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Towards Sustainability in Air Traffic Management

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Abstract: The International Civil Aviation Organization is estimated that the number of domestic and international passengers will be expected to reach six billion by 2030. This exponential growth in air transport has resulted in a wide range of adverse effects such as environmental impacts. The purpose of this research is to develop new air traffic management, and operator (pilots, air traffic controllers) load measuring systems in order to save fuel, and flight time, thereby reducing environmental impact, carbon emission, greenhouse gas generation, noise pollution, and operating cost. This paper deals with: (i) dynamic sectorization and airspace configuration (ii) introduction of the highly dynamic approach and landing procedures, (iii) dilemmas of human in sustainability (related to the individuals, the society, the non-governmental organizations, and the managers), and (iv) development of dedicated non-intrusive operator supporting systems based on eye-tracking, heart rate, and electrodermal activity. Due to the consequent effects of these developments, the dynamic sectorization and air space configuration may eliminate the task overload and reduce the actual operator load by 30–40%. With the developed concept of dynamic approach and landing procedures, aircraft will be able to follow better trajectories to avoid residential areas around airports to (i) reduce ground noise, and emission, (ii) avoid encounters severe weather and prevent incidents and accidents, and (iii) decrease landing distance up to 56% in compared to the "published transition route".

Keywords: air traffic management; operators; high level of automation; optimal trajectories; dynamic approach and landing procedures; dilemmas; sustainability; environmental impact; emission; greenhouse gases

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1. Introduction

Due to the technological advances in avionics, operator working environments have become highly automated by complex operator-machine systems. These automated systems may solve some of the previous problems, e.g., reduce workload, increase comfort, however; they often introduce others e.g., reductions in situation awareness, unbalanced operator load (particularly mental, information and communication load), increased stress, and issues of mistrust, boredom, monotony, surprise, confusion, uncertainty, and attention distribution. On the one hand, the aviation systems are or going to be highly automated so that little effort is necessary to control them as long as the automation system is properly functioning. On the other hand, automation systems bring disadvantages to the aviation environment such as increasing the mental and information load of operators and lowering hands-on skills, particularly when avionic systems fail, malfunction, or be under abnormal situations. These new avionic systems require more thought, new skills, high-quality decisions, and as much as fast actions particularly under being in abnormal or emergency situations. Therefore, the operator models, and load monitoring and management become the level of the most critical tasks. The future workstation of operators (air traffic control tower, cockpit, future ground control tower of pilots) and avionics systems need to be reconfigured by taking into account human factors, measurable psychological parameters, and operator total loads. As the avionics system became more complex, evaluation of the performance of operators was required, such as situation awareness, decision-making, and operator load. Numerous large-scale projects have been conducted globally to cope with the current and future problems of Air Traffic Management including environment, air traffic complexity, airspace capacity, safety, and efficiency of air space operations, such projects as; SESAR in Europe [1], NextGen in the United States [2], CARATS in Japan [3], and SIRIUS in Brazil [4], etc.

This study aims to reduce the environmental effect of aviation by using optimal airspace capacity, shortest trajectories between starting and the target point, and subsystems in the operator environment. To do so, the following analysis and measurements have been conducted in this research: (i) the dynamic sectorization and airspace configuration, (ii) the introduction of the highly dynamic approach and landing procedures, (iii) the dilemmas of human in the sustainability (related to the individuals, the society, the non-governmental organizations, and the managers), and (iv) the development of dedicated non-intrusive operator supporting systems based on eye-tracking, heart rate, and Electrodermal Activity Measurement.

This research has been conducted on operators' working environment to continuously monitor and gather information on operators' activities with different applications, aiming at increasing situational awareness, balancing total loads on the subject thereby reducing the environmental impact of aviation.

2. Present and Next-Generation Air Traffic Controllers' Workstation

Air traffic control requires critical and timely decision-making in the dynamic working environment for safe and efficient operation. It is well-known that air traffic controllers' job requires a stochastic working environment with a high level of responsibility concerning risking lives and as well as the high economic cost of aeronautical activities. Air traffic controllers work with their colleagues at air traffic control towers where they rely on radar and visual observation to control all the movements. In today's aviation practice, an air traffic controller monitors the location and movement of aircraft on the ground and in airspace by radar and directs them to the designated airspace sector. They coordinate the flow of air traffic, taking responsibility for the aircraft's safety; thereby, ensuring safe, secure, and efficient movement of the air traffic including the ground, terminal and en-route operations.

The "Air Traffic Management System" is a centrally controlled and organized system. Due to the increasing level of automation, the workstation of air traffic controllers has been continuously changing since August 1910 that marks the world's first use of a radio between an aircraft in flight to the ground at Sheepshead Bay, New York [5]. Several subsystems have been integrated into the working environment of air traffic controllers to increase situation awareness and decision-making [6–8]. The load monitoring and management of controllers, primarily mental and information, initiate new requirements for information processing. When designing and implementing the workstation of air traffic controllers, the system developers, manufacturers and researchers should consider both physical factors such as the display position, lighting, and auxiliary and subjective factors like knowledge, tacit knowledge, skill, operator loads, stress, and anxiety. Therefore, in this research, several analyses have been conducted to monitor and manage operator total load systems. These developed concepts and systems will help air traffic controllers keep their tasks at an optimal level, which directly connects to excellent performance and safety. For example, in the developed load monitoring system, the total loads of air traffic controllers will be continuously measured by the integrated devices in their working environment, and the changes of each load level will be separately demonstrated on the operators' and as well as for their supervisors' displays. In case of an unbalanced operator load, the supervisors and/or the avionic system automatically will be able to change the arrangement of working teams, tasks, and structures such as decrease the number of aircraft under his control, responsible airspace or basically will bring some suggestions to the operators. This development will balance total operator loads and improving the comfort and well-being of operators in their working environment.

Reduction of active control might lead air traffic controllers less to do with telephoning, listening, and conveying information; therefore, greater emphasis should be placed on developing their attention, particularly in abnormal/emergency situations. The future ATM system that is being developed by several mega-scale projects (SESAR, Next-Gen) under rethinking, redesigning the existing system by using the advantages of the advanced and emerging technologies [9–11]. All the supporting systems will be improved, and innovative technologies will develop a lot of new principles, solutions, tools. Some technology solutions were planned to develop and deploy by NASA's Blueprint Project such as automated airspace, high flow airports, and digital atmosphere [10]. The new developments will generate systematic changes in future ATMs as SESAR evaluates them. The following four major aspects might characterize the future work and working environment of air traffic controllers: (i) air traffic controllers will play the role of the passive operator in the highly automated system—instead of active separation control management, (ii) air traffic controllers will have a "greater" working environment; namely, they will have several displays or large screens, several windows working parallel on their computers, etc., (iii) they will be working on-line in an "off-line" environment, i.e., in remote tower environment equipped with large synthetic vision screens, etc., (iv) they will have too much information that may confuse them.

Numerous research has sought to investigate the link between operator workload and operational errors such as pilots workload analysis [12], pilots' performance and workload assessment [13], pilots' reaction time and mental workload [14], pilots' mental state measurement [15], and, air traffic controllers' workload and decision supporting system [16]. Operators commit errors not only under high workload circumstances but also in low workload conditions due to attention distribution and confusion [17]. In the continually changing aviation systems, it is necessary to define what degree of total load operators receive from the current system. Automation should increase overall performance and reduce the chance of error by lowering task demands on operators. According to Liu et al. [18], operators only monitor what an autonomous system is doing, but if an operator does not know well why and how it is doing it, and what it will do next, the autonomous system will contribute high loads to operators. The intensive technology and automation brings less workload for operators, easy to access to desired information, fast data exchange between units, however; air traffic controllers' responsibilities are getting higher in advanced working environments, particularly in abnormal circumstances. In order to eliminate the adverse effect of the autorotation like reducing situation awareness, poor quality of decision, high mental load, high level of stress, time spent, high fuel burn and GHG emissions, lose the hands-on skills and lose the feel of aircraft, there is a need for new methods and concepts of: (i) air traffic management, (ii) dynamic sectorization and airspace configuration, (iii) operator load monitoring and management.

3. Methodology

The rapid and continuous expansion in air transport generates economic growth, globalization, creates jobs, facilitates international trade and tourism, however; this exponential growth has resulted in a wide range of adverse effects such as environmental impacts of emission and noise. This research aims to develop new air traffic management, and operator (pilots, air traffic controllers) load measuring systems in order to save fuel, and flight time, thereby reducing environmental impact, carbon emission, greenhouse gas generation, noise pollution, and operating cost.

In this research, firstly, the "Dynamic Sectorization and Airspace Configuration" Concept has been developed by the current authors in the framework of a large-scale SESAR project, namely "Innovation through Validation for Air Transportation in Europe —INNOVATE (SJU/LC/0162-CTR)". According to this concept, the total airspace can be divided dynamically into small functional blocks, namely "sectors" depend on the air traffic complexity, operator total loads, and weather condition. Secondly, the dynamic routing concept has been developed by the current authors. Based on this concept, the arrival and departure routes will be dynamically designed by using non-published points depend on the complexity of air traffic, type of aircraft, weather condition, and total load condition of pilots. In addition to this, based on the developed "Dynamic Routing Concept", the Budapest Liszt Ferenc International Airport (BUD) has been simulated as a case study, and the cost function is calculated by using the fuel consumption. Thirdly, in order to analyze the decision-making process, the dilemmas of human in the sustainability (related to the individuals, the society, the non-governmental organizations, and the managers) has been examined and following models have been improved (i) the Endsley decision-making model has been improved and adapted to the current situation by including environmental sustainability, dynamic sectorization, aerospace design, optimal trajectory, and greenhouse gases, (ii) the greenhouse gas emissions have been compared between some countries such as Hungary, Poland, and Iceland, etc. and (iii) V-model approach has been created for the environmental and sustainability education (Figure 1).

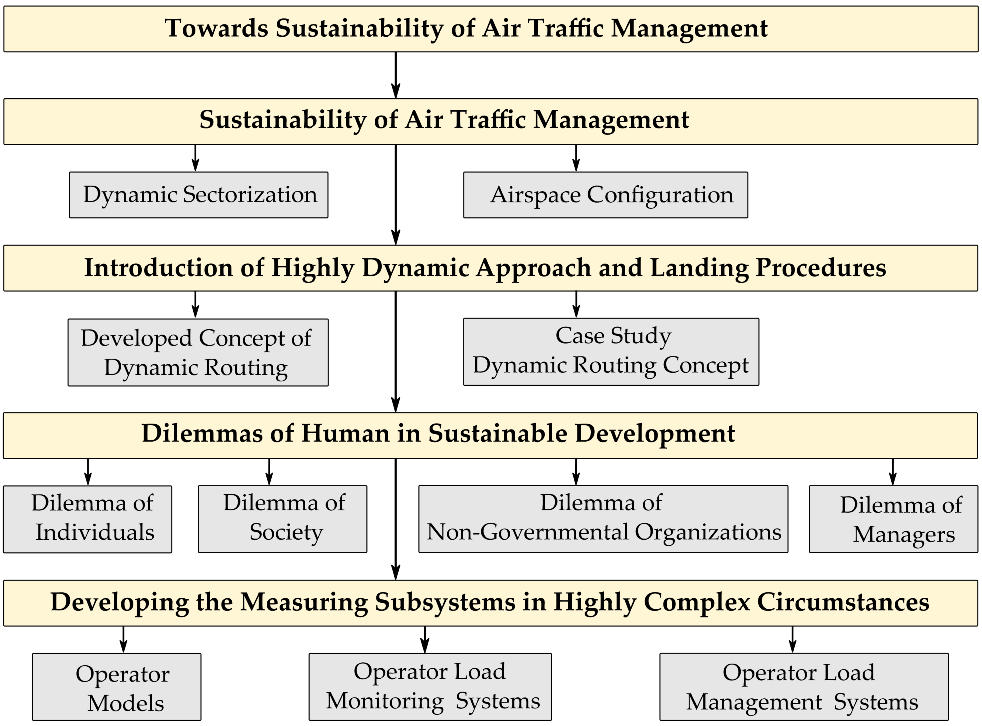

Figure 1. Data flow diagram of the study.

Finally, the dedicated non-intrusive operator supporting systems have been developed in a highly complex environment, and divided into three categories; (i) operator models; Endsley Situation Awareness Model, James Reason Swiss Cheese, and Rassmussen Decision Making Model have been improved and adapted to the human operator work, working in highly automated systems (ii) operator load monitoring systems; several load measuring systems have been used in operators workstations by the current authors such as eye-tracking, heart rate, and electrodermal activity measurement and (iii) operator load management systems; operator load management systems have been created for underload and overload situations.

4. Sustainability of Air Traffic Management: Dynamic Sectorization and Airspace Configuration

Air traffic is growing in the world and will continue to grow rapidly in the next decade. Accordingly, airspaces become increasingly busy and the overall route structure and airspace system will be more complex. Future airspace configuration will be dynamic and adaptable to changing circumstances which vary in time and place to conform to more flexible traffic. Nowadays, several international projects are launched to cope with the present air traffic management issues, including, e.g., airspace capacity, air traffic efficiency, air traffic complexity, and environment [19–21]. The SESAR project develops a new method for sector design and airspace configuration. One of the large projects in SESAR deals with the investigation of operator' workload management. And one of the possible management options is when the airspace is divided into smaller regions referred to as "sectors". They are dynamically changed with an aim of making the configuration of the airspace less complex in terms of both its uncontrolled/controlled airspace classification and its international boundaries. This is the so-called "Dynamic Airspace Configuration". Introducing dynamic airspace configuration will significantly decrease total operator load, and the complexity of the overall route structure and airspace system. A special workshop organized by Budapest University of Technology and Economics for validation of the exercise performed in the scope of the SESAR program in France, namely INNOVATE. During the workshop, a series of questionnaires were used for the evaluation of the opinions of experts. The current researcher took part in this project in the assessment of results. The main goals of the project were: (i) balance the sector workload for ensuring safety, (ii) decrease operator total loads, (iii) better use of the availability of airspace, (iv) offer the maximum capacity to the incoming air traffic, (v) best meet traffic demand at peak times operate with less staff, (vi) reduction in fuel burn and emission, and (vii) minimising all costs. In the framework of the SESAR project, the concept of the dynamic sectorization and airspace configuration has been modeled as seen in Figure 2.

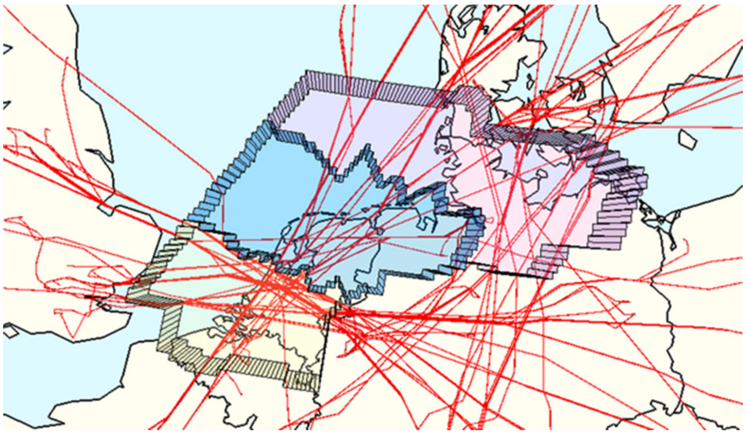

Figure 2. Dynamic sectorization and airspace configuration [22].

Most of the airspace around the world is divided into functional blocks such as centers, sectors, or other airspace components. The decision to reconfigure sectors is driven by the managers' personal experience and judgment. Airspace sector configuration needs to be dynamic, flexible, and adaptable based on changing weather and traffic conditions. According to the developed dynamic sectorization and airspace configuration concept, the total airspace can be divided dynamically into small functional blocks, namely "sectors" (Figure 2). Depend on the air traffic complexity, operator total loads, and weather condition, airspace sectors may be dynamically configured by: (i) combing them into fewer large blocks during low traffic density, or (ii) splitting them into small sectors during high traffic density, to offer the maximum capacity to the incoming traffic. The complexity of the traffic, operator total loads, and weather conditions directly influence operator total load and environmental sustainability. According to the results, the "dynamic sectorization and air space configuration" provide more flexibility to adapt sector configuration in response to demand pattern changes and traffic flows, eliminate the task overload, and reduce the actual operator load by 30–40 percent.

5. Introduction of Highly Dynamic Approach and Landing Procedures

The rapid expansion of air traffic in the world has brought about the need for more sustainable modes of flight. Nowadays, airlines cannot fly optimal trajectories during the flight phases namely climb, cruise, descent due to the airspace regulations country restrictions, air traffic management, and airline company policy. Most pilots feel pressed and stressed during operations to avoid flight delays and miss the flight connections. This pressure forces pilots to fly faster at non-optimal altitudes to arrive at the destination airport in scheduled time resulting in extra fuel burn, and more greenhouse emission generations. Air traffic controllers might grant shortcuts or direct routing to pilots for the shorter route apart from speed and altitude. Consequently, several institutes and companies have been initiated several large-scale proposals for redesigning air traffic control to increase the airspace capacity, air traffic efficiency, and safety such as "Radio Technical Commission for Aeronautics" (RTCA) [23], "Federal Aviation Administration" (FAA) [24], and "EUROCONTROL" [25]. All these proposals have been introduced more freedom for the operators to decide several flight parameters such as speed, altitude, and heading, etc. There are significant transitions in roles and responsibilities of operators from the air traffic tower to the cockpit [26]. For example, The "Distributed Air/Ground Traffic Management (DAG-TM) and RTCA proposed "Free Flight (FF)" [10] which describes a significant transition in air traffic control procedures in which the task of traffic separation has been moved from Air Traffic Controller to pilot [27]. Principally, automation will not take over the whole responsibility, trajectory management; however, it expands the air traffic controllers' functional envelope. Nevertheless, the free flight concept shifts the air traffic management system from a centralized control system to a distributed control system. Therefore, the free flight concept is a revolutionary change of the air transport system [28]. The most significant challenges of free flight are: (i) maintaining the safe distance between aircraft, (ii) potential for more efficient routes, (iii) cutting down flight time, (iv) increasing airspace capacity, (v) fuel efficiency, and (vi) less dependence on air traffic control [29,30]. The workload of air traffic controllers would be reduced considerably by introducing these innovative concepts as well.

One of the aspects of environmental impact, thus contributing factor in sustainability, is aircraft noise. The noise load of departing and arriving aircraft in the vicinity of an airport is one of the most serious problems in the world. Designers of departure and arrival procedures have to cope with this problem, however; the results usually not as satisfying as is expected by the community. In congested airspaces, air traffic controllers ordered aircraft to fly along with a published procedure. This is usually of long duration but offers an opportunity to the controller to ensure the required time and appropriate distance separation. When the number of arriving aircraft allows, Air traffic controllers are able to assign shortcuts to shorten the flight path and total flight time, thereby reducing the amount of burned fuel and emission. The shortcuts are given between published points of a procedure and usually not considering the noise load on underlying urban areas. Another widely used method is "Radar Vectoring" which lets pilots fly a specific heading. Air traffic controllers can use "radar vectoring" during landing and take-off for archiving the most efficient airspace utilization if it is necessary to deviate from published air routes or procedures. One of the most effective ways to reduce noise load on inhabited areas would be to fly between arrival and departure routes over rural areas, depending on traffic load, weather condition, and aircraft energy state, etc. A dynamic routing concept has been developed by the current researchers where air traffic controllers need to dynamically design arrival and departure routes using non-published points depending on the complexity of air traffic, type of aircraft, weather condition, and total load condition of pilots (Figure 3). The details of the designed routes could be transferred to the aircraft's computer via the improved data-link system, where pilots can accept it and load directly to the flight management system.

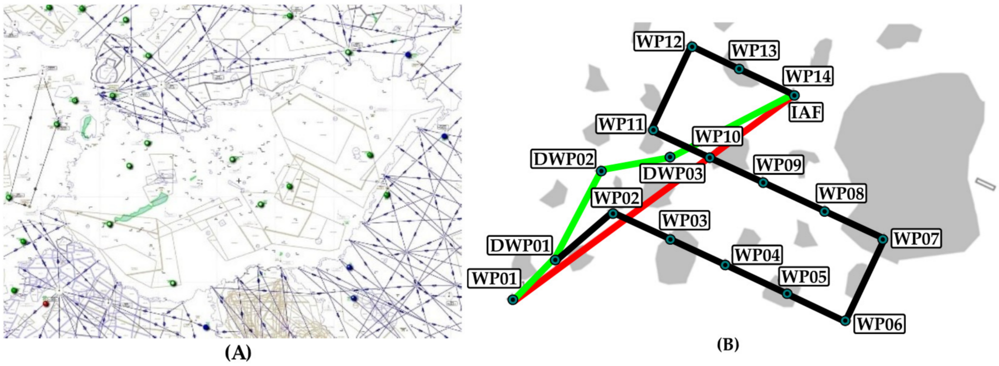

Figure 3. Hungarian free route airspace with border points (**A**) [31], and developed concept of dynamic routing (**B**).

Figure 3 right shows the concept of the dynamically designed route of an arriving aircraft from WP01 to WP14. The black path is a published transition route, the red is a shortcut given by the ATC in low traffic density, and the green line is a dynamically designed route considering noise load, and aircraft energy state, etc. With the developed concept of dynamic approach and landing procedures, aircraft will be able to follow better trajectories to avoid residential areas around airports to: (i) reduce ground noise, and emission, (ii) avoid encounters severe weather and prevent incidents and accidents, and (iii) decrease landing distance up to 56% in compared to the "published transition route". This concept will improve the air traffic situation by decreasing flight durations, fuel consumption, congestion, emission, and noise load. In addition to this, the "Dynamic Routing Concept" has been simulated at the Budapest Liszt Ferenc International Airport (BUD) as a case study, and the cost function is calculated by using the fuel consumption (Figure 4).

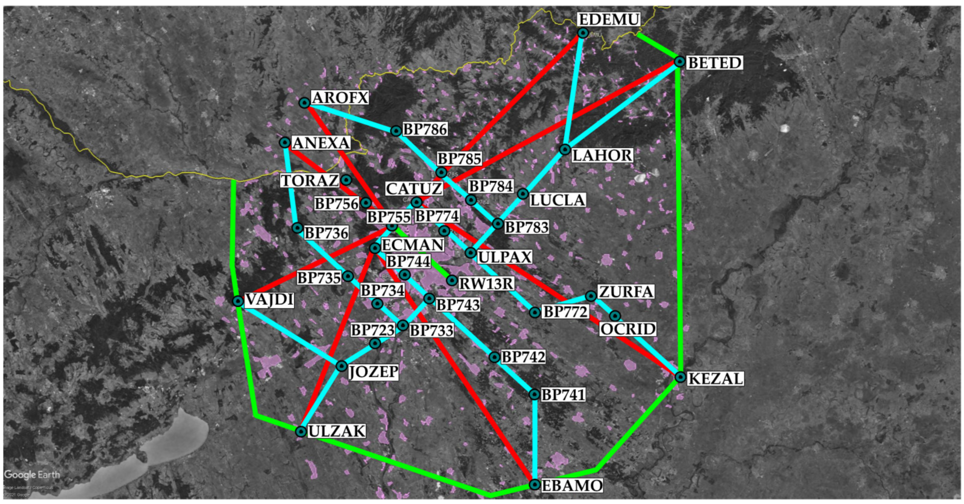

Figure 4. Simulation area of the Budapest Liszt Ferenc International Airport.

Figure 4 shows the simulation area of the Budapest Liszt Ferenc International Airport. The light turquoise lines and dark turquoise points are the published "Standard Arrival Routes" and "waypoints" for the runway 13R of the Budapest Liszt Ferenc International Airport. The red lines are the "shortcuts" to the most suitable points of the STAR considering the turn radius of a medium-range size aircraft. This means that in the same cases, aircraft fly to BP755 or ECMAN, or CATUZ point, depending on the entry point of the STAR. These shortcuts offer the shortest distance for the landing and less fuel consumption. The green lines are the border of the Budapest Terminal Control Area (TMA) and the final approach of RW13R. The pink polygons are representing the inhabited areas under the TMA. Inhabited areas are classified by their population density. A weight factor is assigned to each area, which depends on its population density. High-density areas like cities have higher cost values than villages or resort areas.

In the simulation, the aircraft has to fly a dynamically generated route that avoids the populated areas as much as possible lowering the level of impact of air traffic. In the simulation, a generic medium-range jet aircraft has been simulated which has a similar property then a Boeing 737 Next Generation (B737NG) or an Airbus A320 (A320). In this stage of the simulations, only 1 runway operation has been investigated and the route-finding algorithm has limited capabilities to avoid emerging separation problems.

During the optimization, the cost function is calculated by using the fuel consumption which depends on the length of the generated route and power required by the aircraft (Table 1). The other factor in the cost function is the overall impact on inhabited areas. The value of the impact is a function of the altitude above the ground, power required by the aircraft, and the time. The impact then is weighted by the weight value of the inhabited area.

Table 1. Level of fuel burn compared to STARs and shortest distance.

Name of the Point	Average Decrease in Fuel Burn Compared to STARs	Average Increase in Fuel Burn Compared to the Shortest Distance	Overall Decrease on Inhabited Areas Compared to STARs	Overall Decrease on Inhabited Areas Compared to the Shortest Distance
ANEXA	−56%	20%	−44%	−7%
VAJDI	−40%	17%	−38%	−6%
EBAMO	0%	7%	−31%	−28%
KEZAL	−2%	5%	−22%	−15%
BETED	−8%	8%	−17%	−10%
EDEMU	−22%	6%	−20%	−12%
ARFOX	−59%	2%	−23%	−9%
ULZAK	−15%	11%	−33%	−2%

When the decrease in fuel consumption is 0%, that means the generated route has almost the same length as the STAR has, but the impact is less because it avoids highly populated areas. As can be seen in Table 1, the fuel burn can be decreased (i) up to 56% on average compared to the STARs through the ANEXA, (ii) up to 44% in overall on inhabited areas compared to STARs through the ANEXA, and (iii) up to 28% in overall inhabited areas compared to the shortest distance through the EBAMO.

6. Dilemmas of Human in Sustainable Development

Humans face the necessity to make decisions on a day-to-day basis whether on a personal, or business. The decision-making process is to select two or more courses of action that are the most appropriate for a given situation. Decision-making plays a crucial role in the quality of the performed actions. Consequently, humans encounter dilemmas in almost every decision-making process. Humans' inability to determine the optimal solution to such dilemmas in sustainability may result in serious consequences for the environment. Human dilemmas can be divided into four main groups: (i) dilemma of individuals, (ii) dilemma of society, (iii) dilemma of non-governmental organizations-NGOs, and (iv) dilemma of managers.

6.1. Dilemma of Individuals

Every human being has to make his or her own choices about protecting the environment. One of the biggest problems with environmental sustainability is that a single individual's environmental impact is considered an insignificant step to greener living, however; environmental sustainability starts with individuals. Individual actions, decisions, behavior, personal responsibilities are essential to solving climate crises. In aviation, the decision-making process of the operators who are having a role in sustainable developments strongly depends on many factors, such as total load systems, mental condition, experience, tacit knowledge, and skills. Unfortunately, some decisions lead to the loss of hundreds of people's lives and extraordinary environmental pollution and economic consequences. According to Endsley, the decision-making process can be formed by three stages, namely "situation awareness", "decision-making", and "performance action" [32,33]. In this model, the three-level model of situation awareness is developed: (i) Level 1 SA—Perceiving, (ii) Level 2 SA—Comprehending, and (iii) Level 3 SA—Predicting.

- Level 1 SA: The first level of situation awareness is about perceiving critical factors and information through five senses in the environment. Operators scan and gather all the relevant data in a working environment which is highly affected by tacit knowledge, experience, and skill. It is necessary to filter out irrelevant data and disregard it to balance information load at this level.
- Level 2 SA: Comprehension of a present situation, integration of the information with operational and decision maker's goals. At this level, operators should understand, analyze, classify and integrate the information received in the working environment. This level requires effective and efficient information processing by operators to focus on specific and useful data.
- Level 3 SA: The third level of situation awareness is the ability to project future states of the systems based on the information that has been perceived and analyzed. This highest level of SA is crucial in the operator's decision-making process.

The decision-making model of Endsley is improved, by the current researchers, by including some of the tasks/system factors (such as environmental sustainability, dynamic sectorization, airspace configuration, optimal trajectories, greenhouse gases, operator total loads, etc.), and individual factors (such as competence, skill, knowledge, tacit knowledge, experience, training, intuition, mental condition, etc.) (Figure 5).

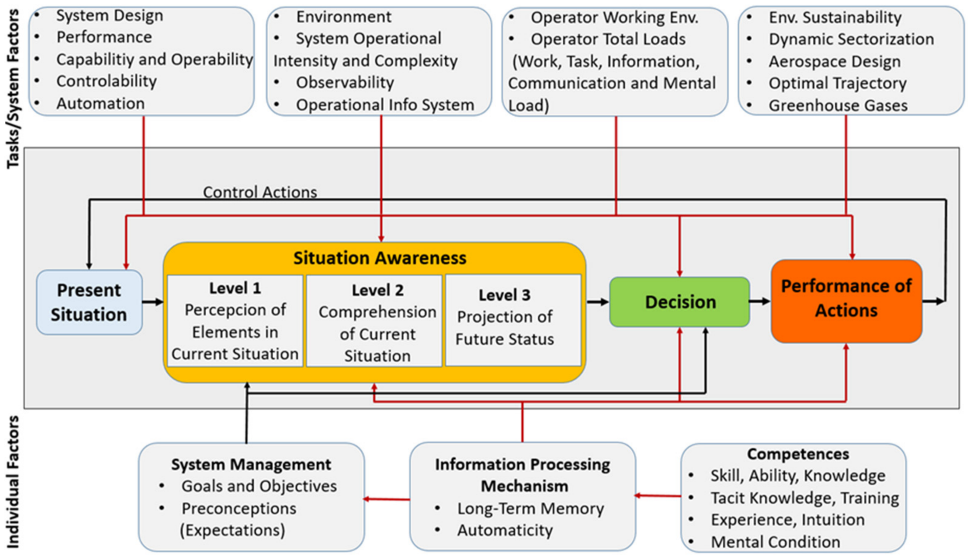

Figure 5. The improved decision-making model of Endsley.

The quality of the decision is highly dependent on the available information and the listed tasks/systems and individual factors. In the improved model, the operator needs to take into consideration environmental sustainability during the decision-making process. The result of operator decisions affects the environment in which all people live and environmental decisions that affect millions of lives, including aircrews and passengers.

6.2. *Dilemma of Society*

One of the most important topics in geography is how groups of individuals interact with the environment. Human activities, preferences and awareness, and decisions might cause a positive and negative impact on the environment. At a group scale, society must be capable of learning all the time, and collectively adopting new ways of interacting with the environment. As the population is increasing worldwide, human activities are also increasing respectively which results in more energy and consumption demand, thus contributing to higher environmental degradation. There are several governmental and non-governmental organizations, international programmers such as UNESCO and the United Nations Environment Programme (UNEP) trying to increase the environmental awareness of society by organizing international conferences on the environment and society. In addition to there is a numerous large-scale international project to cope with the environmental problems such as the European Green Deal, Life Programme, Climate Action Program 2030, Climate Action Plan 2050, Renewable Energy Sources Act. These projects have played a critical role in creating strategies and action plans.

In addition to this, most countries and many regional and local governments all over the world offer grants and incentives for electric vehicles to promote the adoption and spread of electric vehicles (EVs) because of their potential financial and environmental benefits. Examples of these government supports are purchase rebates, subsidies, tax exemption, tax credit, etc. Electric vehicles are reducing energy consumption and emission. Electric cars are greener once the total emissions are calculated from manufacture and electrical generation. This can be true only if the electric vehicles are charged with electricity from renewable sources such as wind turbines, solar panels, etc. The only exceptions are places like Poland, where electricity generation is still mainly based on coal. GHG emissions from transport have increased every year since 2014. According to the European Commission 2050 long-term strategy report [34], the EU set a long-term goal of cutting greenhouse gas emissions by 80–95% by 2050 and an agreed target of a 40% emission reduction by 2030 when compared to the emission level of 1990. Despite considerable progress, transport continues to be a significant source and does not have the possibility to decrease greenhouse gas emissions significantly in many countries such as Hungary, Poland, Iceland, etc. (Figure 6).

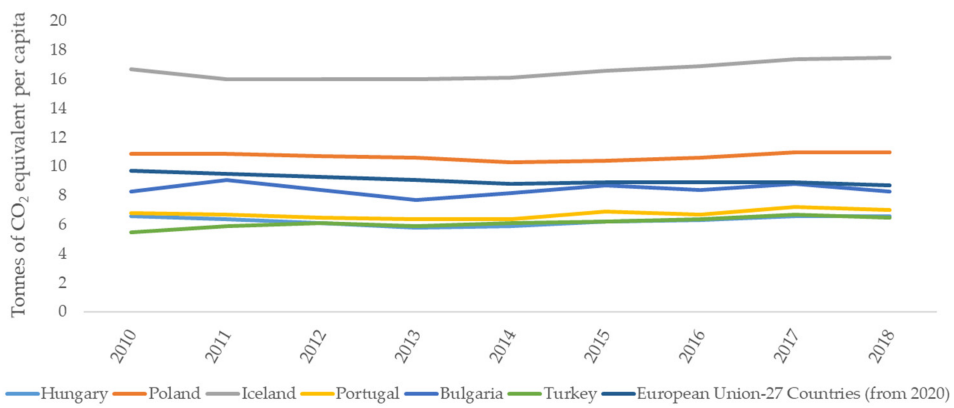

Figure 6. Greenhouse gas emission per capita (data taken from European Environmental Agency—EEA [35]).

Despite the several large-scale international projects, governmental and non-governmental organizations, and government support, it is hard to decrease greenhouse gas emissions significantly. There is a need to move toward greater environmental sustainability and make better decisions by individuals, and society.

6.3. Dilemma of Non-Governmental Organizations (NGOs)

Non-governmental organizations are legally constituted non-profit groups that are not affiliated with a government. Non-governmental organizations are responsible for addressing issues in a wide range of fields for the public good across different societies such as environmental preservation (e.g., Greenpeace, Eco-drive, Climate Conversations, Conflict, and Environmental Observatory), human right promotions (e.g., Amnesty International, Human Right Action Center, Human Right Watch, and International Union for Conservation of Nature), health care (e.g., Doctors of the World, International Medical Corps, Medic Mobile cultural preservation (e.g., Europa Nostra, International Council of Museums, and International Council on Monuments and Sites), and conflict resolution (e.g., Carter Center, and Search for Common Ground), etc.

Non-governmental organizations monitor government activities and exert pressure to be socially and environmentally responsible. They use different strategies and tactics to positively affect a government's decision-making process to introduce the concept of sustainable development and raise environmental awareness. Non-governmental organizations' high pressure on the government sometimes might result in poor decision-making. For example, following Ukraine's Chernobyl disaster in 1986, and Japan's Fukushima Daiichi nuclear power plant disaster in 2011, Germany received high pressure from non-governmental organizations, social and political groups to phase out the nuclear powers in the country and thousands of protesters took the streets against nuclear energy across Germany. Due to social and political pressure, Germany has decided to shut down all the nuclear power powers by 2022 and replace them with plants generating electricity from clean and renewable sources. Germany has already shut down 10 nuclear reactors until now by the following years: 8 reactors in 2011 (8.4 GW of capacity), 1 reactor in 2015 (1.3 GW of capacity), 1 reactor in 2017 (1.3 GW of capacity), and the remaining 6 nuclear power reactors in operation will be closed in 2022 [36]. Germany aims to reduce carbon emissions by shutting off the nuclear power stations at least 80% by 2050 relative to 1990 levels [37], however; according to a study conducted by the researchers at the University of California at Berkeley, the environmental effects of Germany's nuclear power rejection was miscalculated and resulted in releasing extra 36 million tons of carbon dioxide per year which increase emission about 5% [36]. This is because Germany shuts off the nuclear power plants and mostly replaces them with power from fossil power plants. This example demonstrates that non-governmental organizations, society, and individuals directly influence on the system and decision-making mechanism. This is, therefore, the environmental attitudes and sustainability awareness need to be taught well in schools.

According to the Statista Research Department, 26% of the world population are under the age of 15 as of mid-2020 [38] which makes children and young adult education more essential to the success of environmental responsibilities. Education for the environment and sustainability is a holistic, lifelong, and continuous learning process that begins formally in schools, however; the learning isn't happening just inside the classroom. Senior citizens, kindergartners to college-age students, parents, business owners, teachers, and other community members learn, share ideas, connect, and solve real-life problems together. These teams have not only learned how to reduce their energy consumption and switch to renewables, but they've also become adept at tracking energy usage, teaching others in their communities, and planning for future energy and dollar savings. Environmental and sustainability education can be described by a "V-model approach" as seen in Figure 7.

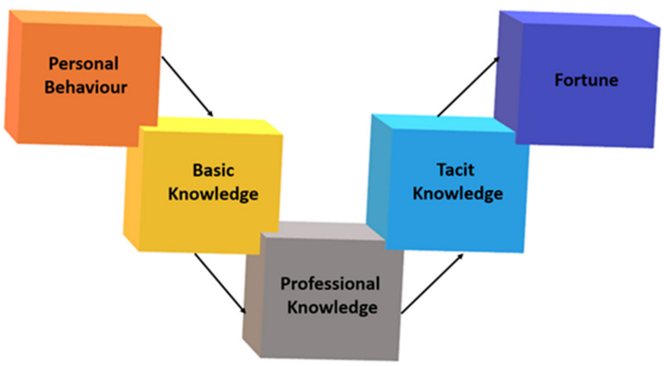

Figure 7. V-model for environmental and sustainability education.

According to the developed V-model, environmental education and sustainable awareness start with parents at a young age when the child's personal behavior (emotional, societal, and intellectual abilities) molds. The basic and professional knowledge will be given in institutions, namely kindergartens, schools, colleges, and universities. Tacit knowledge can be gained only by the application of professional knowledge in practice.

6.4. Dilemma of Managers

Sustainability is becoming essential for all enterprises all over the world. Managers play a significant role in creating a culture of sustainable development in their enterprise. One of their main responsibilities is to implement sustainable strategies, activities, and actions. In order to achieve sustainability goals, managers should better understand the need to act on sustainability.

Managers across the world make all the decisions to maximize the wealth of their enterprise and profits to optimum levels. And all the decisions taken by the managers are expected to have a positive effect on the profits. Most managers are aware of the importance of sustainability as the main responsibility to the environment and society. These managers make strong commitments to sustainability by considering their operation in the social, ecological, and financial environment. However, a considerable number of managers avoid setting regulations and long-term strategic plans for environmental, health protection, safety, and security due to being under pressure to cut costs. Managers, particularly the small and medium-sized enterprises (SMEs) face a dilemma when they decide on sustainability due to lack of funds and tight budget. There is increasing pressure in the enterprises to be more environmentally friendly and behave responsibly to the environment.

7. Developing the Measuring Subsystems in Highly Complex Circumstances

With the rapid development of highly autonomous systems, operators' (pilots and air traffic controllers) decisions may generate extra influence on the environment. A new advisory system for dynamic planning the routes and especially the take-off and landing procedures reducing the environmental impacts depending on the real situations (size of aircraft, its performances, load factor, weather condition, etc.). Therefore, developed monitoring systems were used in the operators' working environment thus increasing situational awareness and improving operators' decision-making. Eye tracker, heart rate, skin resistance, integrated microsensors, and electrodermal activity have been used in operators working environments to control operators' actions.

The operator load measuring system can be divided into 3 groups, namely; (i) operator models, (ii) operator load measuring systems, and (iii) operator load management systems (Figure 8). As can be seen in Figure 8A several well-known operator models have been improved and adapted by the current authors to the operators advanced working environment by including the human performance, skill, competence, and information process that enable fully modeling the situation awareness and decision process of operators in automated systems such as Endsley Situation Awareness Model, Swiss Cheese Model, and Rassmussen Decision Making Model.

The second phase of the load measuring system is the operator load monitoring systems as seen in Figure 8B. In this phase, several operator load monitoring systems have been used to measure operator vital health parameters during operation such as eye-tracking measurement, electrodermal activity measurement, heart rate measurement, and binocular usage, and some of the measurement results published by the current authors in [39].

- Eye movement, fixation duration, and area of interest of pilots were defined with a TOBII eye tracker. By analyzing the result of operator eye movements, eye-tracking systems can be a useful tool for pilot and air traffic controller training.
- Heart rate responses of pilots were recorded using a heart rate monitor in a flight simulator with three realistic scenarios, namely: (i) VMC is the easiest scenario, (ii) IMC is the moderate scenario, and (iii) IMC with ADI failure is the most difficult scenario in this experiment. Based on the result, the average heart rate was the lowest

in the first scenario, highest in the third scenario. The heart rate can be used as a major indicator for detecting the mental load that may indicate the task complexity monotony and the ratio of automation.

- The skin conductance level (SCL) of a pilot was recorded by OBIMON devices (an electrodermal activity device) during all phases of the flight through "a poor visibility and instrument failure" flight scenario. Based on the result, the SCL of the pilot was found to be high during takeoff and banking turns. The result of SCL promises that the actual mental condition of the operator can be estimated with an electrodermal activity device which allows determining if an operator is tired, unbalanced loaded (overloaded or underloaded), or nervous at a moment.

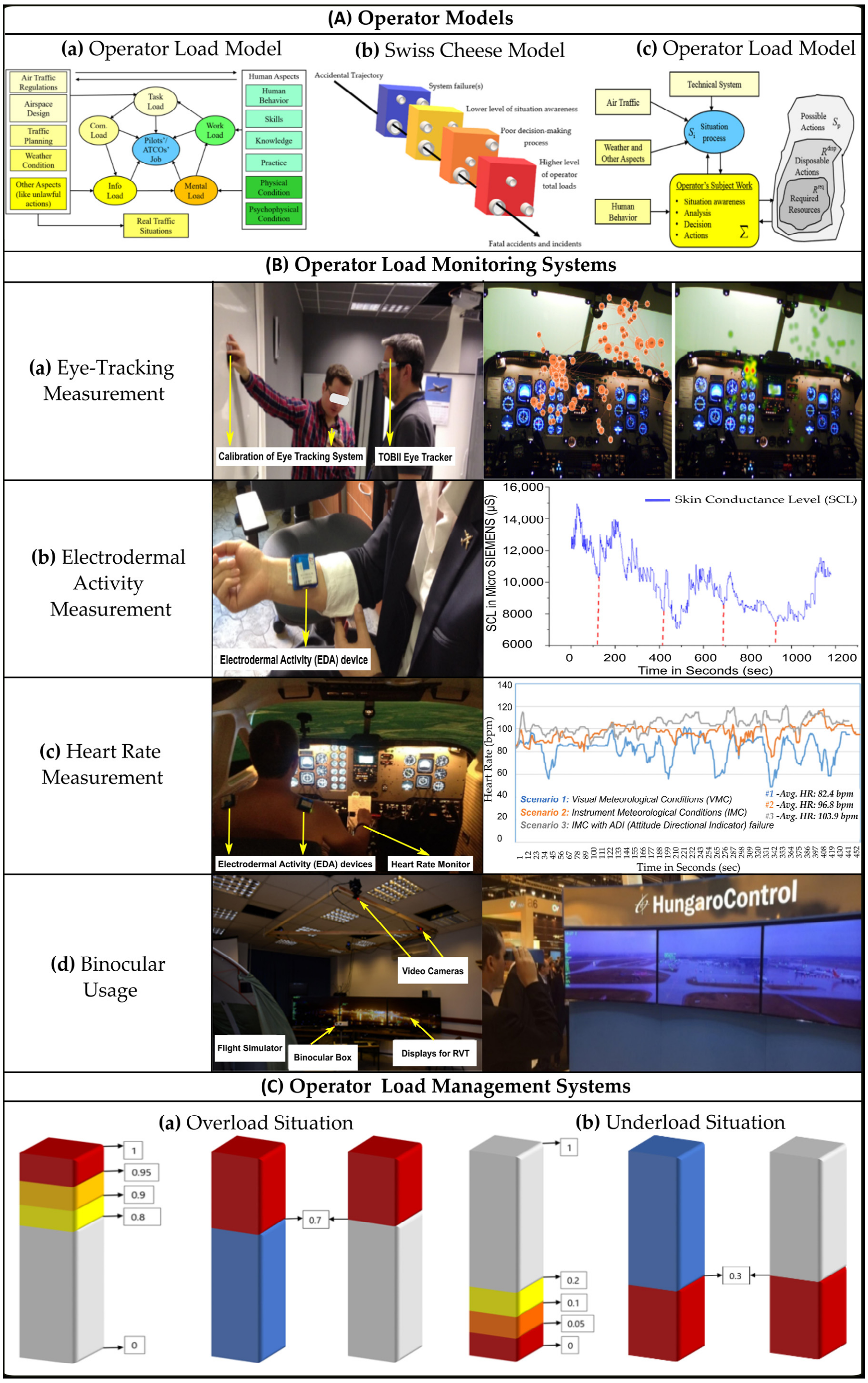

Figure 8. Operator load measuring system: (**A**) operator models, (**B**) operator load monitoring systems, and (**C**) operator load management systems.

In the final phase, operator load management systems have been developed for under/overload situations (Figure 8C) and published by the current authors [40]. According to the load management method, all the measured parameters will be transferred to scores on a 0–1 scale for each load of the operator.

- The thresholds for each load were defined independently for overload situation as (i) warning signals, (ii) high attention, and (iii) emergency, respectively 0.8, 0.9, and 0.95,
- The thresholds for the combination of at least two loads were defined for overload situation, whenever any combination of two loads get to 0.7 or above as (i) warning, (ii) monitoring, and (iii) immediate actions required, respectively 0.7, 0.8, and 0.9,
- The thresholds for each load were defined independently for underload situation as (i) warning signals, (ii) high attention, and (iii) emergency, respectively 0.2, 0.1, and 0.05,
- The thresholds for the combination of at least two loads were defined for underload situation, whenever any combination of two loads go down to 0.3 or below as (i) warning, (ii) monitoring, and (iii) immediate actions required, respectively 0.3, 0.2, and 0.1.

8. Discussion

This research has the scope to develop new air traffic management, and operator (pilots, air traffic controllers) load measuring systems in order to save fuel, and flight time, thereby reducing environmental impact, carbon emission, greenhouse gas generation, noise pollution, and operating cost.

In order to improve air traffic management, and make flying safer, sustainable, efficient, and predictable, several countries have been initiated long-term vision programs for the Future Air Traffic Systems such as European SESAR, American NextGen, Japanese CARATS, and Brazilian SIRIUS. The current authors have been taken part in a SESAR project namely "INNOVATE—Innovation through Validation for Air Transportation in Europe (SJU/LC/0162-CTR)". In the framework of this project, the "Dynamic Sectorization and Airspace Configuration" concept has been created. According to this concept, the total airspace has been divided dynamically into "sectors". Depend on the air traffic volume, operator total load, airspace sectors may be dynamically configured by; (i) combing into fewer large blocks during low traffic density, or (ii) splitting into small sectors during high traffic density, so as to offer the maximum capacity to the incoming traffic. Due to the consequence of the developed concept, air traffic controllers will able to maintain a safe, efficient, and orderly flow of air traffic.

Secondly, the dynamic routing concept has been developed by the current authors. Based on this concept, the arrival and departure routes will be dynamically designed by using non-published points depend on the complexity of air traffic, type of aircraft, weather condition, and total load condition of pilots. In addition to this, the "Dynamic Routing Concept" has been simulated at the Budapest Liszt Ferenc International Airport (BUD) as a case study, and the cost function is calculated by using the fuel consumption.

Thirdly, the dilemmas of human in sustainability (related to the individuals, the society, the non-governmental organizations, and the managers) have been examined, and (i) the Endsley decision-making model has been improved and adapted to the current situation by including environmental sustainability, dynamic sectorization, aerospace design, optimal trajectory, and greenhouse gases, (ii) the greenhouse gas emissions have been compared between some countries such as Hungary, Poland, and Iceland, etc. and the relationship between the dilemmas of society and greenhouse gas generations have been analyzed, and (iii) V-model approach has been created for the environmental and sustainability education.

Finally, the dedicated non-intrusive operator supporting systems have been developed in a highly complex environment, and divided into three categories; (i) operator models; Endsley Situation Awareness Model, James Reason Swiss Cheese, and Rassmussen Decision Making Model have been improved and adapted to the human operator work, working in highly automated systems (ii) operator load monitoring systems; several load measuring systems have been used in operators workstations by the current authors such as eye-tracking, heart rate, and electrodermal activity measurement and (iii) operator load management systems; operator load management systems have been created for underload and overload situations.

9. Conclusions

The International Civil Aviation Organization (ICAO) is estimated that the number of domestic and international travelers will be expected to reach six billion by 2030 [41]. This exponential growth in air transport has resulted in a wide range of adverse effects such as environmental impacts. With the help of large-size international projects (SESAR, NextGen, etc.), aviation has achieved numerous system improvements in the area of air traffic management including optimal trajectory, fuel efficiency, aircraft emissions, etc. Further progress is certainly required to cope with present problems in air traffic management.

In the framework of a SESAR project, the current authors created a new method for sector design and airspace configuration. The complexity of the traffic has a direct influence on operator total load and environmental sustainability. According to the results, the dynamic sectorization and air space configuration may eliminate the task overload and reduce the actual operator load by 30–40 percent.

A dynamic routing concept has been created by the current researchers where air traffic controllers need to dynamically design arrival and departure routes using non-published points depending on the complexity of air traffic, type of aircraft, weather condition, and total load condition of pilots. With the introduction of the highly dynamic approach and landing procedures, aircraft will be able to follow better trajectories to avoid residential areas around airports to reduce ground noise and decrease landing distance up to 56% in comparison to the "published transition route". This concept will improve the air traffic situation by decreasing flight durations, fuel consumption, congestion, emission, and noise load. According to the simulation results of the developed "Dynamic Routing Concept" at Budapest Liszt Ferenc International Airport (BUD), the fuel burn can be decreased (i) up to 56% on average compared to the STARs through the ANEXA, (ii) up to 44% in overall on inhabited areas compared to STARs through the ANEXA, and (iii) up to 28% in overall inhabited areas compared to the shortest distance through the EBAMO.

The dilemmas of humans in sustainable development have been examined in detail and divided into four main groups: (i) dilemma of individuals, (ii) dilemma of society, (iii) dilemma of non-governmental organizations, and (iv) dilemma of managers. The strong link between the dilemmas and the decision-making process has been investigated in this paper. This is because poor and untimely decisions lead to the loss of hundreds of people's lives, and extraordinary environmental pollution and economic consequences.

Moreover, several operator load monitoring and management systems were developed and used in the workstation of operators such as TOBII eye-tracking, heart rate, and OBIMON electrodermal activity. Based on the result of the measurements, the developed load monitoring and management systems serve as a promising tool for balancing operator total load, thereby increasing the safety of operator actions in an abnormal/emergency situation.

The future work concerns testing the "Dynamic Routing Concept", and "Dynamic Sectorization and Airspace Configuration Concept" in an Air Traffic Control Simulator with realistic flight scenarios. In addition to this, the current authors plan to create a load monitoring device that continuously collects, stores, and manages all the measurable parameters of operators such as heart rate, heart rate variability, skin conductance, skin temperature, and respiration rate, etc.

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