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# LIST OF ABBREVIATIONS

|  |  |
| --- | --- |
| ACAS | Airborne Collision Avoidance System |
| ACFT | Aircraft |
| A/C | Aircraft |
| ADM | Aeronautical Decision Making |
| ADS-B | Automatic Dependent Surveillance - Broadcast |
| ANS | Air Navigation System |
| ANSP | Air Navigation Service Provider |
| APU | Auxiliary Power Unit |
| ASSIST | Acknowledge, Separate, Silence, Inform, Support, Time |
| ATC | Air Traffic Control |
| ATCO | Air Traffic Control Officer |
| ATM | Air Traffic Management |
| ATS | Air Traffic Service |
| AU | Airspace User |
| CAT | Category |
| COM | Communication |
| DB | Database |
| DM | Decision Making |
| DSS | Decision Support System |
| ES | Emergency situation |
| EUROCONTROL | European Organisation of Safety of Air Navigation |
| FAA | Federal Aviation Administration |
| FPL | Flight Plan |
| GERT | Graphical Evaluation and Review Technique |
| H-O | Human Operator |
| HDM | Human decision maker |
| HMI | Human Machine Interface |
| ICAO | International Civil Aviation Organisation |
| IFR | Instrument Flight Rules |
| ILS | Instrument Landing System |
| IMC | Instrument Meteorological Conditions |
| NM | Network Manager |
| NTSB | National Transportation Safety Board |
| RA | Resolution Advisory |
| RNAV | Area Navigation |
| RTF | Radiotelephony |
| RWY | Runway |
| SHEL | Software, hardware, environment, liveware |
| SID | Standard Instrument Departure |
| STS | Socio-technical system |
| TCAS | Traffic Collision Avoidance System |
| TSB | Transportation Safety Board of Canada |
| VFR | Visual Flight Rules |
| VMC | Visual Meteorological Conditions |

# INTRODUCTION

Air navigation system can be considered as a complex system with multiple composite parts or subsystems that constantly interact with each other, e.g.:

* Airspace users (AU);
* Air navigation service providers (ANSP);
* Airports;
* Network Manager (NM).

Due to growing demand in air transportation, the complexity of the systems and load on it increases constantly. However, at the same time, the requirements for the level of safety, security remains the same. In order to meet the required levels of safety, there is a need for supporting systems that would support operators (e.g. flight crew, air traffic controller, etc.) of air navigation systems in making decision in day-to-day operations. That’s why the decision support systems became widely used in the air navigation systems to support the human operators.

 They are aimed at helping and supporting decision making processes or human operators in air transportation sphere and allow them to select the best decision in conditions of limited time or uncertainty. The wide introduction of decision support systems in air navigation will contribute to the optimisation of human operator work which will lead to an increase in operational efficiency and safety.

One of the components that negatively contribute to the safety of flights are human errors that could lead to emergency situations and later on to incidents or accidents. The emergency situation of low oil pressure is a serious issue for both flight crew and air traffic controller and possess a threat to the flight safety due to its nature. It can lead to serious incidents and accidents and due to the type of the issue it is close to impossible to eliminate it. However, it is possible to provide all necessary means to support decision making of a human operator (e.g. air traffic controller) to ensure that correct and safe decisions are taken by the operator to resolve an emergency situation.

Based on the abovementioned, the following tasks for the research and thesis can be defined:

* to perform analysis of low oil pressure emergency situations, understand the reasons and possible causes;
* to analyse emergency procedures defined for air navigation system operator (Air traffic controller) for low oil pressure situations;
* to investigate decision making models of air navigation system operator and assess their applicability for low oil pressure emergency situations
* to perform modelling of decision making process of air navigation system operator in the low oil pressure operations.

Created models of the decision making process in the low oil pressure emergency situations can be later on used for training of aviation personnel, further modelling of the decision making process of air navigation system’s operator, etc.

# CHAPTER 1. LOW OIL PRESSURE EMERGENCY SITUATION OVERVIEW

## Definition of emergency situation

According to EUROCONTROL electronic repository of safety knowledge related to Air Traffic Management (ATM), an emergency situation is the one in which the safety of the aircraft or of persons on board or on the ground is endangered for any reason.

An abnormal situation is one in which it is no longer possible to continue the flight using normal procedures but the safety of the aircraft or persons on board or on the ground is not in danger.

Emergency or abnormal situations may develop as a result of one or more factors within or outside an aircraft, for example:

* Aircraft component failure or malfunction (e.g. engine failure, landing gear malfunction or loss of pressurization);
* Worsening weather;
* Low oil pressure;
* Shortage of fuel (or other essential consumable substance);
* Flight crew uncertain of position;
* Pilot incapacitation (e.g. as a result of illness);
* Fire on board the aircraft;
* Aircraft damage (e.g. as a result of collision, bird strike or extreme weather;
* Illegal activity (e.g. bomb-threat, willful damage or hijacking).

An emergency or abnormal situation may result in it being impossible to continue the flight to destination as planned, resulting in one or more of the following outcomes:

* Loss of altitude;
* Diversion to a nearby aerodrome;
* Forced landing. [1]

## Low oil pressure situations

One of the possible causes of catastrophic engine failure that we see is loss of oil and loss of oil pressure.

When we examine these failures, a common thread that can be heard from the flight crew is that they notice a drop or reduction on the oil pressure, but the engine seemed to be operating normally so they continued flying, not recognizing the seriousness of their situation.



Figure 1.1 – Oil pressure indicator

In some cases, the flight crew did not trust the reading of the oil pressure gauge since the engine seemed to be working normally. That’s why the flight deck just considered that the instrument was giving an incorrect indication and therefore did not understand the potential danger of the situation.

The loss of oil from the engine in most cases leads to oil starvation of the engine. In some cases, when the amount of oil in the sump becomes quite low, a slight increase of temperature of the oil can be observed. Since aircraft engines are not equipped with gauges for oil levels, the amount of oil in the sump is not monitored. Hence, the first sign of an issue with low oil level is an oil pressure reduction. [2]

In some cases, the issue might be caused by a leak of oil from the aircraft power plant. If a leak is from an unpressurised part of the engine (e.g. leaking gasket), it can be relatively slow, however, if it is from a pressurised part, then it can be quite fast. Regardless of the cause of the leak, the level of the oil can become extremely low in any flight phase. Once this happens, the failure of the engine is imminent.

Since at the low pressure level of the oil, the engine might seem to work normally, the pilot might think that the issue is with an instrument rather than with the oil pressure itself. That’s why he/she might make a wrong assumption that the engine will continue working properly. This can cause catastrophic consequences. With the low level of the oil pressure, the critical parts of the aircraft engine (e.g. connecting and main rod bearings) are not getting required lubrication and with time the flow of oil to them stops.

With no oil influx, only the residual oil remains and it starts heating up quickly and losing viscosity. Once the oil gets thinner, it cannot support the applied loads. In this case, the metal to metal contact occurs that can lead to destruction of some elements of the engine. Once this occurs, the engine may either stop or continue to operate in degraded mode before it stops due to another issue. Usually, the timeframe for such failure (from reduction in oil pressure to engine failure) is 1-10 minutes. To counteract that, there are a few ways which depend on the type of an aircraft and number of engines:

* single engine aircraft: an emergency forced landing is required.
* twin-engine aircraft: an emergency landing at the nearest suitable runway/airfield is required. A period of single-engine-operation will be required as well.

If the engine is operated at a low power setting, the engine may retain enough integrity to operate for a brief period at a higher power setting giving the flight crew a possibility to avoid an obstacle or reach a runway, etc.

After the landing, the engine will have to be thoroughly inspected to detect any issues or faults before returning to normal operations. [3]

An example of the accidents caused by low oil pressure tool place on the 4th of April. 1994, Amsterdam. KLM Cityhopper Flight 433 was a Saab 340B, registered as PH-KSH, which crashed during an emergency landing in 1994. Flight 433 was a routine scheduled flight from Amsterdam, the Netherlands, to Cardiff, Wales.



Figure 1.2 – Debris ofKLM Cityhopper Flight 433 [4]

According to Netherlands Aviation Safety Board, the aircraft took off from Amsterdam at 12:19 pm, with Captain Gerrit Lievaart as the pilot flying. Eleven minutes after take-off, at 12:30 pm, the pilots received a low oil pressure warning for the No.2 engine. The captain then set that engine's power to idle, probably to reduce the risk of damage. However, the oil pressure gauge was still showing above 50 PSI, indicating that the warning was false. The crew therefore decided to continue the flight as recommended by the relevant checklist. However, the captain did not return the engine to the previous throttle setting, leaving the aircraft effectively flying on one engine. As the Saab reached flight level 170 (17,000 feet), the loss of power prevented the airliner from climbing further. The crew misinterpreted this as confirmation that the right engine was faulty, and made a Pan-Pan call requesting to return to Schiphol Airport. On final approach, at a height of 90 feet, the captain decided to perform a go-around as the speed was not sufficient for landing. He gave full throttle to the left engine, but seemingly forgot about the right, which was still at idle. As a result of the thrust imbalance, the aircraft rolled to the right, pitched up, stalled, and hit the ground at 80 degrees of bank. Of the 24 people on board, 3 were killed - the captain and 2 passengers. Out of the 21 survivors, 9 suffered serious injuries, including the first officer. [5]

Another incident caused by low oil pressure happened with Eastern Air Lines Flight 855 on May 5, 1983. The flight from Miami International Airport to Nassau International Airport was carrying 162 people and 10 crew members and was performed on Lockheed L-1011 aircraft.

During the descent at 15000 ft, the low oil pressure indicator for the second engine has illuminated. The engineer in the cockpit noticed that the oil pressure on the engine number 2 was fluctuating between 15 and 25 psi while the minimum pressure required for normal operation is 30 psi. The pilot-in-command has ordered to shut down the engine. Due to the issue, the flight crew decided to return to Miami and land the aircraft there. On their way to Miami, the low oil pressure lights for first and third engines illuminated as well and the reading on instruments read zero. Even though, the flight crew informed ATC that they believe that the indications are faulty, after some time engine number 3 has failed. In five minutes, the first engine has flamed out while crew was trying to restart the second engine. Due to this the cockpit lights went off and instruments stopped working. The aircraft descended to about 4000 ft before flight crew managed to restart the engine. After that, they were able to land at Miami airport on a single engine. None of the 172 passengers and crew aboard were injured. [6]

Also, worth mentioning the recent case that happened in Canada, 2017. On 02 November 2017, a Perimeter Aviation LP Fairchild SA227-AC Metro III (serial number AC-756B, registration C-FLRY) was operating as flight 959 (PAG959) from Gods River Airport, Manitoba, to Thompson Airport, Manitoba, with 2 flight crew members on board. When the aircraft was approximately 40 nautical miles southeast of Thompson Airport, the crew informed air traffic control that they had received a low oil pressure indication on the left engine that might require the engine to be shut down. The crew did not declare an emergency, but aircraft rescue and firefighting services were put on standby. After touchdown on Runway 24 with both engines operating, the aircraft suddenly veered to the right and exited the runway. The aircraft came to rest in snow north of the runway. The captain and first officer exited the aircraft through the left side over-wing emergency exit and were taken to hospital with minor injuries. The aircraft was substantially damaged. The 406-MHz emergency locator transmitter did not activate. The occurrence took place during the hours of darkness, at 1920 Central Daylight Time.



Figure 1.3 The occurrence aircraft after coming to a rest [7]

The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. A depletion of oil in the left engine and a subsequent loss of oil pressure resulted in a loss of propeller control on landing and upset of the aircraft. There were no indications that fatigue or other physiological factors contributed to the accident. Both pilots were qualified for the flight and held the appropriate license. [8]

## 1.3 Emergency procedures of air navigation system operator in case of low oil pressure

There is no generic set of steps and actions defined that are applicable for all emergencies. Instead, a set of best practices and principles have been developed to support air traffic controller during the emergency. One of the is ASSIST principle. One of the best practices embedded in the ASSIST principle could be followed (A - Acknowledge; S - Separate, S - Silence; I - Inform, S - Support, T - Time) (Figure 1.4):

**A** - Acknowledge the problem, get the squawk;

**S** - Separate the aircraft from other traffic and give it room to maneuver.

**S** - Silence the non-urgent calls (as required) and use separate frequency where it is possible.

**I** - Inform those who need to know and those who can help; inform others as appropriate.

**S** - Support flight crew in any possible way, e.g. think of alternate routing, deviations, etc.

**T** - Give time for the flight crew to assess the situation. [2]

Using this procedure, an air traffic controller knows exactly what to expect from the flight crew, how to react on their request and how to behave in the emergency case. Based on ASSIST a set of other emergency procedures have been developed, such as:

* Airborne Collision Avoidance System (ACAS) / Traffic Collision Avoidance System (TCAS);
* Birdstrike;
* Bomb warning;
* Brake problems;
* Communication (COM) failure;
* Electrical issues;
* Hydraulic problems;
* Smoke or fire on board of the aircraft or in the cockpit;
* Unlawful interference;
* Engine or APU failure;
* Etc.

Table 1.1 contains expected actions/outcomes for air traffic controllers in case of an emergency or abnormal situation.



Figure 1.4 ASSIST emergency procedure [9]

*Table 1.1 - Checklist for actions of air traffic controller in case of an emergency or abnormal situation*

|  |  |  |
| --- | --- | --- |
| Type of an emergency situation | What to expect? | What to remember? |
| ACAS / TCAS | * Climb or descent without prior warning
* No emergency squawk
* Two or more aircraft involved
* Notification from pilot of ‘TCAS climb’ or ‘TCAS descent’
 | When a pilot reports a manoeuvre induced by a resolution advisory (RA): * ATC should not attempt to modify the flight path of the aircraft
* ATC should provide information regarding traffic when appropriate since the pilots are busy
* TCAS altitude data is more accurate than the radar data
* ATC should take responsibility for traffic separation of the aircraft when:
	+ ATC can acknowledge a report from the aircraft that it has continued with the current clearance;
	+ ATC can acknowledge a report from the aircraft that the aircraft is continuing with the current clearance and issues another clearance that is acknowledged by the flight crew.
* After an emergency with RA or ACAS, the flight crew and ATC should complete the incident report.
 |

*Continuation of Table 1.1*

|  |  |  |
| --- | --- | --- |
| Type of an emergency situation | What to expect? | What to remember? |
| Birdstrike | * Abandoned take-off
* Immediate return to airport
* Landing in next suitable airport
* Restricted visibility
* Hydraulic problems
 | Birdstrike may result in:* Broken windshield
* Engine failure (single/multiple engines)
* Hydraulic problems
* Precautionary approach
* Handling problems
* Electrical issues
* Gear problems

ATC should check if pilot is able to control the aircraft.ATC should also allow long final approach if needed and check runway (RWY). If the flight crew requests, ATC should provide all aerodrome details as soon as possible. |
| Bomb warning | * Aircraft may stop climb
* Request for immediate level re-clearance
* Landing at the next suitable airport
* Aircraft early in landing configuration
* RWY in use, length, surface, elevation, ILS and NAV-frequencies.
 | * Clear airspace in the vicinity
* Ask for flying time that is needed
* Evacuation after landing
* Additional stairs required
* Make sure to clear RWY
* Keep safety strip clear
* Arrange parking away from buildings/other aircraft

If the flight crew requests, ATC should provide all aerodrome details as soon as possible. |

*Continuation of Table 1.1*

|  |  |  |
| --- | --- | --- |
| Type of an emergency situation | What to expect? | What to remember? |
| Brake problems | * Pilot request for the longest RWY
* Overrunning RWY threshold at far end
* Burst tyre
* Airfact may overrun off RWY
* RWY blocked after landing
 | * Inform pilot about RWY length / condition
* Keep safety strip clear
* Towing equipment on stand-by if needed
* Technical staff required
 |
| Electrical Issues | * The flight crew will be heavily stressed
* All navigation instruments in the cockpit failed – including compass
* Transponder is switched off to save energy
* The flight crew will provide limited readbacks
* The flight crew will change flight level to maintain VMC
* The flight crew will have to perform manual gear extension
* Aircraft might suffer engine failure
 | * Inform the landing airport regarding the issue
* Inform the pilot about suitable airports around
* Provide airport details as soon as possible
* Inform the flight crew on avoiding IMC
* Provide the flight crew with suitable vectors and position information
 |

*Continuation of Table 1.1*

|  |  |  |
| --- | --- | --- |
| Type of an emergency situation | What to expect? | What to remember? |
| COM failure | In case of Visual Meteorological Conditions (VMC):* Squawk 7600 from the flight crew
* Continue in VMC
* Land at nearest suitable airport
* Arrival report as soon as possible to the appropriate ATS unit

In case of Instrument Meteorological Conditions:* Squawk 7600
* Flight crew maintains assigned speed/flight level for 7 minutes.
* If the flight crew is being vectored or proceeding according to RNAV, they will proceed in the most direct manner possible to rejoin the current flight plan
* The flight crew will try to start descent at time as close as possible to estimated arrival time
 | It is possible that the failure is of transmitter or receiver only. Try to relay the message by other stations (e.g. through another aircraft). |

*Continuation of Table 1.1*

|  |  |  |
| --- | --- | --- |
| Type of an emergency situation | What to expect? | What to remember? |
| Emergency Descent | * Descent without warning
* No squawk indicating an emergency situation or 7700
* No radio contact (RTF) or poor one
* A turn away initiated by the flight crew from the assigned route
 | * Acknowledge the emergency on RTF
* Make sure that the separation is not impeded
* Suggest heading / minimum altitude if needed
* Provide separation or traffic information if needed
* Request intentions of the flight crew (diversion, injuries, aircraft damage)
* Consider aircraft still in the emergency situation even after the descent
 |
| Engine Failure | * High workload of the flight crew
* Deviation from the standard instrument departure (SID) procedure
* Descent
* Course deviation
* Issues with pressurisation
* Fuel dumping
* Abandoned take-off
 | * Inform landing airport
* Clear RWY
* Keep safety strip clear
* Offer the flight long final approach
* Prepare towing equipment
* Record the last known position and time in case of the forced landing
* Provide the flight crew with the next appropriate airport and information on it
* Provide the flight crew with the weather information at the landing airport
 |

*Continuation of Table 1.1*

|  |  |  |
| --- | --- | --- |
| Type of an emergency situation | What to expect? | What to remember? |
| Engine or APU on Fire | * Abandoned take-off
* Engine failure (single/multi-engine)
* Smoke or fire in the cockpit
* Emergency/Forced landing
* High workload on the flight crew
* Engine shutdown / use of fire extinguishers
* Pressurisation issues
* Losing of altitude

When the aircraft is on the ground:* Hot brakes
* Evacuation of passengers
* Runway blocked
 | * Ask the flight crew if there are dangerous goods on board
* Ask the number of passengers on board
* Inform the landing airport about the issue
* Clear RWY
* Keep safety strip clear
* In case of forced landing, record the last known position/time
* Provide the flight crew with information on the next suitable aerodrome
* Provide weather information of the landing airport
* Observe if there is any fire or smoke
 |
| Unsafe Indication or No Gear Indication | * Need for an external (engineering) advice
* Go-around executed by the flight crew
* Low pass of the ATC tower for gear inspection
* Manual gear extension
 | * Prepare for the low pass of the flight crew for visual inspection
* Weight reduction has to be done by the flight crew
* Clear RWY
* Keep safety strip clear
* Prepare towing equipment if necessary
* Infor pilot on the aircraft configuration after consultation with appropriate company.
 |

*Continuation of Table 1.1*

|  |  |  |
| --- | --- | --- |
| Type of an emergency situation | What to expect? | What to remember? |
| Critical Fuel Status | * Engine failure (single/multi-engine)
* Diversion or forced landing
* MAYDAY call in case of low fuel with imminent danger to the aircraft
* PAN PAN call if the aircraft has minimum fuel
* Improper use of phraseology
 | * Maintain aircraft high to save fuel
* Make sure to avoid ATC-caused go-around
* Inform landing airport about the issue
* Ask if there are any dangerous goods on board
* Ask to provide the number of passengers on board
* Clear RWY
* Keep safety strip clear
* Ensure that towing equipment is available
* Provide the flight crew with information on the next suitable aerodrome
* Provide weather information of the landing airport
 |
| Issues with pressure | * Emergency descent or request for emergency descent
* Aircraft stops the climb
* No emergency squawk
* Possible turn off the route
* Poor RTF due to oxygen mask
 | * Clear airspace beneath the aircraft
 |

*Continuation of Table 1.1*

|  |  |  |
| --- | --- | --- |
| Type of an emergency situation | What to expect? | What to remember? |
| Hydraulic issues | * Fuel dumping
* Gear and brake issues
* Relatively high speed of the aircraft on final approach
* Limited manoeuvrability of the aircraft
* Limited flap setting
* Limited bank angle
* Manual gear extension
* Long final approach
* Limited capability of the breaks
* Possible RWY overrun and RWY being block on landing
 | * Increase vertical and lateral separation
* Ask if there are any dangerous goods on board
* Ask the number of passengers on board
* Avoid ATC-caused go-around by the aircraft
* Clear RWY and safety strip
* Prepare towing equipment
* Provide the flight crew with information on the next suitable aerodrome
* Provide weather information of the landing airport
* Inform the flight crew about fire/smoke from the brakes
 |
| Unlawful Interference | * Squawk 7500
* Deviations from route/flight level
* No or unusual replies to RTF communication
* No compliance with given instructions / clearances
 | * DO NOT initiate any RTF referring to hijack unless it is confirmed by the flight crew
* Comply with the flight crew’s reports as far as possible
* Give room for manoeuvre and monitor them and collect any necessary information (destination airport, weather situation, route, etc.)
* Provide any requested information to the flight crew
 |

*Continuation of Table 1.1*

|  |  |  |
| --- | --- | --- |
| Type of an emergency situation | What to expect? | What to remember? |
| Icing issue | * Rapid change of the flight level/heading
* Limited rate of climb/descent
* High speed
 | * Avoid giving holding instructions to the flight crew
* Ensure continuous climb after departure
* Keep safety strip clear
* Report icing issue to other aircraft, ATS units and meteorological unit
* Inform the flight crew to check their anti-icing/de-icing systems
* Ask the flight crew to check: pitot heating, stall warner heating, carburettor heating, propeller heating/de-icing, wing anti-ice/de-ice, windshield heating
* Inform the pilot about higher approach/landing speed due to increase in the stalling speed
* Ask the flight crew to descent with higher power setting to increase bleed air supply
 |

*Continuation of Table 1.1*

|  |  |  |
| --- | --- | --- |
| Type of an emergency situation | What to expect? | What to remember? |
| Smoke / Fire in the Cockpit | * High workload on the flight crew
* Shortest and high speed vector for landing at the nearest airport
* Poor RTF (due to oxygen mask) or no RTF at all
* Evacuation of passengers
* Blocked RWY
 | * Ask the flight crew if there are any dangerous goods on board
* Ask the number of passengers on board
* Inform landing airport regarding the issue
* Clear RWY
* Keep safety strip clear
* Make sure that RWY lighting system is working at maximum capacity
* Offer out of wind landing
* Inform the flight crew on the distance to touchdown
* Report to the flight crew if there is an automatic low visibility approach procedure
* Provide the flight crew with information on the next suitable aerodrome
* Provide weather information of the landing airport [2]
 |

## 1.4 Analysis of the problem and definition of objectives for the thesis

Based on the information and cases that have been described above we can see that the emergency situation of low oil pressure can lead to serious incidents and accidents. Due to the type of the issue it is close to impossible to eliminate it.

However, it is possible to provide all necessary means to support decision making of human operator (in our case air traffic controller or flight crew) to ensure that correct and safe decisions are taken by the operator to resolve an emergency situation. This could potentially contribute to increase in a number of correct and timely decisions taken by the human operator decreasing the number of emergency situations and thus enhancing the level of safety in air navigation system.

That is why the following tasks for the research and thesis can be defined:

* to perform analysis of low oil pressure emergency situations, understand the reasons and possible causes;
* to analyse emergency procedures defined for air navigation system operator (Air traffic controller) for low oil pressure situations;
* to investigate decision making models of air navigation system operator and assess their applicability for low oil pressure emergency situations
* to perform modelling of decision making process of air navigation system operator in the low oil pressure operations.

# CHAPTER 2. REQUIREMENTS SPECIFICATION TO THE MASTER'S DEGREE THESIS

## 2.1. Theme of master degree thesis

Decision making in emergency situation of air navigation system’s operator: low oil pressure.

## 2.2. The background of master degree thesis

* Curriculum of educational qualification of «Master» degree and speciality 272 Aviation transport № PM – 14-272/16.

- The Rector’s order of topics and heads of diploma approval № 2524/ar, 29.10.2019.

## 2.3. The goal and purpose of the work

### 2.3.1. The goal of the work

Development of decision making model for air navigation system’s operator in case of low oil pressure situation.

### 2.3.2. The purpose of the work

To investigate and develop decision making model to support decision making in emergency situation of air navigation system’s operator, in particular, in case of low oil pressure reported by flight crew.

## 2.4. Input data sources

1. Models of Decision Making Operators of Socio-Technical System [Text] / T. Shmelova, Y.Sikirda // Socio-Technical Decision Support in Air Navigation Systems: Emerging Research and Opportunities, 2018.

2. Guidelines for Controller Training in the Handling of Unusual/Emergency Situations [Text] // EUROCONTROL, 2003.

## 2.5. Estimated scientific results and order of their realization

### 2.5.1. Estimated scientific results

As the result of scientific research, the following scientific results should be obtained:

* An algorithm of air navigation system’s operator actions in case of low oil pressure;
* Dеtermіnіstіc decision making models;
* Behavioral models for finding optimal solution or decision.

### 2.5.2. Order of scientific results realization

The result of the research done in the scope of the thesis could be used for the following:

* Training of air navigation system’s operator;
* Recommendations for modelling of decision making of air navigation system’s operator;
* Modelling and determination of best alternative solution for decision making done by human operator
* Etc.;

## 2.6. Requirements to the thesis implementation

Degree Thesis must be performed in accordance with the methodical guidelines and requirements of master’s thesis work performance for students of educational direction 272 “Aviation Transport” direction and State Standard of Ukraine 3973-2000 “СРППВ. Правила виконання науково-дослідних робіт. Загальні положення (SRPPV. Terms of scientific research performance. Basics.)”. Thе wоrk must bе propеrlу аnd cоrrеctly prepared in compliance wіth thе requirements for scientific wоrk.

The explanatory note is issued in accordance with State Standard of Ukraine 3008-95 "Документація. Звіти у сфері науки і техніки (Documentation. Reports in science and technology.)”

## 2.7 Stages of work

*Table 2.1 – Stages of work*

|  |  |  |  |
| --- | --- | --- | --- |
| **Thesis stages** | **Stage content** | **Date** | **Form of report (number of thesis chapter)** |
| Beginning | End |
| Low oil pressure emergency situation overview | Analysis of notion emergency situations and their types | 14.10.19 | 24.10.19 | Subpart 1.1 |
| Analysis of low oil pressure situations and aviation incidents/accidents caused by them. | 25.10.19 | 01.11.19 | Subpart 1.2 |
| Analysis of emergency procedures of air navigation system operator. | 02.11.19 | 10.11.19 | Subpart 1.3 |
| Analysis of the problem and definition of tasks | 10.11.19 | 15.11.19 | Subpart 1.4 |
| Analysis of decision making models of air navigation system operator | Overview of the notion of air navigation system as socio-technical system | 16.11.19 | 23.11.19 | Subpart 3.1 |
| Analysis of factors influencing decision making in air navigation system | 23.11.19 | 01.12.19 | Subpart 3.2 |
| Analysis of decision making process in air navigation systems | 01.12.19 | 15.12.19 | Subpart 3.3 |

*Continuation of Table 2.1*

|  |  |  |  |
| --- | --- | --- | --- |
| **Thesis stages** | **Stage content** | **Date** | **Form of report (number of thesis chapter)** |
| Beginning | End |
| Modelling of decision making process of air navigation system operator in low oil pressure emergency situation | Modelling of decision making under certainty in a low oil pressure emergency situation | 16.12.19 | 28.12.19 | Subpart 4.1 |
| Modelling of decision making under uncertainty in a low oil pressure emergency situation | 29.12.19 | 13.01.20 | Subpart 4.2 |
| Modelling of decision making under risk in a low oil pressure emergency situation | 14.01.20 | 22.01.20 | Subpart 4.3 |

# CHAPTER 3. OVERVIEW OF DECISION MAKING MODELS OF AIR NAVIGATION SYSTEM OPERATOR

## 3.1 Air navigation system as a socio-technical system

Air Navigation System (ANS) in conformity to the principles of functioning may be referred to Socio-Technical Systems (STS) within which close co-operation between human and technological components occurs. The distinguishing feature of the STS is availability of the hazardous kinds of activity as well as usage of the high-level technologies in production. Since operations in STS generally involve high-risk / high-hazard activities, the consequences of safety breakdowns are often catastrophic in terms of loss of life and property. The more a human-operator (H-O) is trying to control a production process being aided by high level technologies, especially in case of distant operation, the more non-transparent becomes the result of the operation of a system, which is accompanied by a high degree of risk of causing catastrophic outcomes. [10, 11, 12]

Socio-technical systems can be characterised as complex, highly organised, technological and large systems. They can consist of the following components: human operator (H-O), technologies, air navigation system subsystems, etc. Also, the socio-technical systems such as ANS system are constantly functioning under the conditions of uncertainty, risk, danger, etc.

Resulting from the researches that were done in Decision Making (DM) there are a few factors that affect the DM by an ANS’s H-O:

* level of knowledge,
* skills,
* abilities,
* preceding experience
* factors of professional and non-professional nature (psycho-physiological, individual-psychological, social- psychological factors). [13]

## 3.2 Factors influencing decision making process in air navigation system

In aviation an element that connects and keeps technical and organizational components functioning is considered to be a human, as well as provides the possibility of effective influence on the rest of its elements. There are a lot of aspects that affect human decision making (DM) ability/skills, among which are some of the most important factors of non-professional nature. The influence of these factors is most important in the event of an extraordinary situation that requires special concentration and full psychophysical and emotional impact.

The importance of factors of non-professional nature may vary in different emergency situations depending on the complexity and hazardous of the situations itself, workplace environment, etc.

Factors of social and psychological impact of the operator consist of five main clusters that outline the scope of the interaction of the individual in society [14, 15, 16]:

Social beliefs - intellectual, emotional, creativity, education of the mind and the senses are the part of a spiritual culture. It’s defined by a set of selected non-material character, of its involvement into the religions and philosophical systems. [17]

Economic interests - economic conditions influence mostly numerous manifestations of the economy and other spheres of public life. It can be considered as satisfaction or dissatisfaction with the quality of life. The aim of economic factor is to enhance their own economic situation, saving money, resources and other assets of the enterprise.

Social indicator - relationship between people, cultural environment, rules of interpersonal communication, etc. There can be pointed out a few behaviour motives: establishment of friendly relations between crew members, work on promotion possibilities, avoidance of conflicts in the team.

Political views - in terms of politics, the difficulty for an individual might be to determine the possibility and means of his impact on political power.

Legal relations - relations between entities regulated by laws and legal documents that are mandatory and formal norms of social society. [17, 18]

## 3.3 Decision making process of air navigation system operator

Air navigation system can be considered as a complex system with multiple composite parts or subsystems that constantly interact with each other, e.g.:

* Airspace users (AU);
* Air navigation service providers (ANSP);
* Airports;
* Network Manager (NM).

Due to growing demand in air transportation, the complexity of the systems and load on it increases constantly. However, at the same time, the requirements for the level of safety, security remains the same. In order to meet the required levels of safety, there is a need for supporting systems that would support operators of air navigation systems in making decision in day-to-day operations.

One of the main decision making practices in air transportation industry is Aeronautical Decision Making (ADM). It considers the decision making process in aviation sphere allowing to select the best line of action depending on given circumstances. The purpose of ADM is to enhance the decision making process and to decrease the probability of human error by best practices in decision making:

* Dangerous, safety-related attitude and personal behaviour;
* Techniques to change behaviour or learn how to change it;
* Techniques to stress management;
* Techniques to assess risk and manage them. [19]

It is clear that the use of the system supporting decision making process can contribute greatly to efficiency of operations in air transportation sphere.

The system to support decision making process or in other words called decision support system (DSS) can be described as in interactive computer system aimed at supporting various types of activities during the decision making process including also unstructured, atypical issues or problems. [20]

Common components of any decision support system are:

1. Data block or subsystem;
2. Model block or subsystem;
3. Human machine interface (user interface) block or subsystem;

Data subsystem usually consists of a database or set of data required as an input into the DSS. Model subsystem is a mathematical mechanism that is used for processing of the data and human machine interface subsystem allows humans to interact with DSS by receiving/capturing his/her input and providing output to the user. [21] The main components of the decision support system are presented on Fig. 3.1.



Figure 3.1 - The main components of decision support system [23]

One of the trends in the latest years in aviation is the development of systems with human-orientation in mind, so called human centered development. The same applies to the creation of decision making systems in air navigation since it is considered as a human-machine systems that consists of technical systems/subsystems and humans that are in constant interaction.

As mentioned above, the decision support system can be used for different activities during the decision making process. Thus, there might be multiple systems developed for various purposes, e.g. for safety assessment and decision making at any stage of a flight or in any emergency situation.

In order to create a decision support system, it is important to make sure that the following properties are implemented:

1. interactivity;
2. integrity;
3. power;
4. availability;
5. flexibility;
6. reliability;
7. robustness.

Interactivity of decision support systems means that the human is capable of interacting with the system - exchange of information happens at a speed that is sufficient for human information processing and system responds to different types of actions from the human.

Integrity of decision support system means that the complex of system components for data management and communication with users during decision support is capable of providing necessary support during the whole process of decision making.

The ability to answer the most significant questions during the decision making process is a power of decision support system.

Availability of the decision support system means that the system is capable of providing a correct answer to a question in the correct time. Ability of the system to adapt to changing needs and environment describes the flexibility of the decision support system. The reliability means the capability of the decision support system to work correctly for a long period of time. Robustness of it stands for the ability of the decision support system to recover from an error regardless whether from external or internal origin, e.g. mistakes in the input of the data into the system do not lead to a failure of the whole decision support system. [22]

Taking into account what has been considered above, it is possible to state that decision support systems are aimed at helping and supporting decision making processes or human operators in air transportation sphere and allow them to select the best decision in conditions of limited time or uncertainty. The decision support systems are widely used in the air transportation sphere at the moment (e.g. departure and arrival management systems [24]), decision support systems in air traffic control, etc. [22] The wide introduction of decision support systems in air navigation will contribute to the optimisation of human operator work which will lead to an increase in operational efficiency and safety.

## 3.4 Decision making models of air navigation system operator

There are a number of decision making methodologies that could be used for assessment and support of the decision making process of a human operator in air navigation system. For this thesis three methodologies will be investigated and applied to model decision making of a human operator - air traffic control officer (ATCO) - in an emergency situation related to low oil pressure. A summary of these methodologies is presented in the table below (Table 3.1) [13].

The selected methodologies will be described in more detail in the next subchapters.

### 3.4.1 Decision making under certainty

The decision making process by a human operator of air navigation system in case of an emergency situation can be described using network analysis of the actions of a flight crew and air traffic controller (ATC) with the help of network planning methods.

This provides us with the following information:

* structural-time table of actions taken by a human operator (ATC, flight crew) in an emergency situation;
* network graph of taken actions of a human operator (ATC, flight crew) in an emergency situation;
* critical time of taking actions by a human operator (ATC, flight crew) in an emergency situation.

With the help of the ASSIST procedure it is possible to build a network graph that can describe action taken by an operator (ATC) in an emergency situation. An example of such a graph is presented on Fig. 3.2.

*Table 3.1 - Selected methodologies for analysis of decision making in an emergency situation*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| № | Methodology | Models | Processes | Result | Parameters |
| 1 | Decision making of a human operator under certainty in an emergency situation | Determined models for a human operator with deterministic run-time procedure | Technology/Algorithm of work of a human operator in an emergency situation.  | Structural-hourly table of actions taken by a human operator in an emergency situation | *ti, Tcr* |
| Determined models for a human operator with probabilistic run-time procedure | Determination of time required for the performance of *i*-procedure according to the algorithm of work | Network graph of actions taken by a human operator in an emergency situation | *ti, Tcr, Tmid, Tmin, Tmax* |
| 2 | Decision making of a human operator under risk in an emergency situation | Stochastic models/decision trees of decision making of a human operator | Structural analysis of decision making of a human operator in an emergency situation | Optimal solution found using a criterion of an expected value taking into account a risk | *Adopt* |
| 3 | Decision making of a human operator under uncertainty in an emergency situation | Matrix of possible results of decision making of a human operator in an emergency situation | Analysis of decision making of a human operator in an emergency situation using Minimax, Laplace, Savage and Hurwicz criteria | Optimal solution found with the help of Minimax, Laplace, Savage and Hurwicz criteria | *Adopt* |



Fig. 3.2 - An example of a network graph of actions of an operator in an emergency situation [25]

In order to apply the decision making under certainty methodology to an emergency situation and describe decision process in it, it is necessary to follow the algorithm described below:

1. Select an emergency situation from ASSIST list (for ATC), flight manual (for pilot) if available.
2. Select procedure describing human operator actions in the selected emergency situation.
3. Decompose the selected procedure into smaller operational procedures ai.
4. Define time ti of operational procedures ai with the help of method of experts’ estimation:
	1. Obtain experts’ group opinion - *tgrj*.
	2. Calculate coordination of experts’ opinion for each *ti*:
		* Dispersion for each *ti* - *Dj*
		* Square average deviation - 𝜎*j*
		* Coefficient of variation for each *ti - 𝜈j*
5. Create a block-scheme of algorithm of decision making in an emergency situation.
6. Create a structural-timing table.
7. Create a network graph of actions taken by the human operator (ATC or flight crew) in an emergency situation.
8. Calculate the critical time Tcr and the critical path in the decision making process. [13]

### 3.4.2 Decision making under uncertainty

Most of the tasks that take place in ATC systems at different levels and stages of activity are resolved under uncertainty. The game approach during research of processes under uncertainty allows to get the optimal and guaranteed (in the worst-case scenarios) decisions. The methodological basis of problem-solving process is the game theory, the subject of which is research of decision-making process under uncertainty, which is considered mainly as conflict situations, collective decisions, problems of developing optimal plans.

It is important to further develop models of decision making of a human operator, to minimize the probability of errors of the human operator in the process of professional activity, because the known fact is that the cause of the majority of aviation events is a human mistake. In most cases, these mistakes are made by certified, qualified personnel. Mistakes are not the result of abnormal behaviour, but they are normal side effects of almost all human activities. Understanding how "normal" people make mistakes is an important element of the human factor in aviation. ICAO documents recommend developing operational understanding of aviation security contexts that facilitate human operator errors. In the first place, the problem is to learn how to manage mistakes when they occur.

There are two approaches to control human error. The point of the first approach is to minimize the probability of errors with the help of ergonomics by providing intuitive ergonomics - a high level design of control elements, so that they could meet human requirements, providing the proper controls, procedures, guides, maps, charts, as well as reduction of noise, vibration, extreme temperatures and other stressful conditions.

The second approach is aimed at reducing the effects of any errors through cross monitoring between crew members.

The well-known SHEL (software, hardware, environment, liveware) model was the first one of its type to ensure aviation flight safety during the process of direct analysis of hidden threats at the level of operational cooperation. The evolution of human factor models is complemented by relevant components: errors H-O, error management, team work, the influence of culture, etc. [18].

If the optimal program of action of H-O is developed, then the game "human and nature " happens, where nature is the phenomena (factors) that influence the result of human action. In this case, the decision is made under uncertainty. The set {*A*} is alternative decisions of H-O, and {*B*} are factors that influence the decision. There is a difference in the formation of decision matrices and “regret” for certain types of tasks. Formal description of the criteria for finding the optimal solution is given in the table. 3.2.

Wald (minmax) criterion is based on the "conservative attitude" and is used if a guaranteed solution needs to be found, Laplace criterion is based on the principle of insufficient reason. With Hurwicz criterion either pessimistic or optimistic decision is made with the help of coefficient of pessimism-optimism α: 0 ≤ α ≤ 1.

The optimal solution for the Savage criterion is found by using the matrix "Regret" that the human decision maker (HDM) didn't make a better decision. In the case of positive outcome, the element of “regret” matrix of defined by the difference between the best value in the column *λj* and the value *r(ui , λj)* at the same *λj* . Thus, the HDM expresses the construction of the matrix *ijr* his "regret" for not being the best action is selected for the state *λj*. After this, in every line of a new matrix the minimum “regret” is selected and the row with the greatest value is defined.

*Table 3.2 – Criteria of finding the optimal solution in uncertainty*

|  |  |  |
| --- | --- | --- |
| **Criterion** | Matrix of benefits | Matrix of costs |
| Wald |  |  |
| Laplace  |  |  |
| Hurwicz  | , *0 ≤ α ≤ 1* | ,*0 ≤ α ≤ 1* |
|  Savage | , | , |

Having accepted this decision, the HDM has a guarantee that in the worst-case scenario, the outcome is not less than found. If the profit matrix contains elements that define loss then the HDM acts on the principle of minimax, assuming that nature acquires such a state, which will be the worst for the HDM, with the highest possible cost.

According to Wald's criterion, to find a collective solution, the most critical opinion of the group member is taken into account about the importance of the strategy. At the same time, the action is optimal, in case it has the best out of the worst views in the group. According to the conditions in table 3.3 it is also possible to define the optimal team decision with the help of Laplace and Hurwicz criteria.

We may get some differences from the usual formation of ‘regret’ matrix in case of application of the Savage criterion. Here, the matrix of wrong decisions can be built with elements *rij = max{yij} - yij*. Each row of the benefits matrix defines the maximum score from which the current score is subtracted. Then by the matrix of wrong decisions ("regret") according to the principle of minimax determines the minimum deviations between the individual and the group benefits *u*\**= maxmin {rij}.*

*Table 3.3 – Matrix of possible decisions of human operator in air navigation system in an emergency situation*

|  |  |
| --- | --- |
| **Factors** | **Alternative decisions** |
| Pressure of the external environment of the human operator towards a positive alternative at the moment of the decision | Pressure of the previous experience of the human operator towards a positive alternative at the moment of the decision | Willed decision (intention) of the human operator towards a positive alternative at the moment of the decision |
| A – choice towards a positive pole | u11 | u12 | u13 |
| B – choice towards a negative pole | u21 | u22 | u23 |

The selected decision differs minimally from the views of separate members of a team. That’s why the maximum coordination of the made decision with the thoughts of members of the teams is achieved. The use of such methods can dramatically increase the effectiveness of the decision making in the system of ATC (within an ATC shift for example).

To consider the application of the decision making model under uncertainty, let’s take an example of decision making by a human operator in case of an emergency situation of generator failure. In case of the abovementioned situation, the following happens on board the aircraft with the indicators: [18; 27]

In our case, there are two possible states of the indicators:

P1 - false actuation of the indicator;

P2 - real actuation of indicator;

The flight crew has the following alternatives:

*a1* - ensure the normal operation of the generator and continue the flight;

*a2* - Switch to a backup system and continue the flight;

*a3* - switch off the generator and finish the flight.

By taking one of the alternative solutions, the flight crew “loses” some usefulness *uij*(*аi*, П*j*) as the outcome of its subjective assessment of the emergency situation and takes the corresponding risk. The matrix of the possible outcomes are described below (Table 3.4).

*Table 3.4 - Matrix of possible results of the decision making by the flight crew in case of generator failure indicator activation*

|  |  |
| --- | --- |
| **Alternative decisions** | **Factors** |
| P1 – false actuation of the indicator | P2 – real actuation of the indicator |
| *а1* – ensure the normal operation of the generator and continue the flight | 0 | 5 |
| *а*2 – switch to a backup system and continue the flight | 3 | 1 |
| *а3* – switch off the generator and finish the flight | 4 | 2 |

Values of *uij* corresponds to the losses of the flight crew (Table 3.4), defined by an expert on a five-point scale in standard units. The most appropriate combination is indicated by the 0 of losses (*u*11=0) and the most inappropriate - satisfying the maximum losses (*u*32=5).

To find the optimal solution Wald, Laplace, Savage and Hurwitz criterion can be used, as shown below.

Wald criterion (minimax criterion) is based on a conservative behavior of the person who makes the decision, and tend to select the optimal solution from the worst. The best solution for the Wald criterion is determined by the following rule:

 (3.1)

where *Lmm* - evaluation function for the Minimax condition for matrix of losses; *u*(*ai*, П*j*) – losses which corresponds to alternative and external conditions П*j.*; *Lmm* = min {max (0;5); max (3;1); max (4;2)} = min {5; 3; 4} = 3.

Following the Wald criteria the optimal solution is alternative *a2*, which is equal to the minimum valuation function.

The criterion of Laplace that is based on the principle of insufficient grounds states that in case of unknown probability, distribution of P*j* states should be considered as equal. The rule for the definition of the optimal solution for the Laplace criterion is the following:

 (3.2)

Where L*l* - evaluation function according to the Laplace criterion; n - the number of possible states of nature.

 (3.3)

Taking into account the calculation above, the alternative a2 can also be considered as the best solution by Laplace criterion.

In case of the Savage criterion, it attempts to mitigate the conservatism of minimax criterion by replacing the matrix of losses with the matrix of risk (Table 3.5). The elements of the risk matrix are defined using the formula below:

 (3.4)

The optimal solution for the Savage criterion is defined by the following condition:

 (3.5)

Where *Ls*- evaluation function of the criterion of Savage;

*r*(*ai*, П*j*) - risk matrix elements that correspond to alternative *аi* and external conditions P*j*.

*Ls* = min {max (0;5); max (2;0); max (2;0)} = min {5; 2; 2} = 2.

*Table 3.5 - Matrix of risk for decision making according Savage criterion*

|  |  |
| --- | --- |
| Alternative decisions | Factors |
| P1 | P2 |
| *а*1 | 0 | 5 |
| *а*2 | 2 | 0 |
| *а*3 | 2 | 0 |

According to Savage criterion the most optimal solutions are both alternatives *a2* and *a3*, they meet the minimum valuation function.

Hurwicz criterion can be used to cover a great number of different approaches to decision-making - from the most optimistic to the most pessimistic (conservative). The optimum solution for Hurwitz criterion is determined by rule:

 (3.6)

where *Lh* - evaluation function according to the Hurwitz criteria; α - optimism index (0 ≤ α ≤ 1).

If α = 0 Hurwitz criterion is conservative because its usage is equivalent to the usage of usual minimax criteria. If α = 1, Hurwitz criterion is over optimistic, because it expects the best of the best conditions. The degree of optimism or pessimism can be specified by selecting α value in the interval [0, 1]. If there is no obvious tendency to optimism or pessimism, the most optimal will be α = 0,5.

*Lg = min {0,5 min (0;5) + (1-0,5) max (0;5); 0,5 min (3;1) +*

*+ (1-0,5) max (3;1); 0,5 min (4;2) + (1-0,5) max (4;2)} = min {2,5; 2; 3} = 2.*

According to the criterion of Hurwicz, the optimal solution for this case is an alternative decision *a2*. Through a comparative analysis of criteria using which the best solutions were found (Table 3.6) it is possible to see that according to Wald, Laplace, Savage and Hurwicz criteria, the optimal solution is to turn on a back-up generator and continue the flight. However, Savage criterion also provides us with an additional decision if the flight crew decides to turn off the generator and finish the flight. This solution can be used in case if there is no backup system for the generators or the flight crew is not sure in its reliability.

The flight crew is responsible for eliminating the threat to the flight safety using timely and reasonable actions. Untimely, false or incoherent actions of the flight crew can lead to an accident or incident as a result of the emergency situation. Such situations require the flight crew to be always ready to overcome any issues or problems or difficulties that they have due to an emergency situation. This can be achieved by careful, organised and well-though preparation for every flight, strong and consistent teamwork of the flight crew, their ability to assess an emergency situation quickly and accurately and take necessary measures to ensure safe execution of the flight. [18]

*Table 3.6 - Comparative analysis of the criteria*

|  |  |
| --- | --- |
| Alternative decisions | Criteria of decision making under uncertainty |
| Wald | Laplace | Hurwicz | Savage |
| *а1* – ensure the normal operation of the generator and continue the flight | - | - | - | - |
| *а2* – Switch to a backup system and continue the flight | *а*2 | *а*2 | *а*2 | *а*2 |
| *а3* – Switch off the generator and finish the flight | - | - | - | *а*3 |

### 3.4.3 Decision making under risk

According to ISO 31000 “Risk Management”, risk is the effect of uncertainty on an objective. Uncertainty includes events which may happen or not and lack of information or ambiguity. It also includes both positive and negative impact on the objective. [13, 26]

One of the main methods of analysis and assessment of risk in decision making is a decision tree. For probabilistic data, decision trees compare the expected profit/cost for different alternatives *A = {A1, A2, … An}* and are a basis for making a decision. Using decision trees, the process of decision making is described with the help of graph theory.

Graph - a graphical representation of a mathematical model. In case of decision making, graph has only one root node. In addition to the root node, there are also solutions (that are described with squares) and events (that are described with round nodes) with probability of their occurrence. An example of the decision tree is presented on Fig. 3.3. [13]



Fig. 3.3 - An example of a decision tree

The algorithm of decision making under risk can be described using the following steps:

1. Analysis of the emergency situation and determination of solution stages;
2. Finding alternative solution at each stage;
3. Definition of probabilities of outcomes for each alternative;
4. Outcome definition;
5. Creating a decision tree for the emergency situation;
6. Determination of the optimal solution via criterion of an expected value and a dynamic programming method.

The use of the analysis of the emergency situation it is possible to obtain the following information:

* graphical-analytical model of the emergency situation and decision making process of the human operator;
* stochastic models of Graphical Evaluation and Review Technique (GERT) type, decision trees and Markov chains;
* reflexive models of bipolar choice in the emergency situation under the external influence, previous experience and choices by human operator. [13]

## 3.5 Conclusions

In this chapter we have considered the notion of an air navigation system as a socio-technical system, its properties and characteristics as well as factors that influence decision making in it.

Besides that, in the chapter the different types of models and methodologies for modelling of decision making process of a human operator in the air navigation system were considered. Based on the literature review and available material, three decision making methodologies were selected for modelling of decision making of an air navigation system operator in an emergency situation of low oil pressure, namely:

* decision making under certainty in an emergency situation
* decision making under uncertainty in an emergency situation and
* decision making under risk in an emergency situation.

The decision making under certainty methodology relies on the ASSIST procedure that contains necessary steps and expected outcomes for a human operator (ATC) in case of an emergency situation.

The decision making under uncertainty methodology relies on Wald, Laplace, Savage and Hurwicz criteria to determine the optimal solution in a decision making process of a human operator under uncertainty.

The decision making under the risk methodology is based on the comparison of the effect of an event on an objective with a probability of its occurrence. One of the main methods used in this methodology is a decision tree or graph that allows to visualise the mathematical model of the decision making under the risk.

# CHAPTER 4. MODELLING OF DECISION MAKING OF AIR NAVIGATION SYSTEM OPERATOR IN LOW OIL PRESSURE SITUATION

In order to model the decision making process of the human operator of the air navigation system (air traffic controller, flight crew, etc.), it is necessary to use the decision making models that have been described in chapter 3. For that, it is also important to use the procedure that has been defined in chapter 1 - ASSIST to correctly describe the actions of the human operator (air traffic controller) in an emergency situation of low oil pressure. Since the standard set of ASSIST checklist do not provide a specific set of instructions for each emergency situation, like in our case the emergency situation of low oil pressure, there is a need to define a set of instructions for the human operator (air traffic controller) to follow in case he/she faces this emergency situation. This will be described as part of the first methodology selected for modelling of decision making (decision making under certainty).

The decision making under risk will consider the case of an emergency situation of low oil pressure from the perspective of the flight crew (specifically general aviation and private pilots) to analyse the decision making process of the human operator under the influence of risks and what would be the best course of actions in the low oil pressure emergency situation.

The last methodology - decision making under uncertainty will consider the decision making process by a human operator (a flight crew during a flight or a flight dispatcher while planning a flight) to analyse the decision making process of selecting an optimal alternate aerodrome under the influence of multiple factors such as weather, flight crew certifications, etc.

## 4.1 Modelling of decision making under certainty in a low oil pressure emergency situation

According to the algorithm of modelling of decision making process under certainty described in subchapter 3.4.1, we need to define the procedure to be followed by an air traffic controller in case of an emergency situation of low oil pressure and decompose it into smaller operational procedures.

This procedure has been created in accordance with ASSIST procedure and is described in Table 4.1.

*Table 4.1 - Low oil pressure emergency situation procedure*

|  |  |
| --- | --- |
| № | Description |
| 1.  | Obtain information about low oil pressure emergency situations |
| 2.  | Acknowledge the low oil pressure |
| 3.  | Ask for the flight crew intentions |
| 4.  | Separate the aircraft from the other traffic |
| 5.  | Report supervisor about the emergency situation |
| 6.  | Inform landing aerodrome |
| 7.  | Clear runway according to the appropriate instructions |
| 8.  | In case of forced landing, record the last known position and time |

Following the algorithm, the low oil pressure emergency situation procedure has been modelled as a block-scheme as well and it can be seen on Fig. 4.1.

In order to determine the timing for each operational procedure defined in table 4.1 and Fig. 4.1, it is necessary to use the method of export estimates to get reliable data on the proper timing of the operational procedure *ti*.

The essence of the method of export estimates lies in the receiving of estimation of the problem based on the opinion of the experts. The outcome of the method can be later on used for the decision making.



Fig. 4.1 - Block-scheme of the low oil pressure emergency situation procedure

There are two types of expert estimates: individual estimates that are based on the individual opinions of the experts and team estimates that are based on the use of the collective expert opinion. The collective opinion is more accurate than the individual one.

The method of expert estimation can be described with the following steps:

1. Setting up of a goal
2. Selection a form of research
3. Preparation of the materials
4. Selection of experts for the research
5. Examination
6. Analysis of the results
7. Preparation of the report with the results of expert evaluation

Algorithm of method of expert estimate can be described as following:

1. Questionnaires for experts (n - number of experts, usually more than 20)
2. Individual estimates of experts in a form of matrix - to determine the opinions of the experts and their systems of individual preferences (Ri, i = 1...n, where n-number of experts, Ri - preferences of the i-expert)
3. Group preferences in the form of a matrix, Rij, i=1...n, j = 1...m:

 (4.1)

where m - number of factors for expert estimates, Rij - group opinion about a problem

1. Determination of coordination of experts’ opinion:
	1. Calculation of dispersion for each factor *D:*

 (4.2)

* 1. Calculation of squared deviation *𝜎j*:

 (4.3)

* 1. Determination of variation coefficient *𝜈j*:

 (4.4)

If *𝜈j* < 33% then the opinion of the experts is coordinated.

However, if it’s more than 33%, so *𝜈j* > 33% there is a need for extra calculations using Kendel’s coordination coefficient.

* 1. Kendal’s coefficient calculation to provide better coordination of experts’ opinion:

, (4.5)

, (4.6)

, (4.7)

. (4.8)

where *S* - is generalised dispersion; *ti* - number of the same rank in the *i*-th row and fixed the *i*-th expert. If coefficient of concordance (*W*) is more than 0.7 then the opinion of the experts is coordinated, if less than 0.7 - the opinion of the experts are not coordinated and that’s why we need to collect expert input again.

1. Using Spearman’s coefficient, comparison the opinion of the group and the first expert:

 (4.9)

1. Calculation significance of the calculation:
	1. Calculation of the signification *W*, criterion - :

 (4.10)

where - calculated value of the variable;

 - table value of the variable.

* 1. Calculation of Student’s *t -* criterion:

 (4.11)

1. Calculation of weight coefficient *wj* for the problem [28, 29, 30]:

 , (4.12)

, (4.13)

, (4.14)

where n – number of examined variables; *Cj* – estimates of the experts.

To model the decision making process under certainty we’ve sent out a questionnaire to 20 experts in the field of air traffic control so that we could receive and process the maximum precise data. In the table 4.2 there are expert estimation related to the time required for the air traffic controller for each procedure in case of low oil pressure emergency situation. In the table 4.3 there is a final evaluation of experts estimates.

*Table 4.2 - Expert estimation of low oil pressure emergency situation procedure*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Expert \** **Procedure** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| **Expert №1** | 5 | 5 | 20 | 20 | 15 | 10 | 10 | 15 |
| **Expert №2** | 5 | 7 | 25 | 30 | 20 | 10 | 11 | 20 |
| **Expert №3** | 5 | 3 | 15 | 15 | 15 | 7 | 15 | 10 |
| **Expert №4** | 5 | 5 | 20 | 15 | 10 | 8 | 10 | 15 |
| **Expert №5** | 7 | 6 | 25 | 20 | 15 | 10 | 10 | 15 |
| **Expert №6** | 6 | 7 | 15 | 15 | 10 | 10 | 15 | 20 |
| **Expert №7** | 5 | 5 | 15 | 20 | 20 | 10 | 15 | 20 |
| **Expert №8** | 8 | 5 | 20 | 30 | 20 | 15 | 15 | 15 |
| **Expert №9** | 5 | 7 | 15 | 30 | 25 | 15 | 10 | 15 |
| **Expert №10** | 5 | 3 | 25 | 20 | 15 | 8 | 13 | 15 |
| **Expert №11** | 5 | 5 | 15 | 25 | 20 | 15 | 10 | 10 |
| **Expert №12** | 5 | 3 | 25 | 20 | 20 | 14 | 15 | 10 |
| **Expert №13** | 3 | 6 | 20 | 15 | 15 | 15 | 5 | 15 |
| **Expert №14** | 5 | 5 | 15 | 20 | 20 | 15 | 15 | 15 |
| **Expert №15** | 4 | 7 | 25 | 20 | 20 | 10 | 10 | 20 |
| **Expert №16** | 7 | 7 | 15 | 25 | 20 | 15 | 15 | 10 |
| **Expert №17** | 5 | 3 | 20 | 20 | 15 | 15 | 10 | 15 |
| **Expert №18** | 5 | 5 | 15 | 20 | 25 | 20 | 9 | 15 |
| **Expert №19** | 5 | 3 | 25 | 20 | 20 | 15 | 15 | 10 |
| **Expert №20** | 7 | 5 | 20 | 25 | 15 | 10 | 5 | 20  |

*Table 4.3 - Evaluation of expert estimates for low oil pressure situation procedure*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **№ of procedure** | *Rgr* | *Dj* | 𝜎*j* | 𝜈*j*, % |
| 1 | 5.95 | 1.29 | 1.14 | 21.24 |
| 2 | 5.25 | 2.20 | 1.48 | 29.08 |
| 3 | 19.5 | 18.6 | 4.26 | 21.85 |
| 4 | 21.25 | 23.36 | 4.83 | 22.74 |
| 5 | 17.75 | 17.04 | 4.12 | 23.25 |
| 6 | 12.65 | 11.71 | 3.42 | 27.71 |
| 7 | 10.75 | 10.87 | 3.30 | 28.30 |
| 8 | 15 | 13.16 | 3.63 | 24.18 |

Based on the outcomes of the evaluation of expert estimates, we can build a structural-timing table per the operational procedure using the values of the group preferences *Rgr* (Table 4.4). Also, based on the block-scheme described on Fig. 4.1, we can define the interdependencies between operational procedure and see which ones support the others or required to be performed before starting the next procedure.

According to the algorithm described in the subchapter 3.4.1, the next step in the modelling of decision making under certainty is to create a network graph of the decision making process (Fig. 4.2).

Based on the network graph and the results we have received after the evaluation of the expert estimates, the critical time for the completion of the decision making is 74,2 sec and the critical path for it is *a1, a2, a3, a5, a7, a8*.

*Table 4.4 - Time for each operational procedure*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| № | Operational procedure | Description of the procedure | Support | Time for the procedure, sec |
| 1 | *a1* | Obtain information about low oil pressure emergency situations |  | 5.95 |
| 2 | *a2* | Acknowledge the low oil pressure | *a1* | 5.25 |
| 3 | *a3* | Ask for the flight crew intentions | *a1, a2* | 19.5 |
| 4 | *a4* | Separate the aircraft from the other traffic | *a3* | 21.25 |
| 5 | *a5* | Report supervisor about the emergency situation | *a3* | 17.75 |
| 6 | *a6* | Inform landing aerodrome | *a2, a3* | 12.65 |
| 7 | *a7* | Clear runway according to the appropriate instructions | *a5* | 10.75 |
| 8 | *a8* | In case of forced landing, record the last known position and time | *a5* | 15 |



Fig 4.2 - Network graph of the human operator actions in low oil pressure emergency situation

## 4.2 Modelling of decision making under risk in a low oil pressure emergency situation

Human factor will always be a problem in the management of complex processes despite constant development and improvement of modern technologies. This factor is especially important in the field of aviation. This is due to the high level requirements related to emergency situations that may cause harm to health and life of people.

Decision making processes in emergency situation also consider the effect of the environment on human operator and management object due to the probabilistic nature of the processes.

Such qualities as timeness and correctness are used to assess the quality of human operator actions in air navigation system. They can also define the timing and precise deviation of human operator actions in comparison to the regular ones, but each potential error is not taken into account. Risk assessment should be a baseline of the standard human operator behaviour.

There are three basic ideas about risk:

* The probability of undesirable outcome;
* The amount of possible costs;
* Combination of both, probability and costs;

Method of quantitative risk assessment depends on the excellence of the data that is used to describe a situation where the decision is taken.

The algorithm for modelling of the decision making under risk is the following:

1. Analysis of the emergency situation and determination of solution stages;
2. Finding alternative solution at each stage;
3. Definition of probabilities of outcomes for each alternative;
4. Outcome definition;
5. Creating a decision tree for the emergency situation;
6. Determination of the optimal solution via criterion of an expected value and a dynamic programming method.

The mathematical model of the decision making process under the risk can be described using the optimal solution which would correspond to this condition:

 (4.15)

where *Mij* - expected benefit of the decision *Aij*:

 (4.16)

where *pij* - probability of the influence of *j* factor in selecting *i* alternative:

 (4.17)

and *uij* - outcomes of the alternative decisions.

It is necessary to establish a number of values in order to perform a risk assessment of the emergency situation of low oil pressure:

*p1* - a probability that the flight will be finished successfully;

*p2* - a probability that the flight will not be finished successfully;

*U* - losses (from 1 to 10);

*R* - risk;

*A* - optimal decision;

The allocation of losses and probabilities has been done using the method of expert’s estimates to get the most reliable data on the assessment of the emergency situation and risks involved. The input from the experts (mainly general aviation and private pilots) is provided in tables 4.5 and 4.6.

*Table 4.5 - Expert estimation of risks and losses for low oil pressure emergency situation (successful flight case)*

|  |  |  |
| --- | --- | --- |
|  | Probability | Amount of losses (U) |
| Expert \ Procedure | Successful flight | Outside landing | Aerodrome landing | Alternate aerodrome | Any nearest aerodrome | Suitable equipment | Not-suitable equipment |
| **Expert №1** | 0.4 | 6 | 2 | 2 | 1.5 | 2 | 3 |
| **Expert №2** | 0.45 | 7 | 2.5 | 3 | 2 | 1.5 | 4 |
| **Expert №3** | 0.38 | 3 | 1.5 | 1.5 | 1.5 | 3 | 2 |
| **Expert №4** | 0.5 | 5 | 2 | 1.5 | 1 | 1.8 | 3.5 |
| **Expert №5** | 0.5 | 6 | 1.6 | 2 | 1.5 | 1 | 1.5 |
| **Expert №6** | 0.35 | 7 | 1 | 1.5 | 4 | 1.5 | 1.5 |
| **Expert №7** | 0.44 | 5 | 1.5 | 2 | 2.8 | 1.5 | 1.5 |
| **Expert №8** | 0.35 | 5 | 2.1 | 3 | 2.5 | 3 | 2.5 |
| **Expert №9** | 0.4 | 4 | 1 | 3 | 3 | 2.5 | 3 |
| **Expert №10** | 0.36 | 3 | 2.7 | 2 | 1.5 | 2 | 1.3 |
| **Expert №11** | 0.42 | 5 | 1.3 | 2.5 | 2.8 | 1.5 | 4.1 |

*Continuation of Table 4.5*

|  |  |  |
| --- | --- | --- |
|  | Probability | Amount of losses (U) |
| Expert \ Procedure | Successful flight | Outside landing | Aerodrome landing | Alternate aerodrome | Any nearest aerodrome | Suitable equipment | Not-suitable equipment |
| **Expert №12** | 0.48 | 3 | 2 | 2 | 2 | 1.4 | 1.5 |
| **Expert №13** | 0.38 | 6 | 1.8 | 1.5 | 1.5 | 2.5 | 2 |
| **Expert №14** | 0.5 | 5 | 1.6 | 2.8 | 3 | 1 | 1.5 |
| **Expert №15** | 0.47 | 7 | 2.4 | 2 | 4.1 | 1.5 | 4 |
| **Expert №16** | 0.33 | 7 | 1.5 | 2.5 | 2 | 2.5 | 1.5 |
| **Expert №17** | 0.46 | 3 | 2 | 2 | 1.5 | 1.7 | 1 |
| **Expert №18** | 0.32 | 5 | 1.8 | 2 | 2.5 | 2 | 3.5 |
| **Expert №19** | 0.32 | 3 | 2.5 | 2 | 2 | 3 | 1.5 |
| **Expert №20** | 0.43 | 5 | 2 | 2.5 | 3 | 2 | 4 |

*Table 4.6 - Expert estimation of risks and losses for low oil pressure emergency situation (Not successful flight case)*

|  |  |  |
| --- | --- | --- |
|  | Probability | Amount of losses (U) |
| Expert \ Procedure | Not successful flight | Outside landing | Aerodrome landing | Alternate aerodrome | Any nearest aerodrome | Suitable equipment | Not-suitable equipment |
| **Expert №1** | 0.6 | 9 | 6 | 5 | 5 | 4 | 5 |
| **Expert №2** | 0.55 | 8 | 5.5 | 3 | 6 | 8 | 9 |
| **Expert №3** | 0.48 | 10 | 7.5 | 4.5 | 4 | 6 | 6 |
| **Expert №4** | 0.56 | 11 | 4 | 5.5 | 8 | 5 | 7 |
| **Expert №5** | 0.59 | 7 | 7.6 | 6.4 | 5 | 6 | 6 |
| **Expert №6** | 0.35 | 9.5 | 5 | 3 | 6 | 7 | 6 |
| **Expert №7** | 0.49 | 10.5 | 6.5 | 4.4 | 7 | 5 | 7.5 |
| **Expert №8** | 0.75 | 7.5 | 5.1 | 3.7 | 5 | 6 | 5 |
| **Expert №9** | 0.69 | 11.5 | 6 | 3.9 | 8 | 8 | 10 |
| **Expert №10** | 0.45 | 8 | 6.5 | 5.2 | 7 | 7 | 4 |
| **Expert №11** | 0.55 | 9 | 5.5 | 7 | 5 | 6 | 6 |

*Continuation of Table 4.6*

|  |  |  |
| --- | --- | --- |
|  | Probability | Amount of losses (U) |
| Expert \ Procedure | Not successful flight | Outside landing | Aerodrome landing | Alternate aerodrome | Any nearest aerodrome | Suitable equipment | Not-suitable equipment |
| **Expert №12** | 0.6 | 11 | 4.5 | 6.5 | 6 | 6 | 7 |
| **Expert №13** | 0.45 | 12 | 6.9 | 6.5 | 6 | 5 | 7.5 |
| **Expert №14** | 0.8 | 5 | 4.1 | 5 | 7.5 | 7 | 6 |
| **Expert №15** | 0.7 | 10 | 7 | 6.5 | 5 | 6 | 8 |
| **Expert №16** | 0.45 | 11 | 7.5 | 5.5 | 5.5 | 4 | 7 |
| **Expert №17** | 0.5 | 8 | 5.5 | 4.5 | 6 | 8 | 6.5 |
| **Expert №18** | 0.44 | 9 | 6 | 5.5 | 7 | 7 | 9 |
| **Expert №19** | 0.66 | 9.5 | 6.5 | 6.7 | 5 | 6 | 8 |
| **Expert №20** | 0.56 | 9.5 | 6 | 6 | 6 | 6 | 7 |

Using the group preferences *Rij* calculated from experts’ individual opinion, it is possible to create a matrix of risks and loss values for the low oil pressure emergency situation (Table 4.7).

*Table 4.7 - Risk and loss values for the low oil pressure emergency situation*

|  |  |
| --- | --- |
| Type of situation | Amount of losses |
| Successful flight(*p1* = 0.4) | Not successful flight(*p2* = 0.6) |
| Outside landing | U12 | 5 | U22 | 9.3 |
| Landing at the aerodrome | U13 | 1.84 | U23 | 6 |
| Alternate aerodrome | U15 | 2.17 | U25 | 5.2 |
| Any nearest aerodrome | U16 | 2.29 | U26 | 6 |
| Suitable equipment | U18 | 2 | U28 | 6.15 |
| Not-suitable equipment | U19 | 2.42 | U29 | 6.88 |

It is necessary to build a decision tree to clearly see the development of the situation and what is the best decision path to take in case of an emergency situation (Fig. 4.3).

Using the data provided by the assessment of experts’ opinions, we can calculate the risk involved in every decision taken in specific situation (4.18).

 (4.18)

Since it is necessary to always choose less risk, the *R8* prevails over *R9*:



Fig. 4.3 Low oil pressure emergency situation decision tree

Following the same rule, it is necessary to select *R5* since it represents lower risk.

Since it is necessary to choose a smaller risk, *R2* prevails over *R3*. Having calculated all of the risks we can create a solution and visualise it on the decision tree (Fig. 4.4).



Fig. 4.4 Low oil pressure emergency situation decision tree with a solution

The decision tree and calculation performed show that the optimal solution for the low oil pressure emergency situation is to perform outside landing, without trying to reach the nearest airport. However, due to the type of background of the experts, it is important to mention that this decision path is more applicable to general aviation or private pilots.

## 4.3 Modelling of decision making under uncertainty in a low oil pressure emergency situation

Uncertainty is the main factor contributing to most of the issues arising in aviation or air navigation systems. That is why the decision making under uncertainty method is aiming at reducing the influence of the uncertainty on the decision making.

Every flight performed under instrument flight rules (IFR) and some of the flights performed under visual flight rules (VFR) have to fill a flight plan (FPL) for the flight. One of the parts of the flight plan is dedicated to selection of alternate aerodromes based on the planned route, weather conditions and time of departure/arrival. While selecting the alternate aerodromes the flight crew has also take into account minimums (CAT I, CAT II, etc.) of the pilot-in-command, the weather situation at the alternate aerodrome, the amount of fuel on board of aircraft and distance to the alternate aerodrome.

In order to maximize efficiency of the flight crew, the task of finding the optimal alternate aerodrome for the flight is usually performed by a flight dispatcher of an airline or operations centre. To automate the process, usually, a decision support system is used that also provides the necessary tools for flight planning and support.

For the decision making under uncertainty, let’s take a problem of choosing an optimal decision for either landing at an alternate aerodrome or continuing to a destination aerodrome in case of an emergency situation of low oil pressure.

To apply the decision making under uncertainty methodology, it is necessary to follow the algorithm described below:

1. Define the payoff matrix;
2. Look for alternative actions - A = {A1, A2, … Ai, … Am};
3. Define factors or states of environment - λ = {λ1, λ2, … λj ,…, λn};
4. Determine outcomes of the payoff matrix uij : i=1...m; j=1...n;
5. Specify conditions of decision making under uncertainty;
6. Select the criteria for analysing the decision process - method of decision making under uncertainty:
	1. Wald criterion;
	2. Laplace criterion;
	3. Hurwicz criterion;
	4. Savage criterion.

Since we consider the problem of choosing alternate airport for a flight, the two possible actions are:

1. Decline emergency landing at an alternate airport and continue flight to a destination airport - A1;
2. Allow emergency landing at an alternate airport - A2;

The next step is to define the multiplication factors that influence the decision of the human operator of selecting the alternate airport. Those factors are:

1. Amount of fuel on board of an aircraft - λ1
2. Distance to the airport - λ2
3. Characteristics of the runway (length, type, etc.) - λ3
4. Weather conditions - λ4
5. Lighting system at the airport - λ5
6. Navigation aids - λ6
7. Runway conditions - λ7

To receive the values for multiplication factors, the opinion of the qualified experts is required to estimate the importance of the factors. That’s why, with the help of the method of expert estimates the individual opinions on the multiplication factor values have been collected (Table 4.8-4.9).

*Table 4.8 - Expert estimation of multiplication factor values for landing at an alternate airport*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Expert \ Factor | *λ1* | *λ2* | *λ3* | *λ4* | *λ5* | *λ6* | *λ7* |
| **Expert №1** | 8 | 4 | 5 | 8 | 1 | 1 | 3 |
| **Expert №2** | 10 | 3 | 4 | 6 | 1 | 2 | 1 |
| **Expert №3** | 7 | 5 | 6 | 9 | 2 | 1 | 2 |
| **Expert №4** | 11 | 3 | 4 | 9 | 3 | 1 | 3 |
| **Expert №5** | 6 | 5 | 5 | 7 | 0.5 | 2 | 4 |
| **Expert №6** | 9 | 4 | 6 | 6 | 1 | 2 | 5 |
| **Expert №7** | 9 | 3 | 4 | 8 | 2 | 3 | 4 |

*Continuation of Table 4.8*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Expert \ Factor | *λ1* | *λ2* | *λ3* | *λ4* | *λ5* | *λ6* | *λ7* |
| **Expert №8** | 7 | 6 | 3 | 10 | 0.5 | 0.5 | 3 |
| **Expert №9** | 6 | 3 | 5 | 6 | 0.5 | 0.5 | 2 |
| **Expert №10** | 8 | 2 | 6 | 7 | 1 | 1 | 1 |
| **Expert №11** | 9 | 5 | 7 | 8 | 2 | 0.5 | 1 |
| **Expert №12** | 10 | 4 | 3 | 10 | 1 | 1 | 2 |
| **Expert №13** | 8 | 6 | 4 | 6 | 2 | 0.2 | 3 |
| **Expert №14** | 9 | 3 | 5 | 7 | 1 | 1 | 5 |
| **Expert №15** | 7 | 4 | 6 | 8 | 1 | 2 | 4 |
| **Expert №16** | 7 | 5 | 7 | 8 | 0.5 | 0.5 | 3 |
| **Expert №17** | 10 | 6 | 7 | 9 | 0.5 | 1 | 2 |
| **Expert №18** | 8 | 3 | 5 | 10 | 1 | 1 | 1 |
| **Expert №19** | 9 | 4 | 4 | 8 | 2 | 2 | 2 |
| **Expert №20** | 7 | 5 | 3 | 9 | 0.5 | 0.5 | 3 |

*Table 4.9 - Expert estimation of multiplication factor values for landing at a destination airport*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Expert \ Factor | *λ1* | *λ2* | *λ3* | *λ4* | *λ5* | *λ6* | *λ7* |
| **Expert №1** | 4 | 7 | 9 | 6 | 7 | 8 | 4 |
| **Expert №2** | 3 | 6 | 9 | 5 | 7 | 8 | 4 |
| **Expert №3** | 2 | 7 | 8 | 6 | 8 | 9 | 5 |
| **Expert №4** | 5 | 8 | 8 | 7 | 8 | 9 | 3 |

*Continuation of Table 4.9*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Expert \ Factor | *λ1* | *λ2* | *λ3* | *λ4* | *λ5* | *λ6* | *λ7* |
| **Expert №5** | 6 | 5 | 7 | 5 | 6 | 7 | 4 |
| **Expert №6** | 4 | 7 | 7 | 6 | 6 | 8 | 6 |
| **Expert №7** | 3 | 8 | 10 | 4 | 7 | 6 | 2 |
| **Expert №8** | 2 | 6 | 11 | 5 | 5 | 6 | 3 |
| **Expert №9** | 4 | 7 | 7 | 6 | 7 | 7 | 5 |
| **Expert №10** | 5 | 8 | 8 | 7 | 8 | 7 | 5 |
| **Expert №11** | 6 | 8 | 9 | 8 | 6 | 9 | 6 |
| **Expert №12** | 4 | 7 | 11 | 6 | 8 | 10 | 4 |
| **Expert №13** | 4 | 7 | 12 | 5 | 6 | 10 | 4 |
| **Expert №14** | 5 | 8 | 12 | 6 | 5 | 8 | 4 |
| **Expert №15** | 6 | 9 | 8 | 7 | 9 | 7 | 3 |
| **Expert №16** | 3 | 8 | 7 | 8 | 8 | 6 | 2 |
| **Expert №17** | 4 | 7 | 9 | 7 | 7 | 9 | 5 |
| **Expert №18** | 3 | 8 | 8 | 6 | 6 | 9 | 6 |
| **Expert №19** | 6 | 8 | 9 | 5 | 5 | 8 | 4 |
| **Expert №20** | 3 | 6 | 7 | 5 | 7 | 8 | 3 |

The assessment of the expert opinions provides a number of multiplication factors for both alternate actions (continuing flight to a destination airport and landing at an alternate airport) that are summarized in the table 4.10.

*Table 4.10 - Multiplication factors influencing decision*

|  |  |
| --- | --- |
| **Alternate actions** | **Factors** |
| *λ1* | *λ2* | *λ3* | *λ4* | *λ5* | *λ6* | *λ7* |
| ***A1*** | 4.1 | 7.25 | 8.8 | 6 | 6.8 | 7.95 | 4.1 |
| ***A2*** | 8.25 | 4.15 | 4.95 | 7.95 | 1.2 | 1.19 | 2.7 |

After the factor values have been received, the values for the criteria (Wald, Laplace, Savage and Hurwicz) can be calculated. First is the Wald criterion:

(4.19)

 *=* 4.1

*=* 1.19

The next one is the Laplace criterion that can be described by the following equation:

 (4.20)

;

;

After the Laplace criterion we can calculate Savage criterion.

*min max rij (ак { max uij (ai; λj)} - uij (ai; λj))* (4.21)

= 4.7;

= 7.06;

And the last criterion is the Hurwicz criterion that can be calculated using the following equations:

 *max ai {*α *max λj { uij (ai; λj)}+ (1 -* α *) min λj { uij (ai; λj)*  (4.22)

Since there is no clear tendency for optimism or pessimism in the described situation we can take α = 0.5:

 *max ai {0,5 max λj { uij (ai; λj)}+ (1 – 0,5) min λj { uij (ai; λj)}*  (4.23)

With the help of the received values of criterion we can compose a final joint table to assess the best decision for selection of the optimal alternate airport (Table 4.11).

*Table 4.11 - Decision matrix for selection of an alternate airport in case of an emergency situation of low oil pressure*

|  |  |  |
| --- | --- | --- |
| Alternate actions | Factors | Calculation |
| λ1 | λ2 | λ3 | λ4 | λ5 | λ6 | λ7 | W | L | S | H |
| A1 | 4.1 | 7.25 | 8.8 | 6 | 6.8 | 7.95 | 4.1 | **4.1** | **6.42** | **4.7** | **6.45** |
| A2 | 8.25 | 4.15 | 4.95 | 7.95 | 1.2 | 1.19 | 2.7 | 1.19 | 4.34 | 7.06 | 4.72 |

As we can see from the obtained matrix, all of the criteria are pointing at the first alternate action which is to continue flight and perform landing at the destination airport in case of an emergency situation of low oil pressure. However, this might be dictated by the fact that the destination airport is more equipped and prepared for the acceptance of the flight. That’s why the criteria are in favour of the first option.

Therefore the decision of whether to continue flight to a destination airport or to divert to an alternate one can be a subjective one based on the experience of the flight crew, the severity of the issue, etc.

## 4.4 Conclusions

In the chapter 4 three models of the decision making of the air navigation system operator have been presented and used to model a decision making process of a human operator (e.g. air traffic controller, flight crew) in case of an emergency situation of low oil pressure on board of aircraft.

The decision making under certainty provided a necessary means to describe decision making process of an air traffic controller in the emergency situation. With the help of the algorithm described in the chapter, the actions of the human operator have been split into smaller procedure, assessed by experts and analysed with the help of the method of expert estimates. Based on the received data, the network graph has been created and used to determine critical time and path of decision making process.

Using the decision making under risk methodology, the decision of flight crew in case of an emergency situation of low oil pressure were analysed. For that the risk assessment using a mathematical model and decision trees. The input data has been received using method of experts’ estimates to ensure that it is accurate and objective. With the help of risk assessment and decision tree it has been determined that the optimal solution for the abovementioned emergency situation is to perform outside landing as soon as possible. It worth mentioning though that the majority of the experts questioned during the collection of individual opinion were representatives of general aviation or private pilots.

The decision making under uncertainty methodology has been used to facilitate the decision making process during the emergency situation and help the flight crew to make a correct decision of whether to divert to an alternate airport or to continue flight to a destination one. All four criteria that are used for the modelling of the decision making process pointed out that the more optimal decision is to continue flying to the destination airport. The result contradicts the modelling performed by the decision making under risk methodology and that can be explained that the factors selected for the decision making under uncertainty do not cover experience of the flight crew, the severity of the issue, etc. that could contribute greatly to the decision of the flight crew.

# CONCLUSIONS

In air traffic management, flight safety is considered to be a top priority. Due to growing demand in air transportation, the complexity of the systems and load on it increases constantly. However, at the same time, the requirements for the level of safety, security remains the same. In order to meet the required levels of safety, there is a need for supporting systems that would support operators (e.g. flight crew, air traffic controller, etc.) of air navigation systems in making decision in day-to-day operations. That’s why the decision support systems became widely used in the air navigation systems to support the human operators. It is also worth mentioning that system is not always there to provide the best-case solution, and that’s when human operator can rely only on his skills and abilities to make a correct decision in dangerous situations.

One of the most negative contributors to the flight safety is emergency situations. In this thesis we’ve considered and analysed low oil pressure emergency situation. Following the information presented in the thesis we can see that the emergency situation of low oil pressure can lead to serious incidents and accidents. Due to the type of the issue it is close to impossible to eliminate it. However, it is possible to provide all necessary means to support decision making of human operator to ensure that correct and safe decisions are taken by the operator to resolve an emergency situation. This could potentially contribute to increase in a number of correct and timely decisions taken by the human operator decreasing the number of emergency situations and thus enhancing the level of safety in air navigation system.

That is why the following tasks for the research and thesis have been defined and performed:

* conducted analysis of low oil pressure emergency situations, understand the reasons and possible causes in Chapter 1;
* analysed emergency procedures defined for air navigation system operator (Air traffic controller) for low oil pressure situations in Chapter 1;
* investigated decision making models of air navigation system operator and assess their applicability for low oil pressure emergency situations in Chapter 3;
* modelled decision making process of air navigation system operator in the low oil pressure operations in Chapter 4.

For the modelling we have selected three decision making modelling methodologies:

* Decision making under certainty - with the help of the algorithm described in the chapter, the actions of the human operator have been split into smaller procedure for more detailed investigation, assessed by experts and analysed with the help of the method of expert estimates. Based on the received data, the network graph has been created and used to determine critical time and path of decision making process;
* Decision making under uncertainty - all four criteria that are used for the modelling of the decision making process pointed out that the more optimal decision is to continue flying to the destination airport. The result contradicts the modelling performed by the decision making under risk methodology and that can be explained that the factors selected for the decision making under uncertainty do not cover experience of the flight crew, the severity of the issue, etc. that could contribute greatly to the decision of the flight crew;
* Decision making under risk - the decision of flight crew in case of an emergency situation of low oil pressure were analysed. For that the risk assessment using a mathematical model and decision trees. The input data has been received using method of experts’ estimates to ensure that it is accurate and objective. With the help of risk assessment and decision tree it has been determined that the optimal solution for the abovementioned emergency situation is to perform outside landing as soon as possible. It worth mentioning though that the majority of the experts questioned during the collection of individual opinion were representatives of general aviation or private pilots.

From the performed modelling and received results it can be stated that the decision making methodologies used in the thesis could be considered as powerful means to perform assessment and analysis of various emergency situations (including low oil pressure emergency situation) and provide the human operator with a correct and timely decision to ensure the high level of flight safety. The use of the decision support system that implement the decision making methodologies described above could contribute significantly to the overall level of safety in air navigation.

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