CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of transportation sciences

Department of Air Transport

Návrh optimálních náhradních cílových letišť ve vybraných světových aglomeracích

Diversion airport selection analysis in selected world polycentric urban areas

Bachelor's thesis

Study programme: Technology in transportation and telecommunications

Study field: Air transport

Thesis supervisor: Ing. Peter Olexa

Ing. Slobodan Stojić, Ph.D.

Tomáš Kříž

Prague 2021

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BACHELOR'S THESIS ASSIGNMENT

(PROJECT, WORK OF ART)

Student's name and surname (including degrees):

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

B 3710 – LED – Air Transport

Theme title (in Czech): **Návrh optimálních náhradních letišť ve vybraných světových aglomeracích**

Theme title (in English): Diversion Airport Selection Analysis in selected World Polycentric Urban Areas

Guides for elaboration

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

- The aim of the work is to create an optimized list of alternative airports for selected world agglomerations
- Prepare an analysis of the issue of aircraft diversion for operational reasons, define economic and operational impacts, current approaches to the operational selection of airports and their limitations
- Based on the analyzes of the proposed list of factors that have an impact on the operational selection of the replaced destination airport and the methodology of their selection
- Identify geographical locations based on the current global air traffic situation and apply the developed methodology to the selected agglomeration
- Suggest a way to validate the results you apply
- The results discussed and set the conclusions of the work

Graphical work range: As per the guidance of the thesis supervisor

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

Bibliography:

YU Gang, QI Xiangtong. Disruption Management. Singapore. World Scientific Publishing Co Pte Ltd, 2004

WALD Andreas, GLEICH Ronald , et. al. Introduction to Aviation Management . Berlin: LIT Verlag, 2010

PRATHER, Daniel. Airport Management. Newcastle, Washington. Aviation Supplies & Academics, Inc 2015.

Bachelor's thesis supervisor: **Ing. Peter Olexa**

Ing. Slobodan Stojić, 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

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I confirm assumption of bachelor's thesis assignment.

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Prague .... October 9, 2020

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ZADÁNÍ BAKALÁŘSKÉ PRÁCE

(PROJEKTU, UMĚLECKÉHO DÍLA, UMĚLECKÉHO VÝKONU)

Jméno a příjmení studenta (včetně titulů):

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Kód studijního programu a studijní obor studenta:

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Název tématu (česky): **Návrh optimálních nahradních cílových letišť ve vybraných světových aglomeracích**

Název tématu (anglicky): Diversion airport selection analysis in selected world polycentric urban areas

Zásady pro vypracování

Při zpracování bakalářské práce se řiďte následujícími pokyny:

- Cílem práce je vytvořit optimalizovaný seznam náhradních letišť pro vybrané světové aglomerace
- Vypracujte analýzu problematiky odklánění letadel z provozních důvodů, definujte ekonomické a provozní dopady, současné přístupy k operativnímu výběru letišť a jejich limitace
- Na základě analýzy navrhněte seznam faktorů, které mají vliv na operativní výběr náhradního cílového letište a metodologii jejich výběru
- Identifikujte geografické lokace na základě současné světové letecké provozní situace a aplikujte vypracovanou metodologii na vybrané aglomerace
- Navrhněte způsob validace výsledků a aplikujte je
- Výsledky diskutujte a stanovte závěry práce

ČVUT FD

Rozsah grafických prací: dle pokynů vedoucího bakalářské práce

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

Seznam odborné literatury:

YU Gang, QI Xiangtong. Disruption Management. Singapore. World Scientific Publishing Co Pte Ltd, 2004

WALD Andreas, GLEICH Ronald , et. al. Introduction to Aviation Management . Berlin: LIT Verlag, 2010

PRATHER, Daniel. Airport Management. Newcastle, Washington. Aviation Supplies & Academics, Inc 2015.

Vedoucí bakalářské práce: **Ing. Peter Olexa**

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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.

Tomáš Kříž
jméno a podpis studenta

V Praze dne .... 9. října 2020

Abstract

The subject of the bachelor thesis ”Diversion airport selection analysis in selected world polycentric urban areas” is the elaboration of an optimal procedure for the selection of alternate airports, which can be used for the optimization of flight planning by airline operators. The thesis analyses the problematics of flight diversion from different perspectives and based on these factors an algorithm is proposed for decision making in the process of alternate airports selection during the planning process. The algorithm incorporates operational and commercial factors determining the suitability of an airport as an alternate destination. Emphasis is put on the economic suitability of the airport in terms of minimising costs in case of flight diversion. The algorithm is then applied to the selected airports using real data and compared with actual operations. The result of the work is an optimized system for selecting an alternate airport in case of diversion from the destination, with the possibility of wider application and further elaboration when using the real-time shared data.

Keywords: Airport data, Airport Suitability Index, Flight diversion, Flight operations

Abstrakt

Předmětem bakalářské práce "Analýza selekce náhradních cílových letišť ve vybraných světových aglomeracích" je zpracování optimálního postupu výběru náhradních letišť, který může být použit pro optimalizaci plánování letů leteckými provozovateli. Práce analyzuje problematiku diverze letů z různých perspektiv a na jejich základě je navržen algoritmus pro rozhodování při výběru záložních letišť v průběhu plánování. Do algoritmu vstupují provozní a komerční faktory určující vhodnost letiště jako náhradní destinace. Důraz je kladen na ekonomickou vhodnost letiště z hlediska minimalizace nákladů v případě odklonu letu. Tento algoritmus je následně aplikován na vybraná letiště s použitím reálným dat a porovnán se skutečným provozem. Výsledkem práce je optimalizovaný systém výběru náhradního letiště pro případ odklonu od cílové destinace, s možností širší aplikace v případě použití dat sdílených v reálném čase.

Klíčová slova: Diverze letu, Index vhodnosti letiště, Letištní data, Letové operace

Acknowledgement

At this point I would like to thank my family, who supported me throughout my studies. Furthermore, I would like to express my gratitude to my thesis supervisor for his help with the selection of the thesis topic and its elaboration. I would also like to thank Ing. Michal Šalanda and Štefan Kukura from ABS Jets for providing valuable information from real operation.

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, 1st of June 2021 ....

Signature

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List of symbols and abbreviations used

ADEP/ADES	Airport of departure/destination
AED	Automated External Defibrillator
ARFF	Aircraft Rescue and Firefighting
ASI	Airport Suitability Index
ATC	Air Traffic Control
CAI	Current Availability Index
CPDLC	Controller-Pilot Data Link Communications
CTU	Czech Technical University in Prague
DME	Distance Measuring Equipment
EASA	European Union Aviation Safety Agency
ETOPS	Extended-range Twin-engine Operational Performance Standards
FAA	Federal Aviation Administration
FL	Flight Level
FOD	Foreign Object Debris
ICAO	International Civil Aviation Organisation
ILS	Instrument Landing System
KMCO/MCO	Orlando International Airport
MEL	Minimum Equipment List
METAR	Meteorological Terminal Air Report
MLW	Maximum Landing Weight
NM	Nautical Miles
NOTAM	Notice to Airmen
OCC	Operations Control Centre
RNAV	Area Navigation
RWY	Runway
SCF	System/Component Failure or Malfunction

SI	Severity Index
SPECI	Aerodrome Special Meteorological Report
KSRQ/SRQ	Sarasota Bradenton International Airport
SSR	Secondary Surveillance Radar
STAR	Standard Arrival Route
TAF	Terminal Aerodrome Forecast
TAF AMD	Amended Forecast
KTLH/TLH	Tallahassee International Airport
UTC	Coordinated Universal Time
VOR	VHF Omnidirectional Radio Range

Introduction

Flight diversion is a process of routing a flight from its original destination to a new one [13]. Alternatively, it can be described as a process of changing the aircraft's original route in-flight because of inability of the aeroplane to reach the desired airport of destination. For the purposes of this thesis, three types of diversion were identified. They are divided according to phase of flight, for simplification purposes named: after take-off, en-route and before landing. First one is after take-off or after departure. It can occur when an aeroplane is forced to interrupt its flight and return either to the airport of origin or to a best suitable destination close by shortly after departure. Second one, so called en-route diversion, occurs when flight crew decide to land at the airport along the planned route. Last diversion case takes place when there are factors preventing the flight from landing at the airport of destination. This paper is focused on the third type of diversion along with planning alternate airports for these cases.

Operators flying the same routes regularly usually use templates for planning the next flight, but these are always updated based on the current weather situation, airport availability and airspace situation. This process relies on the manual - human made inputs and is lacking on automation, hence increasing the possibility on human errors and subjective decision contrary to the objective demands. A unified process of selecting the optimal alternate destination airport during this phase of flight planning could bring higher automation in this process, resulting in higher efficiency of the Dispatch department and lowering its employees' workload. It could also contribute to more predictable traffic flow during unexpected events, as well as more efficient and even spreading the traffic in case multiple flights in the same area need to divert.

1 Theory

1.1 Difference between emergency landing and flight diversion

It is important to differentiate emergency landing from flight diversion. While the classification of every specific occasion is up to the operating airline, some general characteristics of each event can be defined. Emergency landing is considered to be a manoeuvre following a severe safety-threatening event preventing the flight from continuing (i.e. dual engine failure, structural damage to the aircraft, pilot incapacitation etc.). From the Air Traffic Control (ATC) point of view an emergency landing is when the flight crew declare a state of emergency (either via voice 'Mayday' call, Secondary Surveillance Radar (SSR) transponder code 7700 or Controller-Pilot Data Link Communications (CPDLC) message DM 56) and this is not cancelled by the time the aircraft touches down. A flight diversion, on the other hand, is performed as a precaution of possible further threats but with no presence of a direct danger. Such case, most likely to be misinterpreted as an emergency landing, should be a single engine failure, one system failure or abnormality. A flight diversion also ends on an airfield while an emergency landing might be terminated by a forced landing in the terrain or on water, respectively. [28, 34, 40]

Generally, there are two main reasons leading the crew decision to alter from their intended flight destination. The first of them occurs when there are factors degrading the airports characteristics, making the flight destination unsuitable for landing. This can be caused either by the airport closure, runway contamination, weather conditions or due to the decision made by the operating company/state of registration of the operator. All these reasons can be named ground located causes. In the second case, the aeroplane becomes unable to reach its destination due to in-flight cause (e.g., change of aircraft technical state).

Alternate airports are always planned in advance for every flight so that pilots know where they can divert to in every stage of flight even before getting on board. In airlines and bigger aircraft operator companies flight plans are created by Dispatch departments or Operations Control Centres (OCC). Weather situation and Notices to Airmen (NOTAMs) at destination and at the alternate airports as well as significant weather en route are considered. In either case when there is a need to divert, there is always a suitable airport included in the flight plan providing all the required properties guaranteeing safe diversion despite the reason of diverting. Even though the plan is not obligatory and flight crew have the right to divert to an airport they decide, choosing a non-planned alternate is very unusual.

1.2 Reasons for diversion

It is important to understand the causes of flight diversions from the planned airport of destination. As mentioned earlier, these can be divided into two groups according to where the cause is located. These groups are Ground-located and In-flight causes.

1.2.1 Ground-located causes

- **Weather**

  Most common reason for diverting a flight is weather situation at the airport of destination [31]. There are very precise forecasts and up-to-date weather reports available for all international airports. Despite the precise forecast models, especially in the limit cases, the weather can develop in the negative way preventing the safe continuation of the flight. This could mean either visibility is too low, the runway is too contaminated, or crosswind velocity is above the limits for safe landing at the airport. Similarly, a presence of the adverse weather phenomena (thunderstorm, cyclone, tornadoes, sand whirls, etc.) may prevent the aircraft from executing a safe landing manoeuvre. Pilots may decide not to land at the airport, even though it might be still operating, either because they are not equipped or trained for such weather conditions or they do not consider landing as safe. In an extreme weather conditions, the airport authority might decide to temporarily cease the airport operations, as well. In either case this would be classified as a weather diversion.

As an example, on the 10th of February 2020 at Václav Havel Airport Prague, when, during the Sabine hurricane, pilots of Qatar Airways flight QTR5EV from Doha, operated by Airbus A320, were not successful attempting to land due to strong wind and were forced to divert to Vienna.

That day, Terminal Aerodrome Forecast (TAF) was issued as usual, at 05:00Z by the meteorological office at the airport Praha/Ruzyně. This weather report forecasted wind velocity of 15 knots with gusts up to 30 knots with further specification expecting wind gusts at speed of 42 knots with decreased visibility, shower rain and low cloud bases with the duration as long as this TAF report. In the first hour of this forecast there was also a 40 % probability of thunderstorm rain with a 3000 m visibility and wind velocity of 36 knots, gusting up to 56 knots. According to the wind direction and runway direction, the aircraft would be experiencing 28 knot crosswind and almost 50 knot headwind gusts in the worst expected scenario. The TAF issued for the time the flight was scheduled to land read:

TAF LKPR 100500Z 1006/1112 22015G30KT 9999 SCT035 TEMPO 1006/1112
24027G42KT 7000 SHRA SCT020TCU BKN025 PROB40 TEMPO 1006/1007
27036G56KT 3000 TSRA BKN013CB PROB30 TEMPO 1100/1112 3000 SHRASN=

[25]

However, two hours and fifteen minutes after issuing this TAF, the weather forecast changed so significantly that an Amended Forecast (TAF AMD) had to be released. Main changes, in comparison to the previous one, were high wind velocity and gust intensity with low cloud base between 07:00Z 10th of February and 12:00Z 11th of February. The whole TAF AMD read:

TAF AMD LKPR 100715Z 1007/1112 23018KT 9999 SCT035 TEMPO 1007/1112
24027G44KT 7000 SHRA SCT020TCU BKN025 PROB30 TEMPO 1100/1112 3000
SHRASN=

[25]

The pilots attempted to land at the airport even though the weather conditions were poor. They were not able to get the plane on the ground safely, so they rather decided to divert to an alternate destination, in this case Vienna, instead of holding near Prague and waiting for the weather to improve. This decision was probably made because of the remaining fuel amount on board which is calculated to be enough for the route itself, an unsuccessful landing at the destination, flight to the alternate airport and emergency reserve. Pilots then acted according to the operational procedures. This decision also increased passengers' comfort and avoided risk of injury present when plane flies through turbulent environment, which was more than likely in the cloudy and stormy airspace with high wind velocity all around Prague that day.

The plane landed safely in Vienna later. After several hours, the weather situation over Prague improved allowing the Qatar Airways flight to be finished by arriving to Prague. No injury nor aircraft damage were reported.

Another example of weather situation at the destination forcing an aircraft to divert is Swiftair flight number SWT1906 from Cologne, Germany to Ostrava, Czech Republic on 8th of February 2021 [19].

During the flight, weather conditions in Ostrava worsened. 15 minutes prior to the planned landing an Aerodrome Special Meteorological Report (SPECI) was issued reporting snowing (previous Meteorological Terminal Air report (METAR) only reported light snowing) with visibility decreased from 6000 m to 1400 m, few clouds in 800 ft above ground and most importantly it included a message about runway contamination. The only runway at Leoš Janáček airport in Ostrava, Runway 04/22 (RWY04/22) was contaminated by 2 mm of compacted or rolled snow at more than 50 % of its surface resulting in braking actions medium to poor. The whole SPECI report:

SPECI LKMT 080518Z 35007KT1400 R22/P2000N R04P2000N SN FEW008 OVC023 M08/M09 Q0996 R04/890292 RMK REG QNH 0991=

[22]

Pilots attempted to land unsuccesfuly. The flight then entered a holding pattern waiting for weather conditions to improve. The snowing got stronger causing visibility to decrease by 50 % to 700 m. As the airport was not able to improve the friction on the runway, Swiftair pilots decided to divert to Wroclaw after 40 minutes of holding. When the weather in Ostrava allowed the crew to complete the flight, they arrived there 14 hours and 21 minutes after scheduled time of arrival. The entire route up to landing in Wroclaw is recorded and visualised in Fig. 1.1.

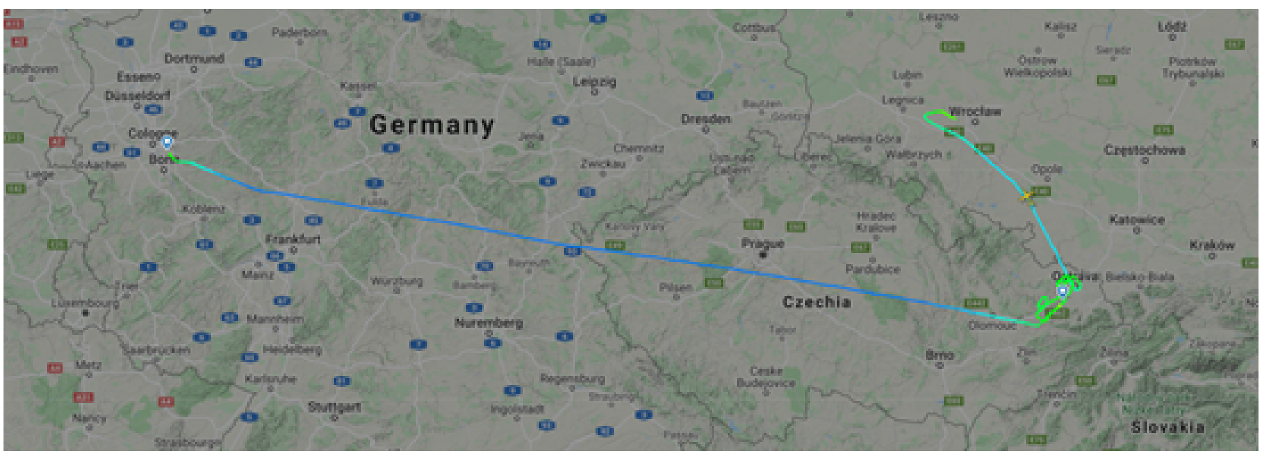

Figure 1.1: The flight route recorded by flightradar24.com [12]

- **Safety and security incidents**

  Airports are very sophisticated and complex parts of infrastructure; hence they are very sensitive to any malfunctions or disturbances. If any part of its critical systems fails as well as backups of these systems, the airport becomes partially or fully unable to accept any flight. There can be many reasons for this, like an electricity outage, damaged, flooded, occupied runway or, for example, a massive violent act against people or equipment at the airport. In these cases, the airport shuts down its operations until the problem is resolved, and all arriving flights are forced to divert to their alternates. As an example, let us look at the runway closure at Auckland airport, New Zealand [18]. This airport has only one runway to its disposal meaning whenever the runway needs to be closed for any reason, entire airport becomes unable to accept or depart any flight. This happened on 6th of February 2020. The airport was suddenly closed without any prior announcement forcing eight inbound flights to divert, ten to be rescheduled and five to be delayed. Also, about twenty outbound flights were either delayed on departure or cancelled entirely.

As Air New Zealand stated on its Twitter, the runway was closed because of an Foreign Object Debris (FOD) removal process. This corresponds to the stuff.co.nz website quoting the Auckland airport's spokesman saying that except for planned runway physical inspections and maintenance closures, occasional closures might take place if FOD removal or maintenance are required. Danger of presence of an FOD is captured on Fig. 1.2.

Airports have implemented procedures which should reduce the risk of an aircraft being damaged by an FOD, especially by regularly checking all the movement areas of the airport ensuring no FOD is present. Also, pilots or any airport employees can report spotting an FOD. The airport then checks the area and removes any object, which could possibly damage an aircraft. Except for procedural protection there are some technological systems preventing FOD damage as well. This might be, for example, an FOD radar or optical device (Fig. 1.3) monitoring movement areas' surface checking for any objects which should not be present at certain areas. But once FOD is spotted, no aircraft is allowed to get to that area and the FOD must be removed. The bigger and the farther from the maintenance' facility the FOD is found, the longer it takes to remove it safely. Sometimes it means even closing runway for a long time resulting in airport closure if there is no other in service.

A slightly different situation took place on the 17th of December 2017 in Hartsfield-Jackson Atlanta International Airport [38]. A fire in the electrical facility caused an

Figure 1.2: Example of an FOD strike [14]

electrical outage in the entire airport as a substation providing the place with electricity was damaged as well as a backup power supply.

The power supply was interrupted for eleven hours leaving all terminals and airport facilities with no power [39]. The only part of infrastructure that continued its operations was the Control tower equipped with an independent backup electricity power system. As the airport was not able to accept or depart any passengers, the tower issued a 'ground stop' meaning all flights scheduled to arrive or depart from Atlanta International that were still on the ground were not allowed to take off.

Hartsfield-Jackson was the busiest airport in the world by number of passengers for more than twenty years. It also serves as a main base to one of the biggest airlines in the world [42], Delta Air Lines. More than a thousand flights are estimated to have

Figure 1.3: Example of an FOD detector combining radar and optical technologies [14]

been cancelled due to the airport closure at the day with over 300 more being cancelled the next day. Delta itself diverted 48 flights inbound the Atlanta International that day. Flights which landed shortly prior and after the outage were not allowed to deplane the passengers for up to six hours after landing, often running out of water resulting in toilets being inoperative. Flight paths of some affected flights are shown at Fig. 1.4 and Fig. 1.5.

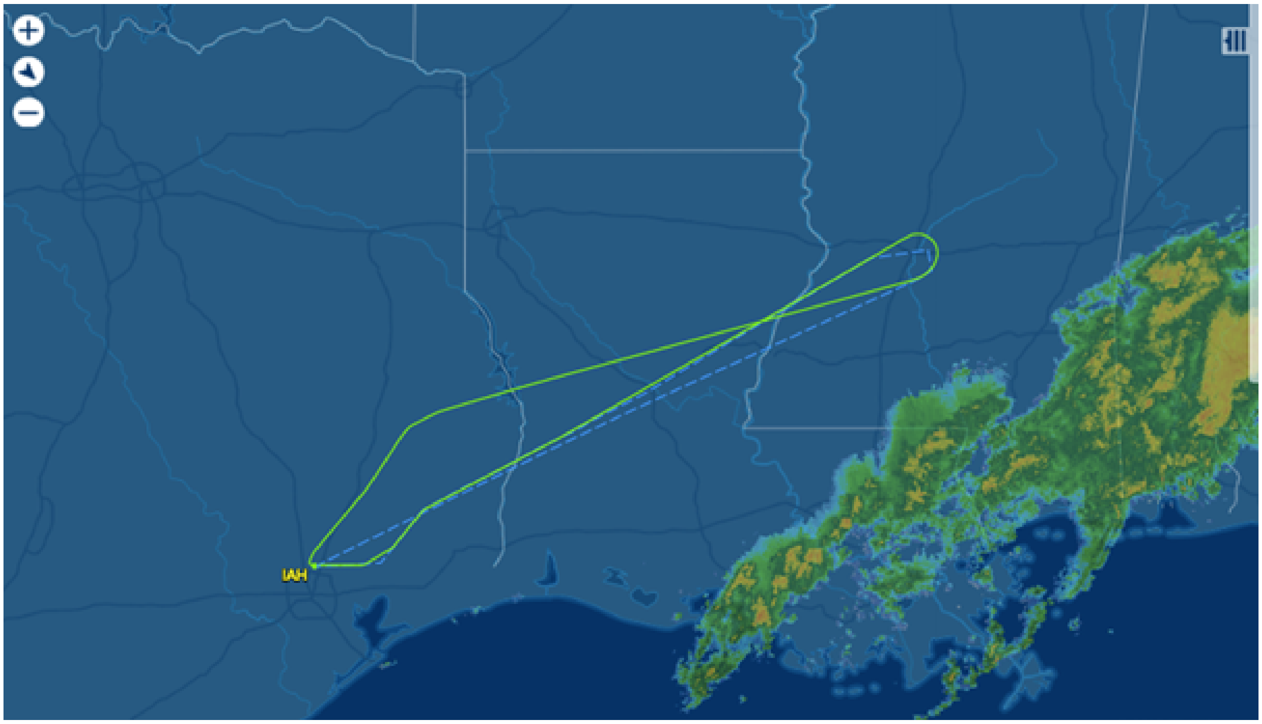

Figure 1.4: United flight 672 returned to the airport of departure [30]

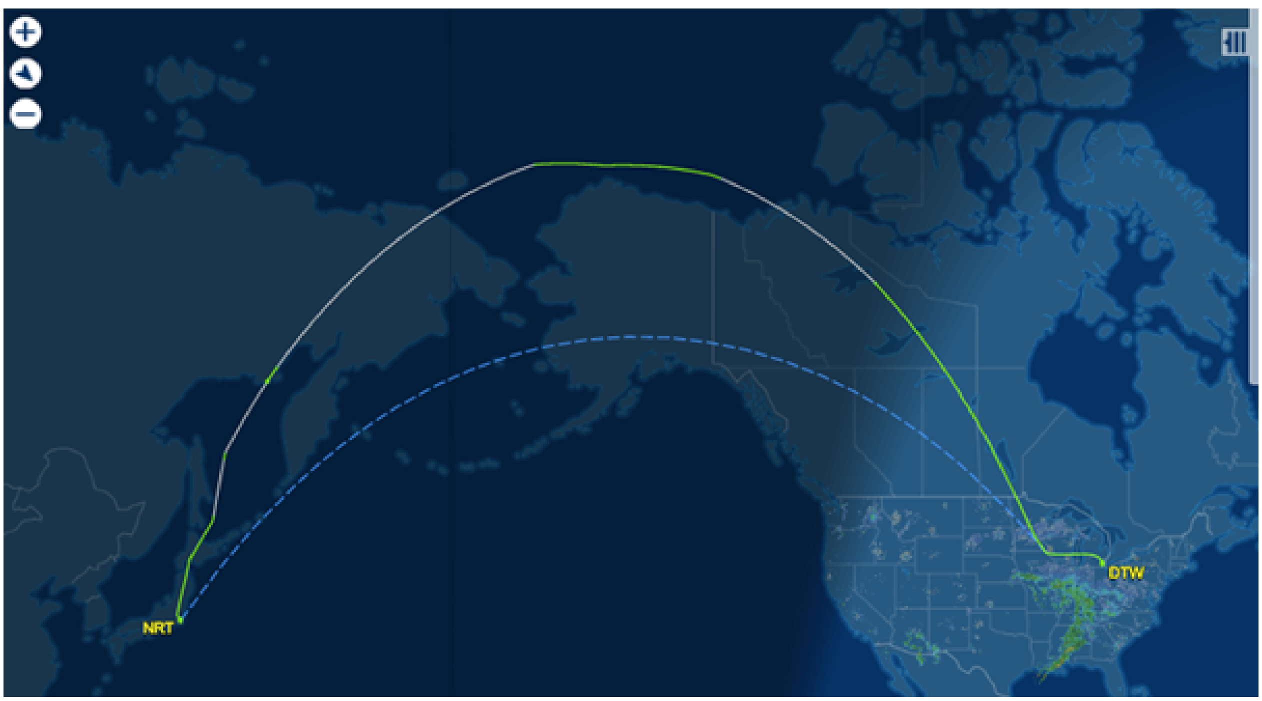

Figure 1.5: The intercontinental Delta flight, number 296, diverted to Detroit. [30]

Also, thousands of people were stuck at the terminal, where there was no way to get accommodation, food, even water from drinking fountains as they were all powered by electricity. After sunset there was lack of lighting inside the buildings, as captured at Fig. 1.6.

Figure 1.6: A hall lit by gas-powered floodlights. [38]

1.2.2 In-flight causes

- **Health-related occurrences**

In 2018 there were more than 1,8 million aircraft movements recorded [9] in the European air space with 4,3 billion passengers transported [1]. This number of passengers represents a significant chance that some of them will experience serious health problems during the flight. For this reason, flight attendants are trained to help passengers with their medical issues. European Union Aviation Safety Agency (EASA) requires [7]all flight attendants to be trained in providing the first aid in these situations, at least: Air sickness, hyperventilation, burns, wounds, the unconsciousness, fractures, soft tissue injuries. Then there are some more serious health issues flight attendants must be capable of dealing with, for example asthma, allergic reaction, shock, diabetes, choking, epilepsy, childbirth, stroke and heart attack.

The U.S. Bureau of Transportation Statistics states [5] 1,02 billion passengers were transported by 10.012 million flights operating both domestic and international routes in the USA in 2018. It is estimated [20] that an in-flight medical emergency will occur with 24 to 130 per 1 million passengers transported annually. These emergencies result in either emergency landing or diversion. The diversions for medical reasons were summarised in a review called In-Flight Medical Emergencies: A Review (Tab. 1.1) [20]

Planes carry limited medical equipment needed for solving these situations [3]. There are basic household medicaments, painkillers, antihistamine and some medical supplements for treating minor wounds and injuries, e.g. disinfection, plasters and bandages. For more serious conditions there are instruments and devices available as well. These are preferably used by a doctor, as they include blood pressure gauge and stethoscope, equipment to free the airway, syringe and transfusion agents and oxygen supply. Many airlines also have an Automated External Defibrillator (AED) on board. With this equipment most life-threatening situations might be handled well. In the USA the minimum requirements [20] for emergency medical equipment include AED, equipment to obtain a basic assessment, haemorrhage control, initiation of an intravenous line and medications to treat basic conditions.

Some health conditions might be so serious they might require change of the planned route in order to provide the passenger with professional health care as fast as possible. This re-routing might have two main reasons: More expeditious landing at other airport than at the destination or better accessibility of health care at the alternate [35].

Table 1.1: Frequency of Aircraft Diversion for In-Flight Medical Emergencies by Christian Martin-Gill et al. [20]

Source	**Study details**	**Total No. of In-Flight Medical Emergencies**	**No. (%) [95% CI] With Diversions**
Peterson et al, 2013	5 Airlines, 34 mo	11 920	875 (7.3) [6.9-7.8]
Mahony et al, 2011	1 Airline, 108 mo	11 326	276 (2.4) [2.2-2.7]
Sand et al, 2009	2 Airlines, 60 mo	10 189	279 (2.7) [2.4-3.1]
Valani et al, 2010	1 Airline, 60 mo	5386	220 (4.1) [3.6-4.6]
Hung et al, 2013	1 Airline, 60 mo	4068	46 (1.1) [0.8-1.5]
Weinlich et al, 2009	1 Airline, 36 mo	3364	94 (2.8) [2.3-3.4]
Kim et al, 2017	1 Airline, 48 mo	2818	15 (0.5) [0.3-0.9]
Delaune et al, 2003	1 Airline, 12 mo	2279	181 (7.9) [6.9-9.1]
Sirven et al, 2002	1 Airline, 72 mo	2042	312 (15.3) [13.7-16.9]
Kesapli et al, 2015	1 Airline, 36 mo	1312	22 (1.7) [1.1-2.5]
DeJohn et al, 2000	5 Airlines, 12 mo	1132	145 (12.8) [10.9-14.9]
Szmajer et al, 2001	1 Airline, 120 mo	380	37 (9.7) [6.9-13.2]
Cummins and Schubach, 1989	1 Airport, 12 mo	192	7 (3.6) [1.5-7.4]
Baltsezak, 2008	1 Airline, 12 mo	191	6 (3.1) [1.2-6.7]
Total		56 599	2515 (4.4) [4.3-4.6]

The second case is less likely as airlines might not have relevant information about medical equipment and personnel available at the particular airport. And if the patient's condition requires a flight diversion, there is usually not much time left and expeditious landing is an absolute priority for the crew.

As an example of the flights diverting due to passenger's medical issues there were two cases examined. First of them took place over the Pacific Ocean on 10th of January 2020. Air Canada's Boeing 787 Dreamliner operating the flight nr. ACA035 from Vancouver, Canada to Brisbane in Australia diverted to Honolulu airport [8] because a passenger suffered from serious medical problems on board [41]. Airline did not provide any specific information about the passenger's medical problems or state after landing. However, according to several news agencies [37, 27], the passenger was ill before boarding the aeroplane and died before the plane got to the nearest airport. This is a disadvantage of long-haul transoceanic flights that there are no airports for long distance available, therefore it might take hours these flights to get on the ground. There was nothing more pilots could do.

In case like this the airline should not only arrange proper medical care for the ill passenger, but also take care of the rest of the passengers as well as the crew. In this case, the flight was not able to continue flying after the sick passenger was handed over to medical personnel, most probably because the flight crew would exceed the maximum duty time. Therefore, the airline arranged accommodation and food services for all passengers and crew in Hawaii, where they stayed until the crew were ready to finish the flight to Australia.

The second incident took place over Paris on board EasyJet's evening flight EZY8485 from Geneva, Switzerland to London, United Kingdom [29]. According to the AIRLIVE's post on Twitter the flight declared an emergency when flying near Paris and diverted to Paris Charles de Gaulle airport shortly after that. The airline confirmed [17] the flight diversion was caused by a passenger's poor medical state. After the passenger was taken to the hospital, the flight continued to London.

This flight differs from the previous one especially by its length. It was scheduled for only 30 minutes and the route was planned over densely populated areas of western Europe with many suitable alternate airports. This provided the crew with many possibilities to land as fast as possible and they could be certain a proper medical service would be available at the airport of diversion. After the sick passenger was taken care of the pilots still had enough time to take off again and land at the original destination before they had to stay on ground for a mandatory rest. In this case, there was no need to provide the rest of the flight's passengers with any extra care, even though some airlines provide them at least with an assistance with transferring to their next flight after such delays.

- **Technical**

  As aircraft are complex machines, there is certain risk of their malfunction. In majority of cases, it is not a serious problem and it does affect the flight execution just in a minor way. However, there can also be more serious malfunctions jeopardising safety of the flight. In 2019 International Civil Aviation Organisation (ICAO) received reports [16] of 13 accidents or serious incidents in the System/Component Failure or Malfunction (SCF) occurrence category, two of which were related to the aircraft powerplant. In cases the flight crew notice such malfunction, they might decide to divert to the nearest or the most suitable airport.

  For example, if the malfunction would not endanger the flight but might preclude another take off, pilots might decide to divert to an airport offering better technical services or to an airport where the airline operating the flight might have contracted a technical company able to solve the malfunction.

  On 6th of July 2020, a Delta Airlines Airbus A319 operating flight DL1076 from West Palm Beach to New York La Guardia Airport experienced navigation problems after flying through hail while on approach to its final destination [33]. The flight diverted to JFK Airport and landed safely. An inspection discovered severe damage (Fig. 1.7) to the aircraft's radome – a cone located in the very front of the aircraft providing protection to a weather radar and Instrument Landing System (ILS) localizer and glide path antennas. This cone is made of composite materials which allow the radar rays go through without interference but in cost of lower durability in comparison with metal.

  The aircraft entered poor weather conditions shortly after reaching the top of descend. Thunderstorms were observed in that area of the United States together with heavy hailing. The hails were estimated to have the diameter up to 1,5 inches (3,8 cm) [21]. Colliding with radome it is likely to cause serious damage. As a consequence, the hardware shielded by the radome could be damaged as well causing several failures to the aircraft systems.

The flight crew had no way to find out, how extensive the damage was until landing. As per the Federal Aviation Administration (FAA) investigators report, they had navigation issues. Considering poor meteorological conditions, the pilots decided to land as quickly as possible (Fig. 1.8) at the nearest suitable airport, which was JFK.

Following SPECI message describes current weather situation in that area:

SPECI KLGA 062229Z 12010KT 10SM -RA FEW060 BKN100 BKN250 25/18
A3003 RMK AO2 LTG DSTN E TSE23 CB DSNT E MOV SE P0001 T02500178=

[23]

Figure 1.7: Damaged radome after flying through hail [26]

Figure 1.8: DL1076 planned (blue) and real (green) route through significant weather [21]

A more avoidable incident affected the Norwegian flight NAX 1933 en route from Dubai to Oslo on the 14th of December 2018 [32]. The flight with 180 passengers on board diverted to Shiraz, Iran after an engine failure. Reportedly, the flight crew received a low oil pressure warning in engine number 1. To prevent it from further damage they shut it down and after reducing the aircraft total weight under the maximum landing weight (MLW) the aircraft landed in Shiraz Shahid Dastgheib International Airport safely.

A replacement flight was arranged to transport the passengers to their destination. There were two mechanics on board the repositioning flight from Oslo to Shiraz who were supposed to prepare the damaged aircraft for flying to a maintenance facility. However, the damage to the engine was found to be too serious resulting in need to replace the engine with a new one. It is worth mentioning this aircraft was only 6 weeks old.

After struggling with sanctions enforced by the U.S. government the airline got a new engine to the airport and flew the aircraft to Stockholm after 10 weeks being inoperative.

- **In-flight security**

Last, but not that rare reason for a flight diversion is a direct flight safety threat such as a passenger's behaviour disturbing or even endangering other passengers, flight crew or the aircraft equipment. In this case, if the crew are not able to calm the passenger down, pilots might decide to divert to the nearest airport in order to deplane the unruly passenger as soon as possible. A bomb threats also belong into this category as it affects the flight directly meaning a serious risk caused by a security failure.

One such threat was discovered during United Airlines flight UA971 from Rome to Chicago on the 11th of June 2018 [2]. A message referring to a bomb on board was found in the bathroom. The flight crew made a decision to divert to Shannon Airport after dumping some fuel reducing the aircraft weight bellow its maximum landing weight. After landing all 207 passengers were searched as well as their luggage and handwriting samples were taken in order to find the author of the threat.

Another case breaching a flight security took place on the 14th of June 2020 over southern Canada [6]. A WestJet Boeing 737 operating flight WS706 from Vancouver to Toronto was forced to land in Winnipeg after a passenger lit a cigarette refusing to comply with flight attendants' instructions.

These days almost all airlines have imposed the bans of smoking in-flight as there is high risk of fire which means a serious threat to the flight safety as it could compromise the airframe integrity. Violating this rule could cause the decision to divert on its own. However, the incident happened during the worldwide SARS-CoV-2 (also known as COVID-19) crisis when many hygiene requirements were implemented in order to minimise spreading the disease. One of the most common ones was wearing a face mask inside public buildings and means of transport, including aircraft. The unruly passenger broke this rule and refused to comply with it even after being asked by cabin to do so.

After an unscheduled landing at James Richardson International Airport in Winnipeg (Fig. 1.9) the passenger was arrested by Royal Canadian Mounted Police and taken into custody. A person offending the Canadian directive enforcing wearing face masks can be fined up to 3,700 US dollars. After refuelling the flight continued to Toronto with a 90-minute delay on arrival.

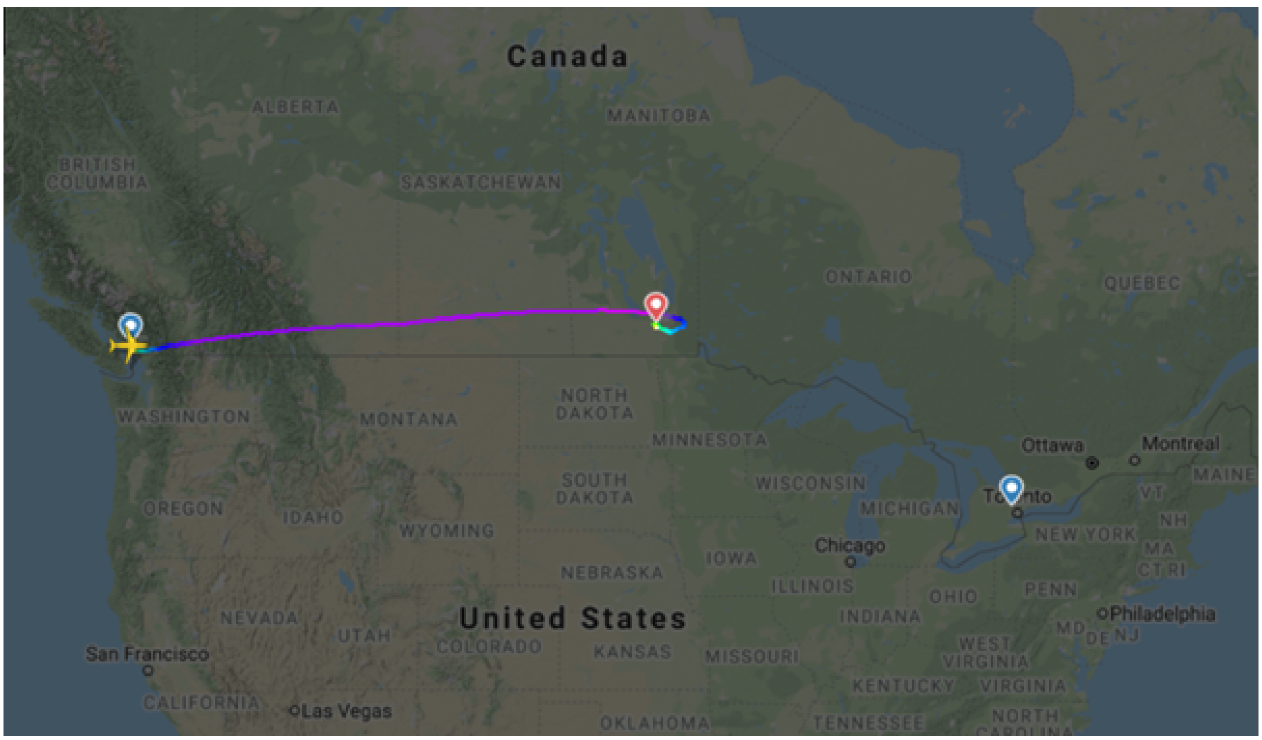

Figure 1.9: Flight WS706's diversion flight path [6]

Some less obvious or unusual bearings might occur in rare cases. These could be political or economic changes affecting relations between companies or even countries during the flight. For example, declaring war between the country of origin and destination would most probably result in diversion so that the plane would not land on enemy's land. The same could happen if landing at the destination airport would become highly unprofitable for the airline. However, it is highly unlikely to experience any of these diversions as such change would have to happen during the flight. It usually takes more than a few hours to these events to happen without any previous sign.

All the disturbances listed above, once they occur, require reaction of a flight crew which needs to use a back up airport for landing. Finding the best suitable one at the moment it is needed, is not possible as it is time-consuming and requires detailed information which might not be available for the crew. Also, many regulations need to be considered when selecting an alternate airport. Therefore, these alternates are selected during the pre-tactical phase of flight planning, which is a substantial part of flight operation.

1.3 Diversion impact on aircraft operator

Flight operation is a complex process consisting of numerous services and procedures. Most of these are vital and need to be performed prior, during or after every flight. As demand for these services grows and flight operators are aiming to become as efficient as possible, the entire process or serving a flight needs to be scheduled thoroughly in advance, sometimes even months before the flight happens. This planning counts on precise timing and delays have highly negative impact to the entire process, no matter the cause. This basically means that delayed flights cause loss of money and diverted flights generate significant extra costs. For example, Alexander Grous from The London School of Economics and Political Science estimates in his report [15] that even a 10 % reduction in flight diversions caused only by medical emergency, could save the airlines over 55 million dollars only in the United States. By 2025 this estimation grows up to 72 million dollars. Therefore, it is highly reasonable to make diversions as efficient as possible.

No matter whether the flight terminates at the alternate or continues to the final destination later, there is some minimal pack or services required for every landing and therefore several charges must be paid. As these services are not requested in advance extra fees might be charged for the ad hoc provision.

As the aircraft lands on an airport's runway, the operator must pay a landing fee. The larger the airport is the higher landing fee is normally charged. Also, the weight of the aircraft influences the price. The aircraft needs a place for parking, either a stand on the apron or a remote stand. Using these is also a subject of charges. Any extension of the flight duration results in extra costs like fuel consumption or crew wage. Every cycle (landing) also expedites the depreciation of the airframe, engines and other parts of the aircraft requiring more frequent maintenance costing more money.

Following paragraphs provide an analysis of the specific expenses arising when a flight is diverted. As described, there are two scenarios of consequences following a flight diversion, each of them resulting in different extra costs. A reason forcing the flight to deviate from its planned route is also crucial as it may result in need of additional care for passengers and/or the aircraft.

1.4 Diversion recovery

1.4.1 Continuing to the final destination

The aircraft might be forced to land at an alternate airport either because the final destination became unable to accept this arrival or because a status of the flight required an assistance provided on ground which would not be available at the destination.

If the status of the airport of arrival did not allow the flight to land there, it could be caused either by significant weather in the area or due to the state of the active runway or other ground facility and the airport operation was not expected to be resumed before the aircraft would reach a critical fuel level in case of holding near the airfield. However, if the forecasted weather situation is about to improve it might be considered as better decision to divert to an alternate and once the situation improves, finish the flight with some delay.

Every operator needs to decide how long delay might be acceptable. This depends, among others, on the distance between the airports.

This decision leads to increased time spent on the alternate airport and therefore to higher costs for the parking spot. It might be also necessary to refuel the aircraft for the flight to the destination. Depending on the weather situation external air conditioning might be required as well as an external electrical power source. According to the time spent on the ground, accommodation for passengers and/or crew might be required, further increasing the costs.

A more speculative but still possible event would be a medical or safety diversion with a situation under control but still requiring a ground assistance. In case the required services were not available at the destination a diversion might be considered to provide better assistance to solve the situation.

1.4.2 Terminating at the alternate

Several aspects might precede the decision to terminate the flight at the alternate airport, part of which depend on the cause of a diversion. It can simply be caused by the original destination not expected to become available in some certain period of time in which case it might be faster and/or more comfortable for passengers to reach their destination by other means of transport. This would result in need of refunding the passengers for not reaching the destination.

A similar situation could be caused by a diversion due to a technical problem. If the malfunction would not endanger the pending flight but after landing it would not correspond to the Minimum Equipment List (MEL) of the aircraft an alternate airport with a suitable maintenance equipment might be chosen for landing. This would be especially applicable on regional lines serving remote airports.

Costs related to the termination of a flight are considerably higher in comparison to finishing the flight eventually. The operator is charged for terminal facility used by its passengers expectably with extra charge for the ad hoc provision. The aircraft might need full service such as cleaning, catering or lavatory services. Depending on the next flight length, an accommodation for the crew might be required together with a parking spot for the aircraft, and the fuel service as well. Also cancelling ordered services at the original destination might be a subject to cancellation fees and fines.

Either of these cases has its pros and cons and should be considered during the alternate airport selection. But not only these. Different airports might provide different level of services required based on the cause of diversion. This paper suggests the airports suitability for being used as an alternate should not only be driven by regulation requirements, but also by economical impact of landing at the particular airport. To compare these impacts an evaluation process is suggested bellow.

2 Methodology

2.1 Criteria used by operators to select an alternate

As there is no methodology for alternate airport selection, flight planners only follow requirements or preferences of the specific flight. According to available publications [36] the factors determining the alternate airport selection can be generally divided into two groups where the first one determines the ability of aircraft to land while the other one influences recovery from the diversion:

2.1.1 Basic factors

Basic factors (safety and performance) – mandatory items expelling the airport from suitable options if any of those does not fit the required values (different aircraft types have different minimal requirements.

- Airport operational, physical and technical characteristics to accept the aircraft type at given time (RWY length, equipment, pavement classification number, opening hours, curfews, NOTAMs, etc.) – the aircraft must be able to land safely at the airport and requires certain minimal equipment and services
- Weather conditions (visibility, runway visibility range, wind velocity and direction, runway contamination, precipitations) – weather situation at the alternate airports should preferably be good as this is the backup and no further change of route might be possible if the weather conditions are poor
- Distance from the intended route and destination (fuel planning, Extended-range Twin-engine Operational Performance Standards (ETOPS)) – the alternate must not be out of reach and a certain fuel reserve must remain onboard even after a flight diverting
- Other (pilot licenses, training, crew and equipment certification, etc.) – any other legal requirements not mentioned above

2.1.2 Commercial factors

Commercial factors (economical and operational impact) – considered after Basic factors to reduce the economic impact of a diversion.

- Company policies – agreements with other operators and companies operating at the alternate, other preferences
- Relative proximity of the diversion location (both along the planned flight route and from Airport of departure/destination (ADEP/ADES)) - as a passenger well-being factor (Ryerson, 2018) – affects options for getting passengers to their final destination
- Level of airport infrastructure (airport size, available services, fire category, length of Standard Arrival Route (STAR)) – allows reduce costs and time of flight as well as providing extra comfort and safety facility
- Airline own infrastructure (own or contracted airline staff present on the location) – reduces extra costs significantly
- Existence of agreements with the handlers, fueller and other stakeholders – might reduce the ad hoc charges while maintaining consistent level of service quality; easier communication
- Experiences with the given location – improves safety, prevents errors and reduces crew workload
- Other commercially important and detailed factors (hotels availability, transportation possibilities, political situation, etc.) [36] – increased comfort for passengers and crew

The suggestion of this paper is to enlist all the airports complying with the basic factors, as these must be always within limits and requirements, and then evaluating these airports by economical factors as well. The expected result is that a flight might end up diverting not to the nearest suitable airport, but to the most convenient one from the view of reducing costs.

2.2 Airport suitability index

In order to compare airports according to their suitability for diversion, certain characteristics were chosen and listed in Tab. 2.1. These are considered to be the most defining for the process of an alternate airport selection.

Table 2.1: Certain airport suitability for diversion

Order	Name	Severity Index	Current Availability Index
1	Airport characteristics	3	
2	Weather	3	
3	Fuel on board, ETOPS	3	
4	Training, licences and other	2	
5	Company policies	1	
6	Transport to the destination	1	
7	Airport infrastructure	2	
8	Flight operator's infrastructure	1	
9	Services agreements	1	
10	Location familiarity and difficulty	1	
11	Services for passengers	1	

Each of these characteristics is valued by a Severity Index (SI) representing importance of the specific characteristic for the overall evaluation of the airport. Values of the SI are described in Tab. 2.2. Values of the SI used in this thesis are suggested by the author and come from a subjective general understanding of airline needs. However different air transportation companies might assign different values to these categories based on their business models, company policies, fleet abilities and many other requirements and restrictions. Therefore, these suggested values might be adjusted for every potential user individually and this thesis only provides an example of application.

Table 2.2: Severity Index scale

1	Low importance
2	Medium importance
3	High importance

As these actual characteristics will change in time, a current availability section is added to the evaluation. This part is filled for every considered airport according to the most recent data available. To express a current state of the characteristic a Current Availability Index (CAI) is used. Its values are defined in Tab. 2.3.

Table 2.3: Current Availability Index scale

1	Available
2	Limited
3	Unavailable
X	NO GO (bellow limits)

To get an ability of a simple and consistent evaluation of the chosen airport allowing comparing it with the others, previously mentioned charts will be used to calculate the overall Airport Suitability Index (ASI). The calculation formula stands as follows:

$$ASI = \sum_{i=1}^{j} SI_i \cdot CAI_i \qquad (2.1)$$

where ASI is Airport Suitability Index, $i = 1, ..., j$, j stands for number of evaluated characteristics, SI_i is Severity Index of the chosen characteristic and CAI_i is Current Availability Index of the chosen characteristic.
The ASI will then be compared between the airports. The lower the ASI gets the more suitable the airport is for the flight to divert to.

3 Application

To examine functionality of the suggested process of evaluation, a real-world data application is provided. State of Florida was chosen for this purpose as a polycentric region with several international airports located relatively close to each other. Unlike in other regions with fewer airports suitable for diversions, the density of possible alternate airports in this state reduces the advantage of proximity to the destination, which is usually one of the most considered variables. Therefore, other criteria must be considered in order to select the most suitable alternate airport. Several diverting flights of Delta Air Lines were chosen and analysed using the suggested method and then compared to the actual course of the diversion. Delta was chosen because it is one of the biggest operators in the North American region with statistically relatively high chance of flight diversion. It also operates several flights to different airports in Florida and there is an active relation between the airline and CTU providing access to some further information if needed.

As the author does not have access to a database of flight diversion with the information of cause of diversion included, only flights scheduled to Florida destination diverting to another airport located in the state of Florida were chosen so that it could be classified as a diversion from destination.

3.1 Model situation

For real-world application let's consider planning a Delta Air Lines flight 1152 from Atlanta to Tampa (Fig.3.1), operated by a Boeing 737-900. According to the Bureau of Transportation Services' statistics for 2019, Delta flights on this route diverted to either Orlando International Airport (KMCO), Sarasota Bradenton International Airport (KSRQ) or Tallahassee International Airport (KTLH). These airports will therefore be evaluated in order to find out which of these might be the best suitable for the airline to divert to. As there is no information about reasons of diversions, only airports located on Florida were taken into account so that the diversion could be considered from destination. The current state will be related to the day of 20th May 2021 at 14:00 UTC as this is very close to the estimated time of arrival of an actual.

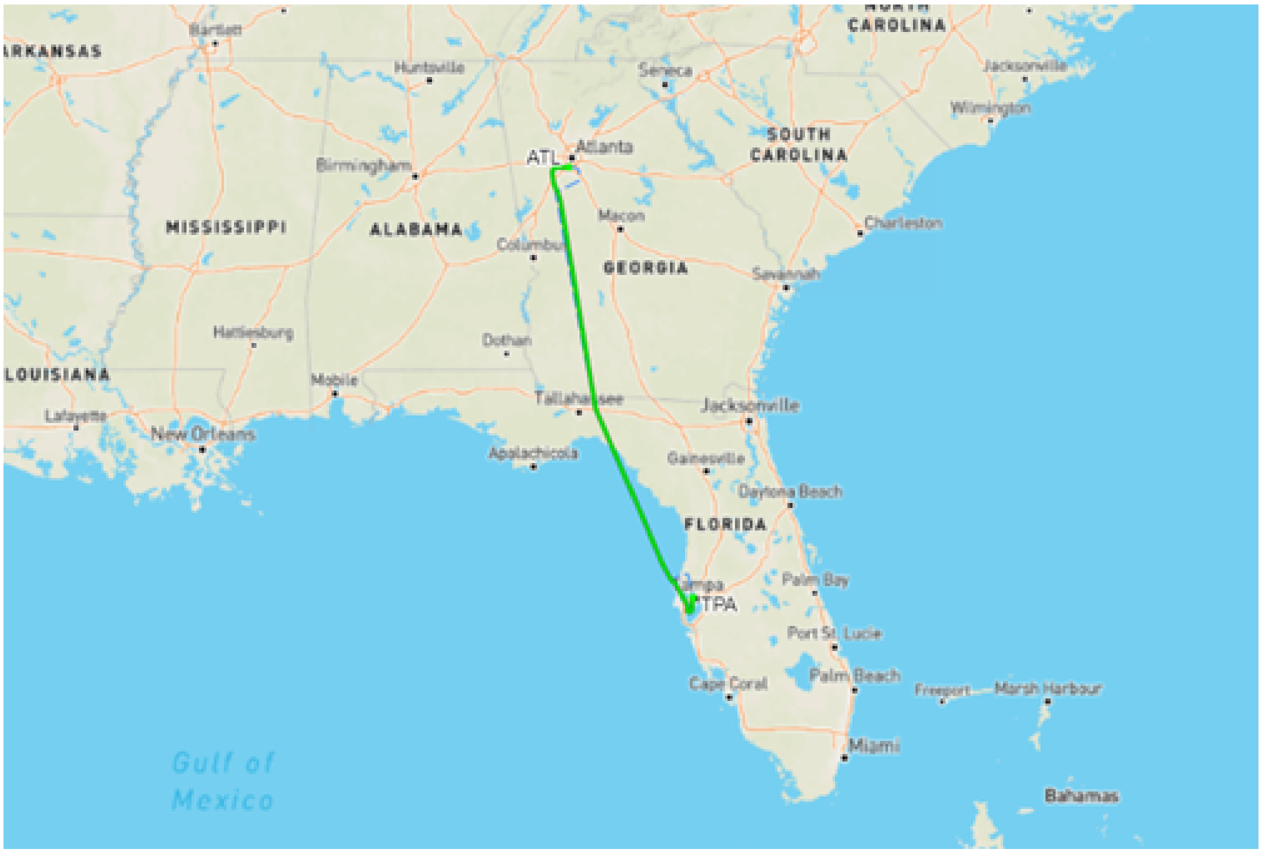

Figure 3.1: Route of the examined flight [11]

Throughout the thesis only the IATA airport codes will be used and the results presented in the same way. Usage of the IATA airport codes is more common in the airline management.

3.1.1 Orlando International Airport (KMCO/MCO)

Table 3.1: Orlando International Airport

Order	Name	Severity Index	Current Availability Index
1	Airport characteristics	3	1
2	Weather	3	2
3	Fuel on board, ETOPS	3	1
4	Training, licences and other	2	1
5	Company policies	1	1
6	Transport to the destination	1	1
7	Airport infrastructure	2	1
8	Flight operator's infrastructure	1	1
9	Services agreements	1	1
10	Location familiarity and difficulty	1	2
11	Services for passengers	2	1

ASI (MCO) = 24

There are 4 parallel runways available at the MCO airport with lengths varying between 9,001 feet and 12,004 feet. Current state of the airport is not optimal for flight diversions as there were 82 NOTAMs (Notice to airmen) [10] published by the date of interest. However, Delta Air Lines performs more than 50 scheduled flight [4] to this airport every day meaning the flight planning department is well aware of all restrictions and changes in force meaning they can provide the crew with all information needed without any extra effort. The fire category of the Aircraft Rescue and Firefighting (ARFF) reaches the highest, E level. This might be useful for technical diversion with higher risk of fire or other dangers for the aircraft related to landing. On the other hand, the Orlando International is said to be the 8th busiest airport in the U.S. which might not be an optimal environment for an irregular operation. But the overall status of the airport characteristics corresponds to the CAI value 1 in Tab. 3.1.

METAR issued shortly before 14 o'clock UTC includes information about 1-2/8 sky covered by the lowest layer of clouds at Flight Level 044 (FL044), which is no factor. The wind of 16 knots with gusts up to 27 knots coming from direction of 070° [24] means a 15-knot (25-knot gusts) crosswind for all runways. Some showers were reported in the vicinity of the airport. TAF for the time of estimated landing period forecasts the wind velocity to be at 16 knots with gusts up to 27 knots, which is close to the aircraft limit (33 knot crosswind). This is still within tolerance, but far from optimal, thus the weather CAI reached value of 2.

MCO is located approximately 70 nautical miles (NM) to the east-northeast from TPA. As the original flight only takes about one hour and thirty minutes there is enough capacity for extra fuel required to divert to this airport, therefore no limitations occur, and the third characteristic is fully available.

There are no special training requirements issued for MCO.

Numerous bus charter companies are operating in the city of Orlando. Transportation of passengers to the destination would therefore be possible.

Company policies are not well known in relation to the specific airports. However, judging by the number of flights Delta operates to MCO daily it is expected to be an acceptable choice from this point of view.

As mentioned earlier there are many NOTAMs issued at the airport informing about numerous limitations of the airport infrastructure, like closed taxiways or RWY 17R/35L. But no critical limitations were found.

As a result of many Delta flight coming to the airport, presence of airline's own facility is expected. This might include offices, check-in desks, claim desks or flight crew background. Also, service agreements are expected to exist for handling, catering, passenger-related services or maintenance. Characteristics number 8 and 9 are therefore valued by 1.

The airport belongs to the biggest and busiest ones in the country. Pilots might be familiar with it as it is likely they have flown there in the past. However, the complexity of the airport requires some extra preparations which might not be stressed enough during pre-flight briefing as the airport only serves as an alternate. This might result in higher workload for the crew increasing stress and possibility of error. Difficulty of flying to the airport is therefore valued by 2.

Advantage of the airport size is number of services available for passengers, like numerous hotels, restaurants and overall comfortable environment providing comfort for waiting for a flight transporting them to the destination. The services' CAI reached 1.

3.1.2 Sarasota Bradenton International Airport (KSRQ/SRQ)

Table 3.2: Sarasota Bradenton International Airport

Order	Name	Severity Index	Current Availability Index
1	Airport characteristics	3	2
2	Weather	3	2
3	Fuel on board, ETOPS	3	1
4	Training, licences and other	2	1
5	Company policies	1	1
6	Transport to the destination	1	1
7	Airport infrastructure	2	1
8	Flight operator's infrastructure	1	2
9	Services agreements	1	1
10	Location familiarity and difficulty	1	1
11	Services for passengers	2	1

ASI (SRQ) = 27

Even though the runway system at Sarasota airport consists of two almost perpendicular runways, only one of them is long enough to accommodate a Boeing 737 landing under maximum landing weight on wet runway. The aircraft also cannot be fully loaded on take-off as the runway length would not be sufficient. Also, the airport only reached C level of the ARFF. Therefore, the CAI of Airport characteristics reached 2 in Tab. 3.2.

The weather reports include wind of 18 knots with gusts up to 28 knots from direction of 110°, resulting in a crosswind of up to 14 knots. This is within tolerance for the aircraft but still considered limiting by the author as the wind velocity is not consistent and requires frequent and significant corrections, especially shortly before landing. This wind condition is forecasted not to change before 01:00 UTC the next day. For this reason, weather conditions are valued as 2 at this airport.

The SRQ airport is located only 35 NM to the south of Tampa not requiring a lot of fuel.

There are no known requirements for additional certification or training restricting crews or aircraft from landing here.

To transport passengers form Sarasota to Tampa a bus service could be used. Several bus charter providers are located in Sarasota providing enough capacity to transport all the passengers to Tampa. The estimated duration of the ride is one hour and thirty minutes.

The infrastructure of the airport is suitable for this flight as there are many regular connections terminating there operated by this or similar aircraft types.

Delta Air Lines operates the average of nine flights a day to Sarasota airport. It is not expected for Delta to have its own facility there as the airport is smaller and the volumes of passengers transported to and from there are estimated to be lower than, for example, at MCO.

Regular operations on daily basis suggest existence of an agreement for providing the flights with necessary services, therefore it might not be a problem to provide these to a diverted flight as well.

The flight crew might not be fully familiar with the airport, however no special procedures were found for this airport. And as the traffic is not very dense, there should be no problem for the pilots to land there.

Also, the airport is categorised as international, meaning there are all necessary services available for the passengers, including several hotels – biggest of them offers 294 rooms - and all of them are located within 10 minutes from the airport.

3.1.3 Tallahassee International Airport (KTLH/TLH)

Table 3.3: Tallahassee International Airport

Order	Name	Severity Index	Current Availability Index
1	Airport characteristics	3	2
2	Weather	3	1
3	Fuel on board, ETOPS	3	1
4	Training, licences and other	2	1
5	Company policies	1	2
6	Transport to the destination	1	2
7	Airport infrastructure	2	2
8	Flight operator's infrastructure	1	3
9	Services agreements	1	3
10	Location familiarity and difficulty	1	1
11	Services for passengers	2	2

ASI (TLH) = 33

The airport of Tallahassee consists of two perpendicular runways, 18/36 and 09/27. But only runways 27 and 36 are equipped with an Instrument Landing System (ILS). Besides that, there are Area Navigation (RNAV) approaches published for all four runways, a VHF Omnidirectional Radio Range/Distance Measuring Equipment (VOR/DME) approach for runway 36 and a VOR approach for runway 18. Also, the runways' lengths only reach 7000 or 8000 feet respectively. This is not enough for take-off of a fully loaded Boeing 737. This in combination with lacking ILS being installed on all runways, decreased the CAI of this airport's characteristics to 2, as shown in Tab. 3.3.

As this day is windy in the entire state of Florida, it is no surprise the wind velocity reaches 14 knots with gusts of up to 24 knots, which is comparable to the other airports. However, the wind direction of 110° combined with the runway system orientation at this airfield results in crosswind no stronger than 8 knots if runway 09 was in use. This should be no factor for airline pilots. As there is no other weather phenomena reported at this location, the overall weather situation means no limitation for the flight.

The city of Tallahassee is located approximately 170 NM to the north-west of Tampa. Its location corresponds to the flight path of this flight. This makes Tallahassee suitable not only for a diversion from destination, but also for en-route diversion or even emergency landing. The distance however means the highest requirements on diversion fuel. But this still causes no problem as the entire route is not very long and capacity of the fuel tanks is more than sufficient for this extra fuel.

According to publicly available information there is no special requirement for landing at the Tallahassee airport. Pilots only need to be aware of slightly shorter runways.

TLH airport is not recently served by Delta Air Lines, hence it is expected the company policy would prefer not to land there and use another airport with airline's regular operations. This resulted in reduced CAI for Company policy.

As mentioned earlier, the air distance between Tallahassee and Tampa is 170 NM or 320 kilometres. This means the alternative transportation of passengers to the destination would last approximately 5 to 6 hours if a bus service were chosen.

Some other airlines operate regular flights to this airport with Boeing 737 aircraft, therefore the airport is equipped to handle this flight if needed. But because of significantly lower traffic, the handling capacities might be limited, which would result in delay on ground, in an extreme case this could prevent passengers from deboarding the aeroplane.

Delta does not probably run any facility or infrastructure at this airport, as no such information was found, and it would not be very reasonable as there are no regular Delta flights to this airfield. Calculating with this assumption the airport is unsuitable form the airline's own facility point of view.

The same reason as in previous paragraph also means it is highly unlikely there are any services contracted by the airline. Therefore, once again the CAI reached 3 points.

No special requirements are published for landing at this airport and as the Tallahassee International is one of the smaller airports in the state it is not estimated to put any extra high demands on pilots' performance, thus TLH should be suitable from this perspective.

The regular airline traffic at TLH is approximately three times lower than at SRQ and almost thirty times lower than at MCO. Therefore, the services for passengers are not very wide-ranged. There is no hotel at the airport meaning passengers as well as crew would have to be transported to other parts of the city. This resulted in CAI of 2 for Services for passengers.

4 Results

The results of this analysis should allow the dispatchers and pilots to choose an alternate location, that would potentially cause least disturbance in terms of overall time delay, operational disruption, passenger discomfort and unplanned expenses. Should the selected airport be suitable from safety point of view and available in the given time frame, it is expected the soonest recovery of operation or least disruptive flight termination in accordance to the given scenario.

The limitations of the results, as given in our analysis, are laying in the subjective selection of the factors and their severity indexes, that were evaluated based on general assumptions of the thesis author and consultants. It is, however, expected that in case of real situation application the actual requirements of the airlines would not differ significantly from the values of severity indexes as proposed in this thesis but the scope uf examined factors would be adjusted and enlarged.

Results of this analysis are:

$$\text{ASI (MCO)} < \text{ASI (SRQ)} < \text{ASI (TLH)}$$

As suggested, the airport with the lowest corresponding ASI is supposed to be the most suitable one for a flight diversion. According to this method, the Orlando airport should be chosen as an alternate. This also makes sense from the conventional point of view: The airport is close to the destination, the weather situation is not optimal, but still within limits and there is a lot of facility available for the airline.

This is also confirmed by the real data mentioning 23 diversions of Delta flights to Orlando International Airport, 13 diversions to Sarasota Bradenton International Airport and 9 to Tallahassee International Airport in 2019. More specifically flights operated by this company from Atlanta to Tampa diverted 6 times to MCO, once to SRQ and twice to TLH [4]. This fact supports the algorithm's proper functioning. However, to fully prove its functionality it would be necessary to gain real internal data of multiple airlines, their preferences and wider network of examined flights and airports.

5 Discussion

5.1 Limitations

The proposed selection and evaluation procedure is not expected to be rigid and used exactly as proposed. Every operator can use their original strategy, process of decision-making and might consider other factors or with different level of importance. It is then highly recommended to adjust this procedure of alternate airport selection to specific requirements of every aircraft operator individually as this paper is meant to suggest a general approach to the problematic. This also means different operators might reach different Airport Suitability Indexes for the same airport at the same time. Thus, this algorithm is excluded from a unified application across the industry as the airport evaluation is subjective from the operators' point of view.

There are several limitations of this algorithm. The list of factors evaluated for every airport was created by author of this thesis based on his own experience, knowledge gained from Olexa and Špák's research[36] and on interview with an OCC manager of a private jet operator company. But no actual requirements of airlines were examined. This thesis also only evaluates a small part of the aviation network, focusing on passenger transportation. Also, the only way of proper evaluation of the process' functionality is a broad simulation for many different operators, routes, and airports. But even this complex simulation would face the main problem of this whole algorithm – the necessity of real-time data.

5.2 Airport data

The main aim of this algorithm is to make the flight operations more efficient while decreasing workload demands on flight-planning departments. In most industries it is highly desirable to optimize processes, decrease workload of employees and implement automation, if possible. This paper might bring these optimizations to the flight operations.

Main focus and attention should be aimed on the data items and resulting data set which would enable, when shared in real time, proper Airport Suitability Index calculations.

The industry should conclude on the data items and their specifications and require their availability and appropriate data quality. Similarly, also the means of the data flows should be examined. As the process of airport evaluation is intended to be fully automated, it is expected to work continuously and react to any changes at any considered airport. This would be significant in case of diversion as the flight crew would be able to receive the best alternate airport suggestion on demand with a minimal delay.

The lack of precise and up-to-date data makes it very complicated to reliably valorise the airport suitability. Therefore, to implement this algorithm, a service of real-time data sharing is required. This global database needs to contain constantly updated data of actual handling capacities, terminal capacities, airport hotel availability, public/on-demand transport services and many other to effectively deliver all the information relevant for decision related to flight diversion planning. The most crucial information is already available, like the weather situation or airport and airspace slots. Now, the less critical, but still important data need to be collected, processed, and shared in order to optimise the entire industry.

Subsequently, existence of such database might also be used by all participants on this data collection. For example, hotels might be able to adjust their prices for accommodation based on other hotel's actual available capacity. This could result in a more competitive economics, which is advantageous for the customers.

Collection of such data might also be used for more precise usage analysis of an airport, for instance. Monitoring and analysing capacities in real time might result in better queue management, aircraft stand assignment and many other optimisations, all of which might increase comfort of passengers, improve airport operations, and save financial resources.

6 Conclusion

This thesis serves as a first suggestion of a complex flight operations optimisation focusing on improved diversion airport selection, resulting in reduced financial loss for flight operators. Main focus is put on understanding flight diversion causes and considering not only safety factors, but also economic ones during the process of selecting the most suitable alternate airport. As result a process of complex airport suitability evaluation was presented. Main problem of this process is in requiring accurate, real-time data, which is not available at the moment. But creating a system acquiring such data might not only be prosperous for flight operators but for the industry of aviation services provision in general.

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