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A MODEL OF AIR TRAFFIC ASSIGNMENT AS PART OF AIRPORT AIR POLLUTION MANAGEMENT SYSTEM

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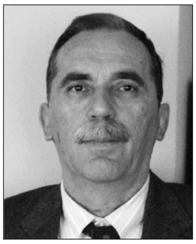

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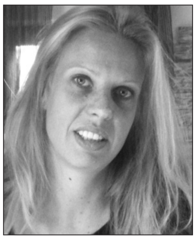

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Abstract. The critical concern of modern airports is the air pollution generated by air traffic and its impact on the airport environment. Air pollution is an unavoidable consequence of air traffic, but it can be reduced in numerous ways, including technical innovations in aircraft design and legislation. This paper presents a model of air traffic assignment as a measure to mitigate the concentration of air traffic pollution. The air traffic assignment model was developed specifically for Nikola Tesla Airport but could easily be applied to other airports. The model is based on the categorisation of aircraft according to engine type and the assignment of specific runways for take-off and landing for each aircraft category. It incorporates two basic goals: to increase airport capacity and to reduce the pollution level in the area around the airport. Although these goals are contradictory, it has been shown in the case of Nikola Tesla Airport that the proposed air traffic assignment model successfully creates pollution level equilibrium in the area around the runway thresholds and an increase in airport capacity. The paper suggests pollution measurement points as the basis for a pollution management tool and system for daily air traffic pollution control.

Keywords: aircraft, air pollution, pollution abatement measures, air traffic management, pollution control.

1. Introduction

Modern airport hubs became aware of air quality problems at the end of the 20th century. This arises from the non-concordance between the present situation and the situation desired by the public and presented in national strategies. From one side, operators create the air quality nearby the airport hub by producing emissions from aircraft operations and ground operations (e.g. ground vehicles, aircraft service vehicles, etc.) (The Advisory… 2002). From the other side, this pollution influences public awareness and initiates the creation of legislation and new standards for the mitigation of pollution, as well as new airport structure (Kazda 1997). Both legislation and the public perception of pollution have influenced air operations at airports as shown in Fig. 1.

We can define a full circle from the initiation of the problem and feedback. An excellent example of the development of legislation is Swiss clean air legislation (Flueti 2007). This legislation from 1986 (LRV, March 1986, rev. March 1998) introduced emission standards, pollution standards, and mitigation planning and established a fundamental approach and solution for the problem of airport pollution. An important consequence of this legislation is the obligation of airports to perform environmental reporting (Saving… 2001).

In the next decade, airport authorities will develop plans for the mitigation of pollution based on pollution assessment, which introduces emission charges, operational improvements, etc. (Climate… 2001) The assessment effort of airports will require the development of tools and methods to calculate the emission of pollutants. Three well-known models are currently being used to calculate airport emissions:

- the EDMS Emission and Dispersion Model System developed by the FAA,
- the LASPORT Emission Calculation and Dispersion Model developed for the German Airport Association,
- ALAQS-AV version 1, Emissions Inventory, developed by the EUROCONTROL Experimental Centre (EEC).

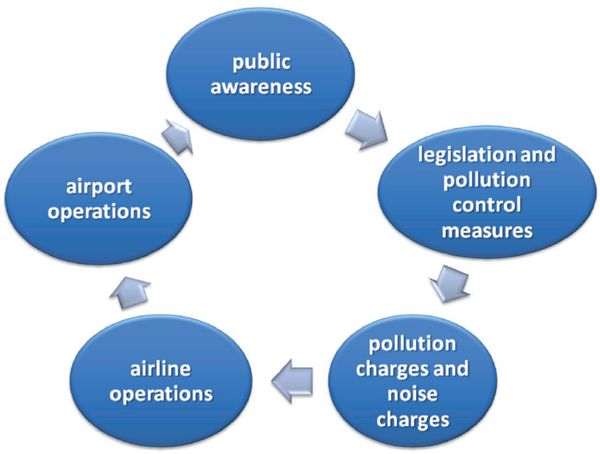

Fig. 1. Process of developing pollution mitigation measures

This paper investigates pollutant emissions from air transport in areas around airports. As highlighted it is necessity to develop a model of air traffic assignment as part of an airport air pollution management system. The model developed was tested at Nikola Tesla International Airport in Belgrade, where high concentrations of pollutants accumulate in the air and can be harmful to human health and the environment.

The Ministry of Science and Technological Development of Republic of Serbia have a strategic plan for better air quality, but no improvement has taken place for years in the city of Belgrade.

In parts of Belgrade under SID (departure routes) and STAR (arrival routes) air routes, where aircraft fly at low altitudes and low speeds, the concentration of pollutants such as carbon monoxide, sulphur dioxide, and particulate matter (dry particles and liquid droplets emitted by sources such as aircraft turbo fan, turbo prop, and reciprocal engine) in the air are increasing.

This paper also illustrates the present situation at Nikola Tesla Airport and possible measures to reduce pollution density and increase airport capacity.

The first part of the paper investigates the present situation and identifies the airport pollution and capacity problem.

The second part is devoted to the development of various traffic assignment scenarios and the determination of potential benefits from the proposed scenarios.

The final part of the paper is devoted to finding future measures in pollution and capacity control at Nikola Tesla Airport by considering the future development of the airport.

2. A model for mitigating air traffic pollutant emission

Airports are attempting to reduce emissions and noise (Vanker *et al.* 2009) in the environment of the airport by using emission management, which comprises traffic assignment measures and restrictions. Airports also have a commercial interest to increase capacity and maximise the number of aircraft serviced (Netjasov 2008).

In light of those facts, it is obvious that airports must have an emission management system that measures pollution and minimises the concentration of pollution with the use of air traffic assignment (Rogers *et al.* 2002).

This system must also maximise the number of aircraft operations or maximise the utilization of the airport. On this basis we developed an air traffic assignment model with this aim and constraints. The air traffic assignment model developed is useful in emission management, airport design, and airport development actions.

The air traffic assignment model consists of several steps and, for a given airport, contains the following assumptions:

- the number of aircraft daily flight operations (all departures and arrivals flights within 24 hours) and their daily distribution is known,
- an emission monitoring system with measuring points is implemented at the airport,
- the level of pollution generated by specific aircraft is known;
- departure and arrival routes and characteristics are known and published in an aeronautical information publication (AIP-Aeronautical Information Publication),
- the presence of specific aircraft types in the total daily traffic is constant (day, evening, night);
- the time interval of arriving and departing traffic as well as the location of parking positions at aprons are not taken into account; and
- entering/exiting from/in *en-route* sectors to CTR BEOGRAD (control zone-CTR: local air traffic control or tower TWR) is not taken into account. In other words, maximum consideration was given to final approach, landing, take off, and initial climb, all flight operations at low altitude and low flight speed, neglecting flight operations at higher altitude and higher flight speed.

The structure of the air traffic assignment model can be presented by following five steps.

1th STEP: Analysis of daily traffic dispersion to determine the structure of the aircraft fleets that depart from or arrive at the airport. The important input is aircraft type, as well as number of aircraft, *F*, of specific type during daily operations.
2th STEP: Analysis of emission values generated by aircraft type at *S* specific measuring points separately for departures and arrivals.
3th STEP: Distribution of aircraft of different classes on runways in use based on average emission level for each aircraft type (departures and arrivals) and meteorological condition.
4th STEP: Determination of emission for each emission measuring point separately for arriving traffic by equation (1), departing traffic by equation (2), and total traffic by equation (3). Finally we calculate pollution costs for all pollutants as presented by equation (4).

$$E_{arrival\,hp} = \frac{\sum_{k=1}^{F} ac_{arrival\,kh} \cdot e_{arrival\,khp}}{ac_{arrival\,h}},$$
$$ac_{arrival\,h} = \sum_{k=1}^{F} ac_{arrival\,kh} \quad (1)$$

$$E_{depart\,hp} = \frac{\sum_{k=1}^{F} ac_{depart\,kh} \cdot e_{depart\,khp}}{ac_{depart\,h}},$$
$$ac_{depart\,h} = \sum_{k=1}^{F} ac_{depart\,kh}, \quad (2)$$

$$E_{hp} = E_{depart\,hp} + E_{arrival\,hp}, \quad (3)$$

$$PE_{h} = \sum_{p=1}^{P} PC_{p} \cdot E_{hp}. \quad (4)$$

The variables used in equations (1), (2), (3) and (4):

- h is emission check point, $h = 1$ to S,
- k is aircraft type, $k = 1$ to F,
- p is pollutant type, p has a value from 1 to P, $P = 2$ (in our case CO_2 and NO_x are the most dominant pollutants). The value $p = 1$ is reserved for CO_2 and the value $p = 2$ is reserved for NO_x,
- PE_h is maximum pollution cost at pollution measuring point h,
- E_{hp} is total emission level at pollution measuring point h, by pollutant p,
- $E_{arrival\,hp}$ is emission level at pollution measuring point h during arrival operations, by pollutant p,
- $E_{depart\,hp}$ is emission level at pollution measuring point h during departure operations, by pollutant p,
- $ac_{depart\,kh}$ is daily number of aircraft, type k, that fly over pollution measuring point h during departure,

- $ac_{arrival_{kh}}$ is daily number of aircraft, type k, that fly over pollution measuring point h during arrival,
- ac_{depart_h} is total daily number of aircraft that fly over pollution measuring point h during departure,
- $ac_{arrival_h}$ is total daily number of aircraft that fly over pollution measuring point h during arrival,
- $e_{arrival_{khp}}$ is average emission of aircraft, type k, that fly over pollution measuring point h during arrival, by pollutant p,
- $e_{depart_{khp}}$ is average emission of aircraft, type k, that fly over pollution measuring point h during departure, by pollutant p,
- PC_p is average pollution cost produced by pollutant p.

The real meaning of pollution cost is the cost involved in removing or cleaning pollution (Mirosavljević *et al.* 2009a, b), where for CO_2 pollution the cleaning cost is PC_1 expressed in euro per kg of CO_2 (the average cost of cleaning CO_2 pollution is 0.033 €/kg) (EUROCONTROL 2007).

For NO_x pollution the cost of cleaning (the average cost of cleaning NO_x pollution is 4 €/kg) (EUROCONTROL 2007) is PC_2 in euro per kg of NO_x. Since pollution of CO and HC is relatively low compared to pollutants CO_2 and NO_x, as shown in Fig. 2, in the next parts of the paper we consider only CO_2 and NO_x pollution.

5th STEP: Determine minimum of maximum pollution cost by optimal fleet mix determination, over pollution measuring points

$$\min_{ac_{depart_{kh}}, ac_{arrival_{kh}}} \rightarrow PE_h, h = 1,..,S. \tag{5}$$

3. Present distribution of air traffic pollution

The model was tested on Nikola Tesla Airport in the Republic of Serbia (Nikola Tesla Airport in Belgrade, Republic of Serbia, RWY 12 and RWY 30, ICAO 4 dig. code: LYBE, Fig. 3).

First we collected the necessary input parameters. From analysis of the busiest summer month in 2009, of the aircraft fleets that use Nikola Tesla Airport and are presented in Fig. 4, we can conclude that the major polluters are the B737-300 classic, ATR 72, and Fokker 100, which all belong to the old generation of aircraft. We also collected information concerning the distribution of aircraft flight paths as important input for calculating total pollution in areas below the flight paths of arriving and departing aircraft. For an average summer month in 2009, the distribution of flight paths used for arrival is presented in Fig. 5, and the distribution of flight paths used for departure is presented in Fig. 6.

The benchmark level for considering a specific type of aircraft in the total level of pollution was its presence above 1% in all operations ($F = 8$ in the model, we consider only these significant polluters: B733, ATR 72, F100, C550, RJ85, A319, A320 and B734). From this analysis based on the aircraft fleet mix, we can expect potential pollution contamination higher than the acceptable level. Besides the aircraft fleet mix analysis, we identified the daily peak hour. In Fig. 7 the average daily distribution of operations from data for June, July and August in year 2009 (months with the most intensive air traffic in Serbia) are presented. We also identified the peak hour as taking place between 13.30 and 14.30, or the period of the day when daily temperatures are the highest during the summer months. We concluded that the distribution of arrival and departure paths was not uniform. Considering the relatively normal meteorological situation during the summer days of 2009—without extreme wind or precipitation and with high RVR (*runway visual range*) – we cannot blame the meteorological situation for this (Fig. 8).

Of all departing traffic, 82% use RWY 30 for takeoff and of all arriving traffic 86% use RWY12 for landing. This implies that the area northwest of Nikola Tesla Airport is used for more than 80% of departure and arrival routes. The most used arrival routes are those from the point TADAM and the most used departure routes go over the point KOTUS. Bearing in mind all input data from traffic, the aircraft fleet mix, and the use of air routes, we can conclude that the unbalanced use of the northwest area can bring both a high concentration of pollution and much congestion of airspace. More than 80% of all air traffic is over threshold 12, which requires actions to balance air pollution and increase the capacity of the airport. To determine the emission of pollutants, we use the well-known ICAO LTO cycles, because of the investigation of pollution generated by takeoff and landing operation until 3000 ft altitude (Correlation… 2007). This is adopted as an assumption, because ICAO LTO cycles pollution calculation method is valid only up to 3000 ft above the runway (Mirosavljević *et al.* 2010).

ICAO publishes aircraft engine emission certified data, which includes emission indices, time of flight mode, throttle setting, and fuel flow (ICAO…2009).

ICAO has formed the Aircraft Engine Exhaust Emissions Data-Bank to provide emission indices for CO, HC, NO_x, and smoke, for each one of the four engines throttle settings (take-off, climb, approach and idle). For Jet A1 fuel used in transport aircraft, 1 kg of fuel burned produces 3.15 kg of CO_2 as publish in the Boeing Company (The Boeing… 1981a, b, 1985, 1990, 2000).

This model and data are regularly used to estimate aircraft emissions, and we used this emission model in our paper.

The present total pollution level as shown in Fig. 9 clearly indicates an unbalanced level of pollution on thresholds that require treatment (e.g. in the area of threshold RWY 12, arrival and departure air traffic produced 123.547 kg of CO_2 compared to 23.768 kg of CO_2 produced in the area of threshold RWY30). One of the possibilities is to define air traffic assignments that achieve pollution level equilibrium in the area around the airport runway thresholds. The decision-making process during traffic assignment can be supported by the introduction of a pollution monitoring system.

For environmental protection, airport operators need timely information about air quality and other factors (e.g., weather conditions) that affect it. Access to air quality forecasts allows ATC (Air Traffic Control) to reduce pollution concentration, by traffic assignment, when the emission level is high.

This is important particularly for balanced pollution, which reduces pollution concentration in areas around the airport. Nikola Tesla Airport has not installed a pollution control system. In this paper we investigate the position of pollution monitoring points according to Belgrade meteorological data, the design of CTR BEOGRAD, STAR routes, and SID routes.

This design of an air quality-monitoring system will have the main task of monitoring and determining daily air traffic pollution distribution and concentration in the area of runway thresholds. The main area of interest is under the STAR and SID air routes, at the points of highest pollution. Based on meteorological data collected in Belgrade for 20 years, we proposed potential locations suitable for the pollution measuring points.

Those pollution measuring points, which will be equipped with fixed monitoring stations, are chosen after detailed modelling of airport pollution. The most important parameters for the development of an air pollution model are STAR and SID routes, aircraft fleet mix, wind speed, wind direction, pressure, temperature gradient, and topography.

Because of the simplicity of CTR BEOGRAD and the single runway at Nikola Tesla Airport, pollution measuring points *P1* and *P2* (in model $S = 2$) should be located in the extension of the runway direction, at 3 Nm before the runway thresholds. This proposal for the location of pollution measuring points as shown in Fig. 10 is optimal, because the highest concentration of air traffic pollutants are detected in this part of the airport area. This conclusion concerning the location of optimal pollution measuring points is based on the fact that all traffic must fly over these points when arriving at or departing from the airport. Points P1 and P2 are the entering or exiting runway gate points where all aircraft take-off or landing operations are executed.

4. The possible traffic assignment scenario

We can develop different strategies of traffic assignment that will lead to balanced pollution and the reduction of unit pollution at the airport. First of all we can introduce two simple solutions:

- SCENARIO 1: all departures over threshold 12, pollution monitoring point P1, all arrivals over threshold 30, pollution monitoring point P2, presented by Fig. 11,
- SCENARIO 2: all arrivals over threshold 12, pollution monitoring point P1, all departures over threshold 30, pollution monitoring point P2, presented by Fig. 12.

If we analyse the two simple scenarios of traffic assignment, we can detect unbalanced pollution on different thresholds.

This is obviously not an optimal solution that produces balanced pollution over thresholds.

If we apply the model of traffic assignment presented in part 2 of this paper, we can determine traffic distribution in total and separately for every type of aircraft.

The total distribution of traffic is 51% over pollution measuring point *P1* and 49% over pollution measuring point *P2*.

This result obtains equal pollution values on both thresholds. Fig. 13 and Fig. 14 represent the distribution of arrival and departure traffic for equal pollution on both thresholds, presented by condition $PE_1 = PE_2$.

This last condition, $PE_1 = PE_2$, is an outcome from the fifth step of the model and can be applied on a simple runway with two thresholds.

5. The Nikola Tesla Airport runway capacity

This paper explores the possibilities of increasing airport capacity, which is in the commercial interest of the airport, as well as achieving balanced pollution on both thresholds. For calculation of runway capacity, we use software that is based on an analytical model developed by W. Harris from the MITRE Corporation and programmed by A. Trani, (Trani 2009) and that calculates airport capacity as a Pareto frontier. The software parameters were adopted for the present layout of Nikola Tesla Airport, shown in Fig. 2, and various traffic assignment

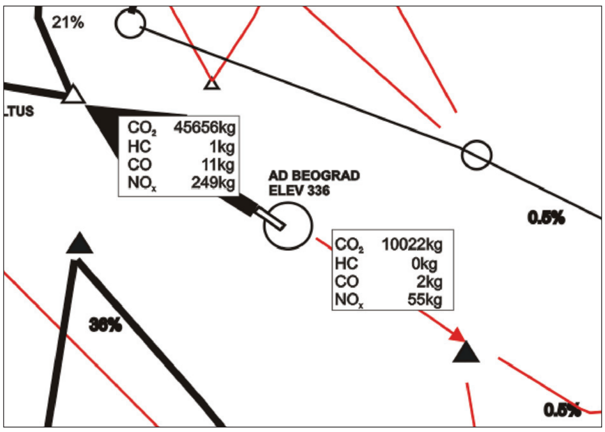

Fig. 2. The distribution of emissions during departure on an average summer day of 2009

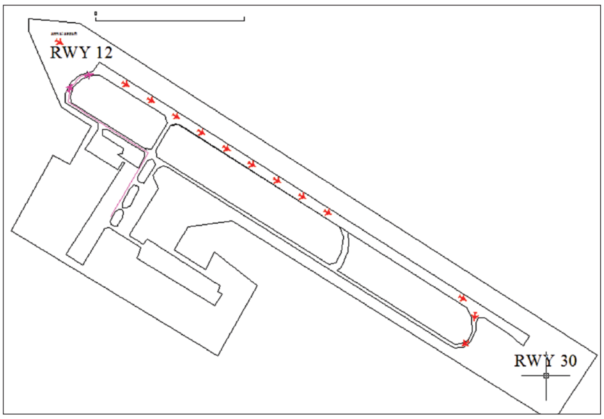

Fig. 3. The present layout of Nikola Tesla Airport

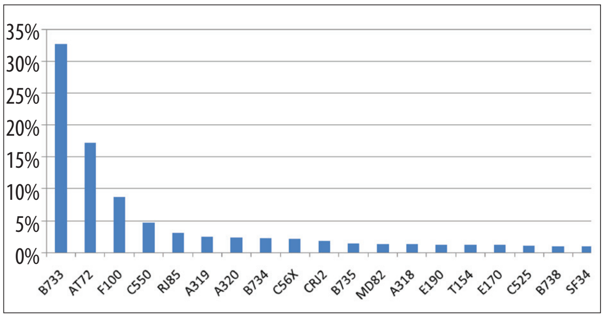

Fig. 4. Different aircraft types in total traffic (average summer day 2009, only IFR operations)

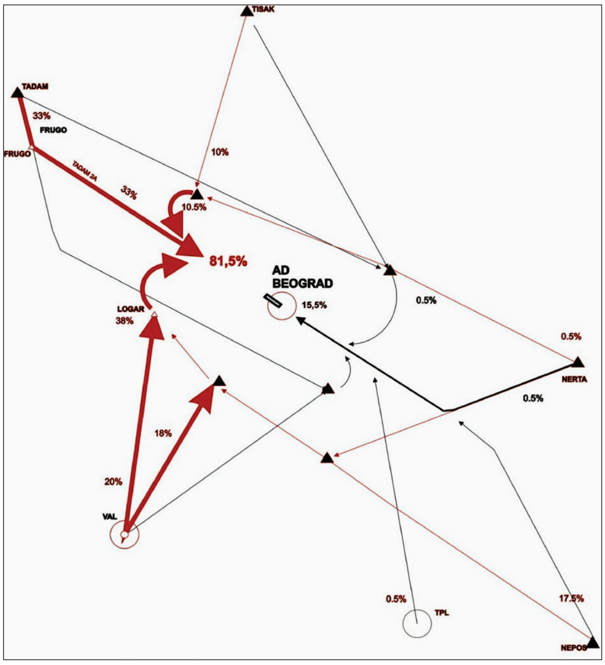

Fig. 5. The arrival routes at RWY 12 (red line) and RWY 30 (black line) with percentage of arrival route use

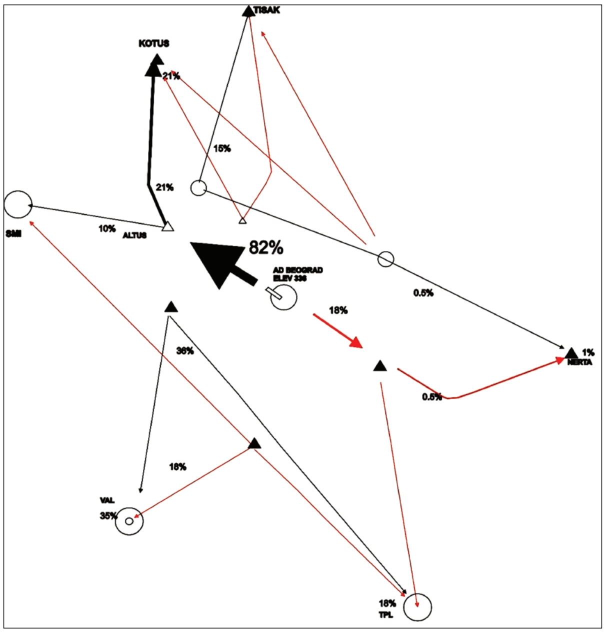

Fig. 6. Departure routes at RWY 12 (red line) and RWY 30 (black line) with percentage of arrival route use

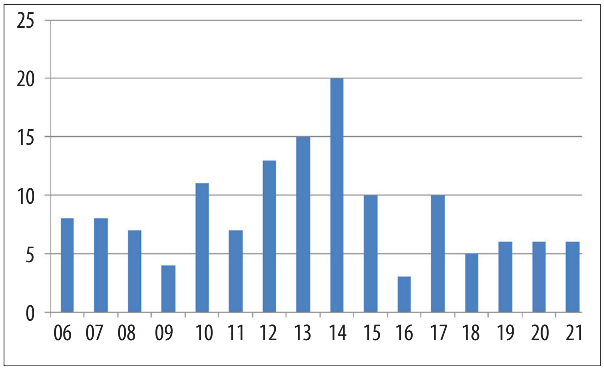

Fig. 7. Average summer day 2009 peak period (arrival and departure IFR operations)

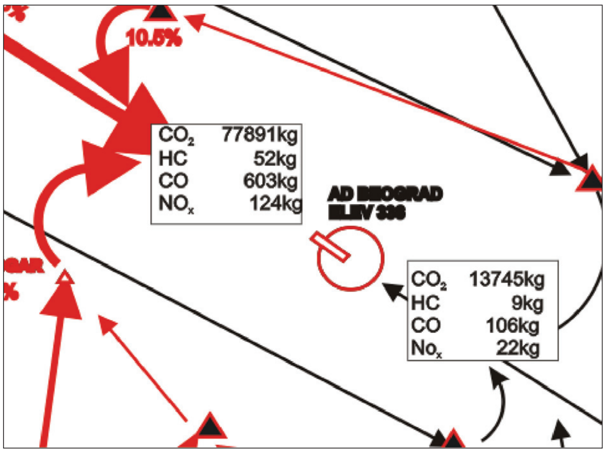

Fig. 8. The distribution of emissions during arrival on an average summer day of 2009

scenarios. The software clearly indicates low present airport capacity utilisation. This was shown in Fig. 15. Also, airport capacity utilisation improvement was shown in Fig. 15, with the application of traffic assignment scenario 1 and 2, and the biggest airport capacity improvement with the application of traffic assignment (for balanced pollution on both thresholds), presented by condition $PE_1 = PE_2$. By this traffic assignment, we achieve both results: balanced pollution and improvement in airport capacity. The total number of operations determined by the

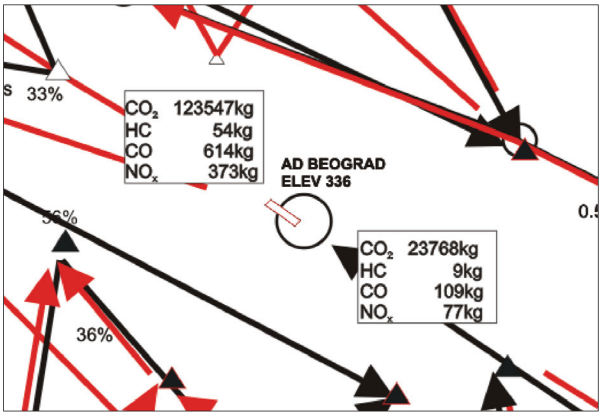

Fig. 9. The distribution of total emissions during arrival and departure on an average summer day of 2009

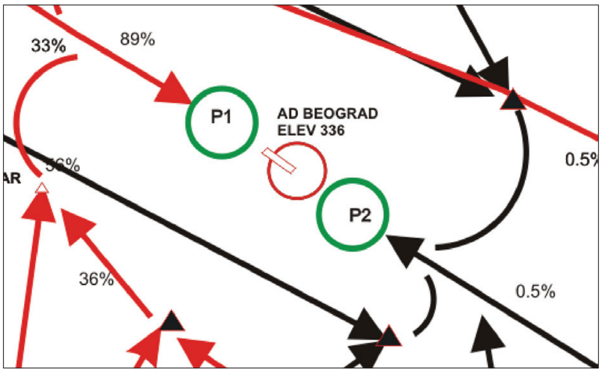

Fig. 10. The proposed location for pollution monitoring points

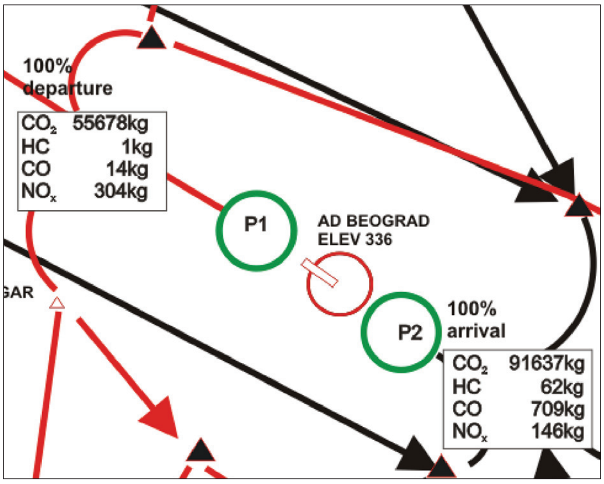

Fig. 11. The proposed scenario 1 of air traffic assignment

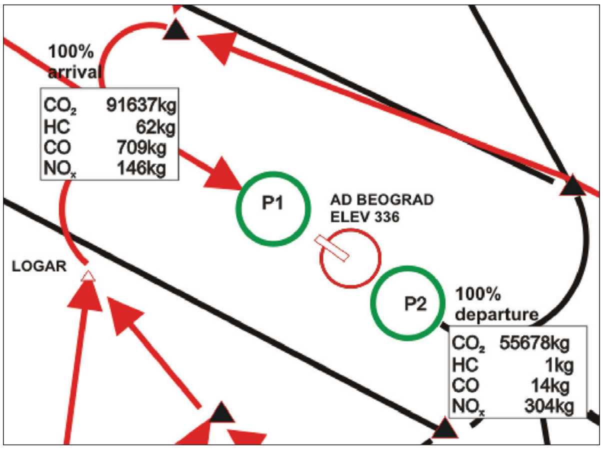

Fig. 12. The proposed scenario 2 of air traffic assignment

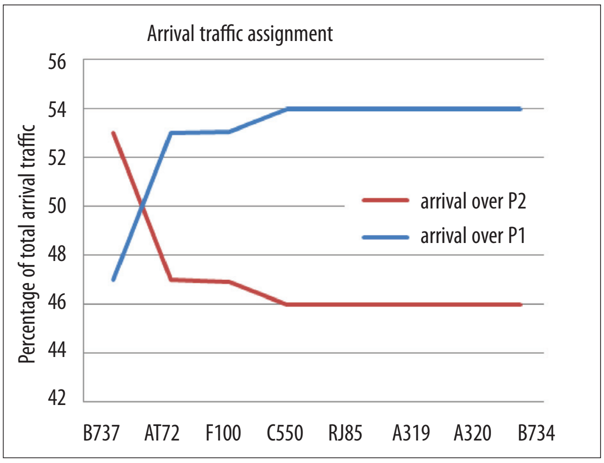

Fig. 13. Arrival traffic distribution for balanced pollution

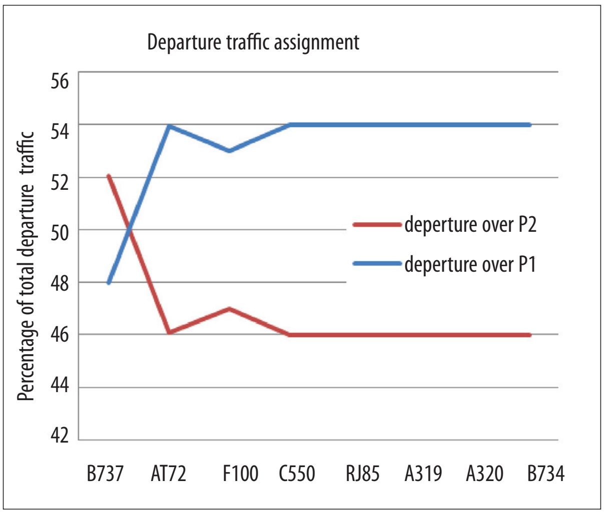

Fig. 14. Departure traffic distribution for balanced pollution

proposed traffic assignment scenario, shown in Fig. 16, contributes to the validation of the model. From Fig. 16 we can notice that maximum number of operations (21 operations) is just above operations during peak hour (20 operations), shown in Fig. 6. This implies airport capacity saturation and possible air traffic operations delay induced by insufficient capacity. The proposed air traffic assignment model for balanced pollution can also be easily applied to potential future development at Nikola Tesla Airport, as seen in Fig. 17.

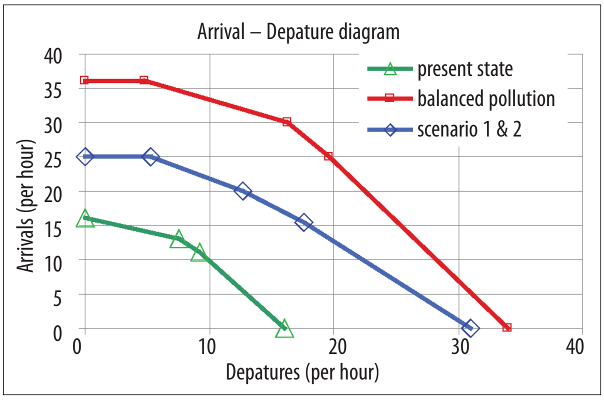

Fig. 15. Potential future development at Nikola Tesla Airport

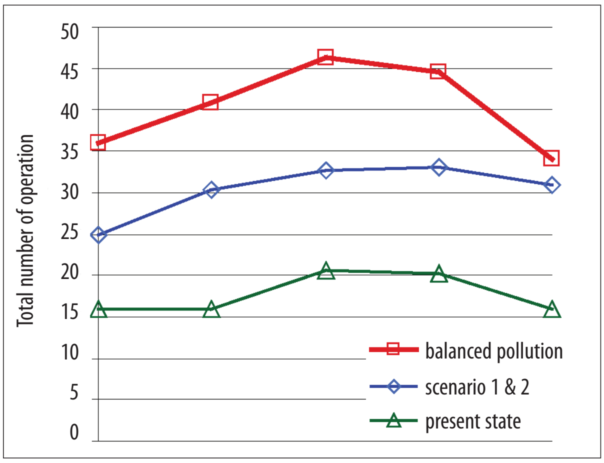

Fig. 16. The airport capacity of total number of operations for various traffic assignment scenario**s**

6. Conclusions

1. In this paper, we develop an air pollution model and propose pollution measuring and monitoring points based on real air traffic. The model and points are emission management measures for the determination and control of pollution. The major advantage of this air pollution model is its flexibility.
2. It can be used on a daily basis to determine airport runway thresholds pollution inequality and initiates actions, by air traffic assignment, to minimise pollution differences. During strategic decision making, the proposed model and pollution monitoring points provide an optimal future development layout for the airport, yielding the lowest pollution differences at thresholds and maximum airport capacity. This shows that we cannot achieve at the same time minimum pollution differences at thresholds and maximum airport capacity. The investigation in the paper shows that we can achieve minimum pollution differences at thresholds with air traffic assignment, which produces minimum decrease in airport capacity.
3. The proposed method has practical benefit for the airport authority and can be synthesised in the air traffic assignment model based on pollution monitoring point data. Indirect benefit can be obtained from the information on how much it costs to clean the pollution from aircraft operation in the airport environment. Beside this, determination of the quantity of real pollutants in the air or on the ground in the airport environment, by using the presented pollution cost calculation model, the airport authority can verify the level of pollution produced by airline operations.
4. The results analysis indicates that the present traffic assignment acts as an obstacle to increasing airport capacity and also produces a high concentration of pollution in the area around threshold 12. The present state has negative effects both on level of pollution and airport capacity. This is a rigid and non-sustainable solution to the development of the air traffic sector in the Republic of Serbia. The most important contribution of this paper is the measure of present aircraft pollution and determination of real benefit from proper air traffic assignment.

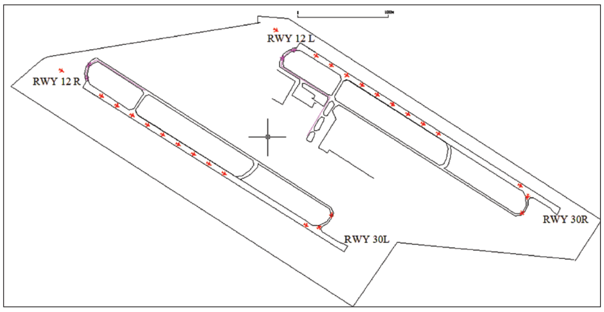

Fig. 17. The airport capacity Pareto frontier comparison for different traffic assignment scenarios

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The final result of the project is the *Manual for Reducing Pollution and Noise in the Air Transport System of the Republic of Serbia* (furthermore—MANUAL). The first part of this research project contains analyses of the generation of major air transport pollutants such as CO_2 and NO_x and their mitigation through development of pollution charges that apply to aircraft during take off and landing. The real application of the proposed MANUAL will support the efforts of the Republic of Serbia and European Union to reduce air transport pollution and noise.

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ORO TRANSPORTO PASKIRSTYMO MODELIS ORO UOSTO ORO TARŠOS VALDYMO SISTEMOJE

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Santrauka. Šiame straipsnyje aprašomas oro transporto paskirstymo modelis, leidžiantis sumažinti oro transporto srautų sukeliamą oro taršą. Šis modelis sukurtas Nikola Tesla oro uostui, bet yra lengvai pritaikomas ir kitiems oro uostams. Modelio pagrindas – tai orlaivių klasifikavimas pagal variklių tipus ir tam tikrų KTT paskyrimas atitinkamoms kategorijoms. Siekiama išnaudoti visas oro uosto galimybes ir sumažinti taršos lygį. Nors tikslai atrodo priešingi, tačiau įrodyta, kad pasiūlytas oro transporto paskirstymo modelis sėkmingai išlaiko taršos lygio pasiskirstymą prie KTT pradžios ir padidina oro uosto galimybes. Taip pat siūlomi tinkami taršos matavimo taškai kasdienei oro taršos kontrolei.

Reikšminiai žodžiai: orlaivis, oro tarša, taršos mažinimo priemonės, oro transporto valdymas, taršos kontrolė.