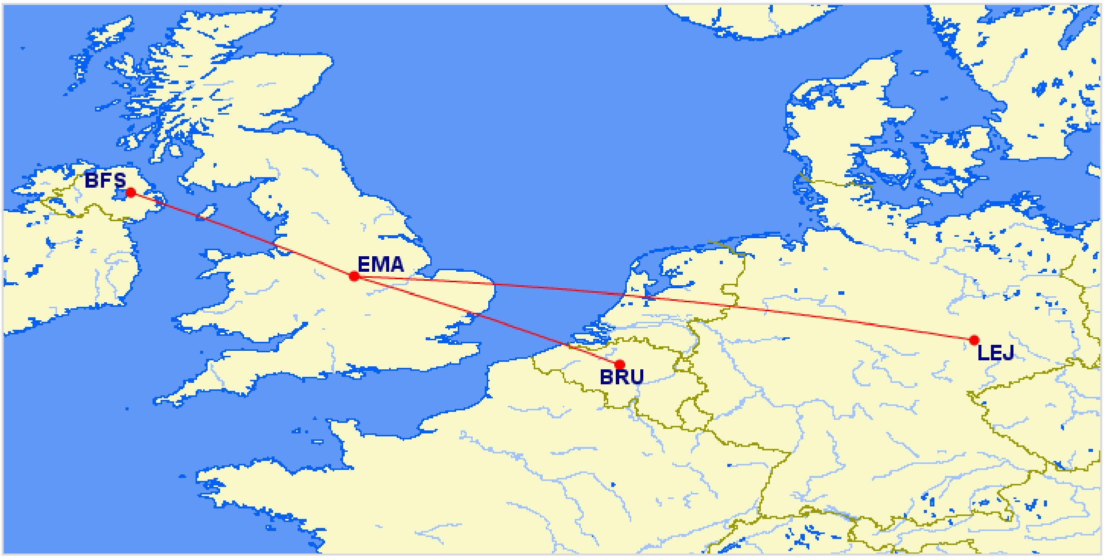

Figure 22, Flights of DHL's Boeing 767 reg. G-DHLG, 12.07.21-19.07.21, [86].

Figure 23 shows the flight schedule of Lufthansa Cargo's Boeing 777F, which has operated the flight LH8404 from FRA to PVG on July 12, 2021. The flight schedule of the aircraft for the 12.7-19.7 week was Frankfurt – Shanghai – Seoul – Frankfurt – Shanghai – Seoul – Frankfurt – Atlanta – Frankfurt – Bengaluru – Hong Kong – Seoul – Frankfurt – Shanghai – Seoul – Frankfurt – Shanghai, which results in 16 flights in 7 days [87].

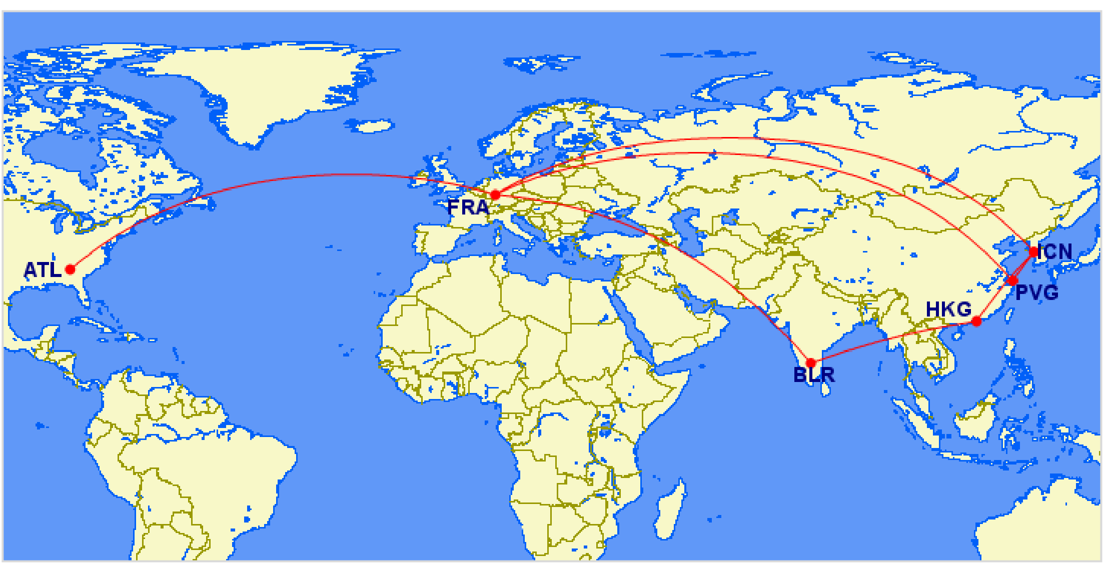

Figure 23, Flights of Lufthansa Cargo's Boeing 777F reg. D-ALFD, 12.07.21-19.07.21, [87] .

Figure 24 shows the flight schedule of Cargolux's Boeing 747-8F, which has operated the CV7211 flight from HKG to LUX via GYD on July 13, 2021. The aircraft flight schedule for 12.7-19.7 weeks was Bangkok – Hong Kong – Baku – Luxembourg – Alma-Ata – Seoul – Hong Kong – Novosibirsk – Budapest – Luxembourg – Mexico City – Los Angeles – Prestwick – Luxembourg – Milan – Dubai – Kuala Lumpur – Hong Kong – Anchorage – Los Angeles – Luxembourg, which results in 20 flights in 7 days [88].

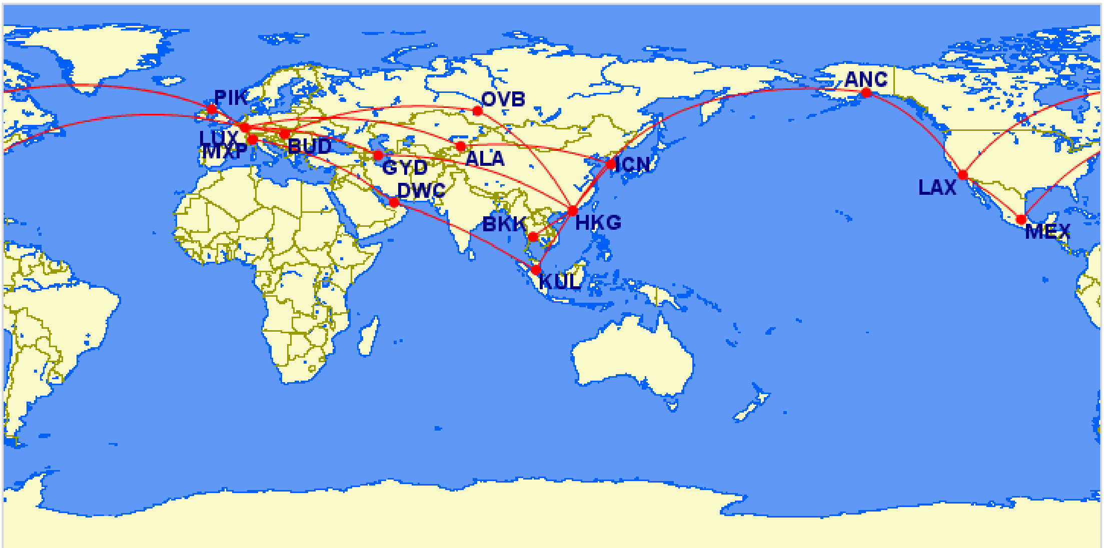

Figure 24, Flights of Cargolux's Boeing 747-8F reg. LX-VCD, 12.07.21-19.07.21, [88].

As can be seen from the examples above, cargo operators keep their aircraft very busy. Certain patterns in schedule building can be observed – integrators (DHL and UPS) have strong base dependence (EMA, LEJ and SDF), their routes tend to be shorter, and they return to their hubs after a smaller number of flights; all-cargo carriers and combination carriers (Lufthansa Cargo, Cargolux) tend to have larger circle routes, and they return to their hub less frequently. Nevertheless, based on the flight schedule we can assume that adding new flights without supplying new planes is hardly possible. It would require an advanced network simulation, in order to predict changes in the flight network. For this reason, this analysis will consider adding planes to the routes based only on the predicted growth in volume; changes in the flight network will not be considered.

Payload

The maximum payload of each aircraft defines the maximum weight of cargo that can be taken onboard. In practice, aircraft rarely operate with the maximum payload. Usually, the amount of cargo carried can be expressed with the load factor. The load factor is the ratio of the average load to the total freight capacity of the aircraft [89]. As was mentioned in Chapter 3.1., IATA estimates that the average industry-wide payload was 57.2% in May 2021.

The maximum payload of the converted aircraft has to be adjusted to the industry-wide load factor in order to obtain the amount of cargo, which is usually carried by a certain type of aircraft.

In Table 5 the maximum and adjusted payloads of the most popular models of P2F converted aircraft can be seen.

Table 6, Maximum and Adjusted Payloads of Most Common Converted Aircraft Types, [57] [58].

A/C TYPE	MAX. PAYLOAD [TONNES]	ADJUSTED PAYLOAD [TONNES]
A320P2F	21,9	12,53
A321P2F	27,9	15,96
A330-200P2F	60	34,32
A330-300P2F	61	34,89
B737-700BDSF	18,8	10,75
B737-800BDSF	24	13,73
B747-400BDSF	114,76	65,64
B767-200BDSF	45,81	26,20
B767-300BDSF	56,79	32,48
B777-300ERSF	100,69	57,59

CGN – SDF Route

The first route chosen for the estimation was the route between Cologne and Louisville. Both Cologne and Louisville are airports with a strong cargo accent. In addition, Louisville is UPS' main hub, usually called the Worldport. This route was chosen due to the homogeneity of the fleet operating on this transatlantic route. According to Flightradar24 data, there are 8 flight numbers on this route (either CGN to SDF or SDF to CGN) – 2X213, 2X214, 2X223, 2X224, 2X226, 2X227, 2X228, 2X229 [90]. The total number of flights between these two airports is 26 flights each week or 104 flights each month. Only airline that operates on this route is UPS, two of the most common freighters on this route are Boeing 747-400/8F and Boeing 777F. Based on these data and the method described above, the number of additional aircraft that will cover the growing cargo volume until 04/2022 is 4 in the case of Boeing 747-400BDSF and 5 in the case of Boeing 777-300ERSF.

Table 7 shows the number of additional aircraft required, adding only one each type of aircraft.

Table 7, Additional Aircraft Required for the CGN – SDF Route.

Additional flights/aircraft required	**(per month)**			
A/C Type	**Max. Payload [tonnes]**	**Adjusted Payload [tonnes]**	**Variance [tonnes]**	**Additional flights/aircraft**
B747-400BDSF	114,76	65,64	249	4
B777-300ERSF	100,69	57,59	249	5

LEJ-CDG Route

The second route, where the estimations were performed, was the route between two European airports – Leipzig Halle and Paris Charles de Gaulle. Leipzig is one of the busiest cargo airports in Europe and serves as the key hub for AeroLogic and DHL. Charles de Gaulle Airport in Paris is the largest airport in France and AirFrance's main hub. This route was chosen to show cargo traffic between a major hub and a large cargo airport. According to Flightradar24 data, there are 4 flight numbers on this route (either LEJ to CDG or CDG to LEJ) – D01262, D01264, D01265, MB224 [91]. The total number of flights between these two airports is 14 flights each week or 56 flights each month. Two operators have flights on this route – Turkish MNG Airlines and DHL. There are several aircraft types that operate on this route, the most popular being Airbus A300, Airbus A330 and Boeing 757. Based on these data and the method described above, the number of additional aircraft that will cover the growing cargo volume until 04/2022 is either 22 Airbus A321P2F, 11 Airbus A330-200P2F, 10 Airbus A330-300P2F, 26 Boeing 737-800BDSF, 14 Boeing 767-200BDSF or 11 Boeing 767-300BDSF. Here the number of aircraft required is significantly larger than on the previous route because the predicted growth of cargo volume is more rapid on the CGN – SDF route. This fact can be explained by the growing operations of integrated carriers in Europe.

Table 8 shows the number of additional aircraft required, adding only one each type of aircraft.

Table 8, Additional Aircraft Required for the LEJ – CDG Route.

Additional flights/aircraft required	**(per month)**			
A/C Type	**Max. Payload [tonnes]**	**Adjusted Payload [tonnes]**	**Variance [tonnes]**	**Additional flights/aircraft**
A321P2F	27,9	15,96	348	22
A330-200P2F	60	34,32	348	11
A330-300P2F	61	34,89	348	10
B737-800BDSF	24	13,73	348	26
B767-200BDSF	45,81	26,20	348	14
B767-300BDSF	56,79	32,48	348	11

LEJ – EMA Route

The next route chosen for estimation was the route between Leipzig Halle and East Midlands. Once again, these two airports are among the main cargo airports in Europe. East Midlands serves as a hub for cargo carriers such as DHL, UPS, and ASL Airlines. This route is served by many different aircraft types from standard to large freighters. This route was chosen to estimate the number of planes on a route between two major cargo hubs in one region, which has different types of aircraft operating on this route. According to Flightradar24 data, there are 21 flight numbers on this route (either LEJ to EMA or EMA to LEJ) – ABR551, ABR552, D0101, D0103, D0105, D0109, D0110, D0111, D0112, D0114, D0190, D0191, D0192, D0193, D0200, PO112, PO368, 3S194, 3S195 [91]. The total number of flights between these two airports is 61 flights each week or 244 flights each month, this is a very busy route. There are several cargo airlines operating this route, AeroLogic, ASL Airlines Ireland, DHL, and Polar Air Cargo. Based on these data and the method described above, the number of additional aircraft that will cover growing cargo volume until 04/2022 is either 143 Airbus A321P2F, 67 Airbus A330-200P2F, 66 Airbus A330-300P2F, 166 Boeing 737-800BDSF, 87 Boeing 767-200BDSF, 71 Boeing 767-300BDSF or 40 Boeing 777-300ERSF. In this case, the numbers are even higher due to the higher variance between historical and forecast data and the overall large cargo volume on this route.

Table 9 shows the number of additional aircraft required, adding only one each type of aircraft.

Table 9, Additional Aircraft Required for the LEJ – EMA Route.

Additional flights/aircraft required	**(per month)**			
A/C Type	**Max. Payload [tonnes]**	**Adjusted Payload [tonnes]**	**Variance [tonnes]**	**Additional flights/aircraft**
A321P2F	27,9	15,96	2278	143
A330-200P2F	60	34,32	2278	67
A330-300P2F	61	34,89	2278	66
B737-800BDSF	24	13,73	2278	166
B767-200BDSF	45,81	26,20	2278	87
B767-300BDSF	56,79	32,48	2278	71
B777-300ERSF	100,69	57,59	2278	40

FRA – PVG Route

The fourth route chosen for the estimation is route between two major hubs in Europe and Asia – Frankfurt and Shanghai Pudong. Frankfurt is one of the main Lufthansa's hubs and Shanghai serves as a hub to multiple Chinese airlines. This route was chosen because of the great importance of these two airports for the regions they are located in, and because of it's great cargo volume. According to Flightradar24 data, there are 16 flight numbers on this route (either FRA to PVG or PVG to FRA) – CA1002, CA1021, CA1041, CA1047, CA1048, CK211, CK212, CZ406, CZ461, CZ462, CZ463, LH8400, LH8402, LH8404 [92]. The airlines that serve this route are following – Air China Cargo, China Cargo Airlines, China Southern Cargo and Lufthansa Cargo. Heavy large freighters such as Boeing 747-400/8F and Boeing 777F operate on this route. Based on these data and the method described above, the number of additional aircraft that will cover growing cargo volume until 04/2022 is either 10 Boeing 747-400BDSF or 11 Boeing 777-300ERSF. Here the forecasted growth is moderated, but because of the overall high cargo volume a pretty big number of large freighters is required.

Table 10 shows the number of additional aircraft required, adding only one each type aircraft.

Table 10, Additional Aircraft Required for the FRA – PVG Route.

Additional flights required	**(per month)**			
A/C Type	**Max. Payload [tonnes]**	**Adjusted Payload [tonnes]**	**Variance [tonnes]**	**Additional flights/aircraft**
B747-400BDSF	114,76	65,64	591	10
B777-300ERSF	100,69	57,59	591	11

LUX – HKG Route

The final route chosen for the estimation is the route between the Luxembourg Findel and Hong Kong airports. Hong Kong is one of the busiest cargo airports in the world and Luxembourg is one of the busiest cargo airports in Europe, also serving as a hub for Cargolux. This route was chosen because it connects a major hub and a major cargo hub, which are located on different continents. According to Flightradar24 data, there are 8 flight numbers on this route (either FRA to PVG or PVG to FRA) – CV7025, CV7211, CV7332, CV7333, CV7335, CV7417, CV8575, C86751 [93]. The only airline that operates this route is Cargolux. And the only aircraft that fly between Luxembourg and Hong Kong on this route is the Boeing 747-400/8F. Based on these data and the method described above, the number of additional aircraft that will cover growing cargo volume until 04/2022 is 5 Boeing 747-400BDSF or 5 Boeing 777-300ERSF.

Table 11 shows the number of additional aircraft required, adding only one each type aircraft.

Table 11, Additional Aircraft Required for the LUX – HKG Route.

Additional flights/aircraft required	(per month)			
A/C Type	**Max. Payload [tonnes]**	**Adjusted Payload [tonnes]**	**Variance [tonnes]**	**Additional flights/aircraft**
B747-400BDSF	114,76	65,64	283	5
B777-300ERSF	100,69	57,59	283	5

6.9. Results Evaluation

This analysis has only focused on five selected routes due to the complexity and multi-stage character of the whole estimation process. Estimating for other routes can be done by following the same steps as that performed for the selected routes. The analysis focuses on capacity on each route without changing flight network, because it is a complex research with the network simulation.

As for the results of these five estimations, they can be divided into two groups. The first group contains results for the CGN – SDF, LEJ – CDG, FRA – PVG and LUX – HKG routes, where the estimate in increase of the cargo aircraft serving these routes is quite moderate. The second group of the only consists LEJ – EMA route, where the estimated increase in the number of planes is very high. The LEJ – EMA estimation can seem unrealistic, but based on the volumes of cargo flown on this route in 2020, which has increased rapidly during this last year, we can assume that the cargo flow will grow even more in the near future and this forecast is accurate to a certain extent. However, any fleet prediction can never be completely exact, because it depends on a huge number of factors and the rapidly changing situation in the industry can influence the fleet in a very significant manner. But an ongoing positive trend in the air cargo industry can be spotted thanks to many factors (e.g., freighter orders, opening of the new conversion facilities, market analysis and forecast, etc.) and this trend will surely result in the increase of the cargo fleets, by means of passenger-to-freighter conversions as well.

7. Discussion

As the main aim of this thesis was to conduct the appraisal of suitability of P2F conversion from the capacity perspective, the results of the research in this thesis can be counted as satisfactory. It can be clearly seen that current situation and forecasted figures require additional dedicated freighter aircraft. Shortage of the cargo capacity along with growing cargo volumes on the examined routes can lead to the conclusion, that P2F conversion are suitable, at least from the capacity side of the problem.

However, proposed method of estimation of increase in the number of aircraft can be used in a limited way, which is adding additional planes to operate on each individual route. As mentioned before, at this point, adding more flights to one particular route without increasing the number of aircraft operating on that route is not considered, mainly due to the high occupancy of cargo operator aircraft. This would require a complex network simulation for which certain expert tools and deeper knowledge are required.

Also, the complexity and multistep character of the analysis described and used did not allow one to perform the estimation for each particular route which was forecasted. Only five of them were chosen for the estimation; only routes with an undoubtful growing cargo volume were chosen. Some of the routes, such as LEJ – EMA, have required major addition of the aircraft operating on them, mainly because of the big cargo volume and large number of flights. On the other hand, there were routes, such as LUX – HKG, that have only required a small number of aircraft to be added. One of the reasons for addition this small can be quite high scale of saturation on this route. For the remaining city pairs, there are forecasts available in Attachment 1. Like already stated, the estimation for the remaining routes would have to be performed the same way as for five selected routes. Overall, the thesis results can be considered as valid, because main goal of appraising of suitability of P2F conversion was achieved. Exact number of aircraft is a much more complex problem and was not a goal of this thesis.

There are two ways of supplying new cargo aircraft to operators: factory-built freighters and converted from passenger freighters. Based on the values that we have for 5 routes only, operators will require a solid number of freighters just to fulfill the demand for air cargo. With Boeing producing and delivering only about 4 cargo aircraft each month and Airbus not producing new freighters at all, only factory-built freighters will not be enough for the industry. Hence, freighter aircraft converted from freighters are a righteous way to expand fleets of cargo operators. Surely, the precise number of aircraft that have to be converted cannot be estimated, at least as a part of this work. But considering the growing cargo potential on selected routes and the capacity of cargo aircraft on those routes, these mentioned above numbers of cargo aircraft needed can be estimated. By reviewing flight networks through a complex simulation, the estimated number of required aircraft can (but does not have to) be lowered. However, considering that in the near future cargo operators will need to replace older airframes, such as DC-10, MD-11, or Boeing 757, passenger-to-freighter conversions can get another boost. Summarizing the results, a conclusion of the suitability and even need of P2F conversions can be drawn in the air cargo industry.

8. Conclusion

This thesis serves as a primary analysis of the suitability of P2F converted freighters from a capacity perspective. The result of this thesis was that several additional aircraft were required on each of the evaluated routes. The main focus of the whole analysis was on the cargo capacity part of the whole situation. The analysis of cargo volume and estimation in the number of aircraft on 5 routes was performed. The result of the analysis was that certain routes will require additional aircraft to operate at (the numbers differ from 5 aircraft to more than 100). Some of these routes are more saturated and require less supplementary aircraft, other require more. The main issue with the aircraft is the source of the airplanes. This additional capacity cannot be filled by factory-built freighters only. For this reason, P2F conversions can serve as a great source of the dedicated freighters for cargo airlines and can fill up the missing capacity. In the context of the current market situation, we can assume that P2F conversion is certainly an area that will grow in the near future and we will see more converted freighters flying. Actual state of air cargo with insufficient cargo capacity, strong demand driven by e-Commerce and long waiting lines for the new freighters makes airlines turn to passenger-to-freighter conversions. It results into numerous orders of converted freighters (as stated before), opening new facilities and even introducing new conversion programmes (such as Boeing 777-300ERSF).

The first limitation for this research was relatively narrow data set, which was only aimed at European cargo airports. The second limitation is the nature of forecast. The forecast performed in this study is aimed at each route's capacity (not the flight schedule) and can only tell estimated number of planes, mainly because of the complexity and time-consuming nature of a research with this large portion of data. Furthermore, predicting exact number of aircraft required for each route can be very troublesome, because the variety of factors influencing the forecast is diverse. Among these factors the following can be named: pandemics, fuel prices, availability of other modes of transport, transportation prices, political situation, economic situation, etc. That's why, this problematic requires deeper and more sophisticated analysis. Further research can possibly determine number of aircraft required for each individual route, considering the factors stated above. This research would also require a simulation of the flight network and advanced tools and methods, in order to base the analysis not only solely on the capacity, but also on the improvements of the flight schedule and enhanced planning.

The main contribution of this thesis is the positive appraisal of the suitability of the P2F conversions for enlarging the world's freighter aircraft fleet and identification of routes with growing cargo potential for selected European airports.

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List of Attachments

Attachment 1 – Regression Analyses and Forecasts for Selected Routes