Dynamic noise maps for Ljubljana airport

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Abstract—**The main purpose of this research is to assess the impact of aircraft noise around an airport considering spatial and temporal variations in the population. The concept of dynamic airport noise mapping has been demonstrated on Ljubljana airport case study. Detailed population mobility information for Slovenia were retrieved from a survey. The hourly noise contour levels generated by the airport's departure and arrival operations were calculated, and the annoyed population was thus estimated considering a reference scenario, where only the residential area was taken into account, and also a dynamic one, in which the population's mobility was included. The results show that for the dynamic scenario, the total number of people annoyed by noise increases by 2.9%, while the number of highly annoyed people decreases by 10% compared to the reference scenario. On the individual level, there are many cases of both overestimating and underestimating the noise impact. Since so far the standard in airport noise mapping has been to use census data, we have shown the importance of including explicit population mobility in noise impact calculations.**

Keywords-aircraft noise; daily population mobility; noise mapping; noise annoyance; sleep disturbance

I. INTRODUCTION

The study of human mobility has undergone a revolution in the last decade [1]. New computational resources, as well as information and communication technologies, have allowed for a more dynamical and precise characterization of trips, locations, and times. Such enhanced and improved information is contributing to the refinement of models to be able to capture mobility patterns at both individual and collective level (see, for example, [2] or [3]). Applications of this new knowledge and data are manifold. A better understanding of mobility demand leads to more appropriate infrastructure design, new tools to monitor health and well-being in cities, reduction of pollution, etc.

Collection of information on mobility has a long tradition. As an example, we can cite the pioneering work by Mitchell and Rapkin [4] who established an important link between activities and trips as early as in 1954 and called for systematic collection of information on these issues in surveys [5]. However, the lack of abundant and prompt information sources prevented the implementation of their ideas and massive use of activity-based models in urban mobility until much later. It was not until the 1970s when Hagerstrand (1970) [6] proposed a time–geographic approach and Peter Jones conducted the first comprehensive study of activities and population travel behaviour in Oxford in 1979 [7].

Ever since then, the models and, especially the data, have dramatically improved. Still, one may wonder what the link between ground mobility and air transport management is. While citizens move, they are continuously interacting with the environment. This means, for instance, that the daily dose of pollution the citizens receive is related to the concentration of pollutants in the places they stay at (home, work, school, etc.) but also along their trajectories and movements. What is valid for the concentration of chemical substances in the air is as well valid for the impact of noise, the so-called annoyance.

Air transportation can generate a certain level of noise disturbance around main airports. Decisions regarding aircraft routes must consider the people exposed to high noise levels with the intention of minimizing impacts. Visser introduced a method to assess noise annoyance and to search for noise reduction procedures around airports [8]. The population in absolute numbers and in density refers here to residents. In short, the current methodology to quantify noise impact consists of developing noise contour maps and estimating the affected population living in the areas encircled by different contours based on census data. It is important to be able to assign the population to small geographical areas in order to efficiently assess the noise impact. This high spatial detail assignment has been carried out, for example, in [9] by dasymetric models [10]. However, actual population present in an area during air transportation operations can significantly vary if mobility is taken into account [11]. Ott pointed out this inconsistency when relying only on census information, since the residents may spend a considerable part of the day outside the affected areas and, vice versa, people residing elsewhere may enter the affected areas to work or study [12]. The very same conclusion was reached in [13], which considered workplaces and schools/colleges in the calculation of road traffic noise impacts. Kaddoura et al. introduced a noise internalization framework that employs an activity-based road transportation model to estimate ground traffic noise levels and in which the agents may adjust their behaviour to minimize the impacts. In this way, the overall noise impact can be reduced by modifying routes and travel habits [14].

Despite the fact that relevance of these questions for other transportation modes has been recognized [14]–[19], not many researchers have focused on how the noise produced by air transportation affects the dynamic population in an airport's neighbourhoods. The first attempt was carried out by Ganić and Babić [20] in a paper presented at the ATRS2017 conference. This work was followed by a series of papers by Ganić et al. [21]–[23] and Ho-Huu et al. [24] dealing with optimisation of air traffic assignments to departure and arrival routes with the aim to reduce noise annoyance and fuel consumption. The main caveat of these studies concerned the quality of the available data, since many assumptions were introduced to obtain population mobility data. Under the H2020 ANIMA project [grant agreement No 769627] ("Aviation Noise Impact Management through Novel Approaches"), a pilot study on novel land-use planning approaches around airports is being conducted. In this context, dynamic noise maps are being elaborated for Ljubljana and Heathrow airports. The first results of this pilot study have been included in the work described hereafter.

In this paper, we are going to focus on a particular case study where detailed mobility information from a daily passenger mobility survey is accessible in the form of protected microdata on the individual level. We study the noise annoyance generated by Ljubljana airport and compare the results with and without considering the daily mobility of the population. Our results show the difference between the two approaches and highlight even further the need for detailed ground mobility information when estimating noise annoyance.

The structure of the paper is as follows. Section 2 explains the methodology to calculate dynamic noise maps. Section 3 describes the Ljubljana airport case study and data collected. The results and discussion are presented in Section 4. Finally, some conclusions, remarks and ideas for further research are presented in Section 5.

II. METHODOLOGY

A. Daily mobility patterns of population

To understand how population movement can influence the noise exposure experienced by individuals (i.e. the noise dose) as they travel during the day, it is necessary to collect data about daily mobility patterns of the population. Activity-based models are used to simulate activity patterns that represent activity travel decisions of households and individuals. These activity patterns are composed of many smaller, often related decisions, such as at what time to depart home for work in the morning, what mode of transport to take, whether to make an extra stop for groceries on the way home, and where to make that stop. Other longer-term decisions also have a bearing on activity and travel, such as the choices where to work, where to live, how many cars to own, and whether or not to participate in an employer's transit pass program [25].

Data for assessing a population's daily mobility patterns may come from a population census or dedicated household and travel surveys. In addition, digital footprints of inhabitants that use different digital services (mobile phones, smart phone applications, social networks, etc.) could also be used for model development or for its validation [26], [27].

Instead of simulating the mobility patterns for a synthetic population, in this research we use actual travel patterns on the individual level obtained from a daily passenger mobility survey. For each participant in the survey, the data available include: municipality of work/school location and whether the person is working from home or not, number of trips per day, start time for each trip, travel time, distance and purpose of each trip, mode of transport, car ownership status, vehicle occupancy, etc.

To increase the level of detail beyond municipality level, an algorithm was developed so as to assign the exact location within the municipalities for each trip by considering the number of buildings and their actual usage within the 500 m x 500 m grid. This means that if a person conducts a trip with an educational purpose, the exact location, represented as cell's centroid, will be assigned to that person based on the number of buildings intended for educational purposes (schools, universities, etc.) within different cells in that particular municipality; the cells containing more buildings are more likely to be selected. The same goes for other trip purposes and buildings. As a result, the time each individual spends (in minutes) within each cell during the day has been calculated.

B. Aircraft noise contour modelling

To be able to conduct the noise calculations, a noise model needs to be created. Input data for noise modelling that need to be collected consist of yearly air traffic data including information about origin and destination, aircraft type, actual take-off and arrival time, and runway in use. Ground track data representing departure and arrival routes and flight profiles need to be modelled based on either radar data or Standard Instrument Departure (SID) and Standard Arrival Routes (STAR). Distribution of operations per each runway, aircraft type, route and time of day needs to be assessed. In addition, meteorological data such as headwind speed, pressure, air temperature, and relative humidity, as well as topographical data, could also influence the shape of noise contours. More about modelling aircraft noise could be found in ECAC Doc 29 [28].

C. Calculation of dynamic noise maps

After creating noise model and obtaining daily mobility patterns of the population, the next step is to extract the distribution of people at a desired spatial and temporal resolution. The most detailed spatial resolution would include every single location where people spend time. Nevertheless, such a detailed approach is neither practical nor needed for airport noise impact studies, since aircraft noise levels do not differ significantly among closely located points. Another approach is to aggregate points into grid cells (e.g. 500 m x 500 m) and to calculate noise levels only at the cells' centroids which will then represent all the points within that cell.

As for the temporal resolution, it will depend on the change in the number of people at different locations and frequency of activities in the observed model. The minimum temporal detail should include at least four or five time periods in the day, as opposed to some models that use continuous time (e.g. 1,440 one-minute periods in the day). Furthermore, the temporal resolution could be observed separately for working and non-working days, since these population's daily mobility patterns could be different from one another. As explained above, here we will use temporal resolution in minutes.

The noise metric that needs to be calculated for each location is the LAeq,T or the A-weighted, equivalent continuous sound level determined over the time period T. After calculating LAeq noise levels, the next step is to match the number of people exposed to those noise levels at each location (spatial resolution) during each time period (temporal resolution) and calculate the cumulative noise impact for each person. The two most important indicators defined by the Environmental Noise Directive 2002/49/EC used to determine exposure to environmental noise from major transport and industry sources are the L_{den} (the day, evening, and night-level indicator designed to assess annoyance) and the L_{night} (the night-level indicator designed to assess sleep disturbance). With (1) we determine L_{den_j} for each person j by taking into account that within each hour people might spend different amounts of time (t_{jlt}) at different locations that are exposed to different yearly average noise levels $(LA_{eq,1h_{lt}})$:

$$L_{den_j} = 10 \cdot \log_{10}\left(\frac{1}{T}\left(\sum_{l\in L}\sum_{t\in T_d} t_{jlt} \cdot 10^{\frac{LA_{eq,1h_{lt}}}{10}} + \sum_{l\in L}\sum_{t\in T_e} t_{jlt} \cdot 10^{\frac{LA_{eq,1h_{lt}}+5}{10}} + \sum_{l\in L}\sum_{t\in T_n} t_{jlt} \cdot 10^{\frac{LA_{eq,1h_{lt}}+10}{10}}\right)\right), \forall j \quad (1)$$

where $LA_{eq,1h_{lt}}$ is the A-weighted, equivalent continuous sound level determined over one hour at the location l during the time period t; t_{jlt} is the amount of time that each person j has spent at the location l during the time period t; T_d, T_e and T_n represent day (12 hours), evening (4 hours) and night periods (8 hours) as stated in the Environmental Noise Directive 2002/49/EC, while T is equal to 24 hours.

The night time noise indicator L_{night_j} for each person j can be calculated by (2):

$$L_{night_j} = 10 \cdot \log_{10}\left(\frac{1}{T_n}\left(\sum_{l\in L}\sum_{t\in T_n} t_{jlt} \cdot 10^{\frac{LA_{eq,1h_{lt}}}{10}}\right)\right), \forall j \quad (2)$$

where T_n, t_{jlt}, $LA_{eq,1h_{lt}}$ have the same meaning as explained for the L_{den_j}. Night time period usually lasts eight hours, starting from 10 PM to 6 AM.

In order to assess the expected annoyance and harmful effects of aircraft noise upon population, dose-effect relation is used, concerning the following:

- the relation between annoyance and L_{den} for air traffic noise,
- the relation between sleep disturbance and L_{night} for air traffic noise.

From noise levels obtained for each person L_{den_j}, the total number of people annoyed by aircraft noise (NPA) is estimated using the polynomial approximation in (3) as suggested by the European Commission [29]:

$$NPA = \sum_{j\in J}\left(\left(8.588 \cdot 10^{-6} \cdot \left(L_{den_j} - 37\right)^3 + 1.777 \cdot 10^{-2} \cdot \left(L_{den_j} - 37\right)^2 + 1.221 \cdot \left(L_{den_j} - 37\right)\right)/100\right). \quad (3)$$

The European Commission also gives the approximation for estimating the total number of people highly annoyed by aircraft noise ($NPHA$) as follows (4):

$$NPHA = \sum_{j\in J}\left(\left(-9.199 \cdot 10^{-5} \cdot \left(L_{den_j} - 42\right)^3 + 3.932 \cdot 10^{-2} \cdot \left(L_{den_j} - 42\right)^2 + 0.2939 \cdot \left(L_{den_j} - 42\right)\right)/100\right). \quad (4)$$

The number of people who are sleep-disturbed (NPSD) and the number of people who are highly sleep-disturbed (NPHSD) during the night by air traffic noise are determined by using L_{night} indicator, as described in the EU-position paper on night time noise [30]:

$$NPSD = \sum_{j\in J}\left(\left(13.714 - 0.807 \cdot L_{night_j} + 0.01555 \cdot (L_{night_j})^2\right)/100\right) \quad (5)$$

$$NPHSD = \sum_{j\in J}\left(\left(18.147 - 0.956 \cdot L_{night_j} + 0.01482 \cdot (L_{night_j})^2\right)/100\right). \quad (6)$$

Equation (3) indicates that people are annoyed by aircraft noise only when the L_{den} values are higher than 37 dB, while people are highly annoyed if the L_{den} values are higher than 42 dB, as in (4). For the L_{night} indicator, 40 dB was used as the lower limit, as suggested by the World Health Organisation [31].

III. Ljubljana Airport Case Study

To assess the influence of aircraft noise on dynamic (daily mobility patterns) and reference (census) population, a case study has been carried out at Ljubljana Jože Pučnik Airport. Ljubljana airport is the largest and the busiest international airport in the Republic of Slovenia. It is located 20 km northwest of the Ljubljana capital. With a single runway 3,300 m long (direction 12/30), the airport handled more than 1.7 million passengers and approximately 31 thousand aircraft operations in 2019.

Since Ljubljana airport has not reached 50,000 movements per year, preparation of strategic noise maps and action plans according to the implemented EU Directive 2002/49/EC is not mandatory, and neither is the implementation of the Balanced

Approach Regulation (EU) 598/2014. Nevertheless, the airport has proactively developed noise contour maps and has been regularly performing continuous noise monitoring in the most noise exposed areas for several years.

According to the airport official statistics, yearly traffic for 2018 comprised of 35,512 operations. Departure and arrival routes for each runway were obtained from the radar data (OpenSky, https://opensky-network.org/), because data for SID and STAR routes were not available from neither the airport nor the ATC, and in many cases could be less accurate, as most aircraft were vectored.

Nine representative routes were selected from the radar tracks presented in Fig. 1. There are two departure routes and one arrival route from runway 12, and three departure routes and three arrival routes from runway 30. Departure routes are marked blue, and arrival routes are marked red.

The fleet mix consisted of 213 different aircraft types. However, to simplify the calculations, the aircraft were classified into groups based on the substitution methodology described in the ICAO Doc 9911 and ECAC Doc. 29 noise modelling guidance using the aircraft substitution tables available in the Aircraft Noise and Performance (ANP) Database. Table 1 shows the number of arrival and departure operations for different times of day for 15 aircraft types which make up to 80% of the total traffic.

Fig. 2 shows the total number of aircraft operations in 2018 for each hour of the day. There are several peaks during the day, while night operations are rare. Most flights are operated between 5 PM and 6 PM with an average value of nine flights per hour during this peak period.

The sound exposure levels (SEL) from which LAeq noise levels were calculated at each location caused by each aircraft type on the different routes are calculated by the SONDEO software. For each operation, the standard ANP profile settings are used. Before calculating the noise data, it is crucial to choose a reasonable number of locations for which the noise data and

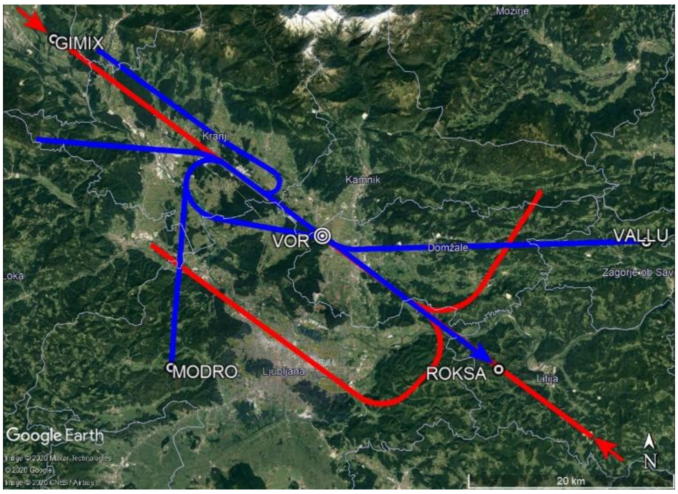

Figure 1. Departure (blue) and arrival (red) routes (source: OpenSky, Google Earth)

the population data will be obtained. In this case study, the SEL was calculated for 18,481 locations, with each location representing the centroid of a 500 m x 500 m grid.

TABLE I. FLIGHT STATISTICS PER AIRCRAFT TYPE AND TIME OF DAY

ICAO aircraft type code	Day		Evening		Night	
	A	D	A	D	A	D
CRJ9	3586	4674	1284	522	445	117
A319	1302	1542	587	434	305	219
CRJ7	875	1116	305	101	85	48
CRUZ	796	855	79	19	0	0
F100	505	633	137	88	100	21
A320	259	249	262	263	22	29
C172	367	416	84	40	5	0
B734	328	2	3	401	80	8
A320	119	118	72	60	148	162
AT72	369	214	158	350	110	74
L410	66	311	253	6	1	1
DH8D	289	278	2	12	0	1
P28A	239	263	30	6	0	0
SW4	54	260	211	5	0	0
AT75	110	110	132	130	0	2
All others	2709	2868	763	613	119	111
Total	11973	13909	4362	3050	1420	793

a. A -arrival; D - departure

Fig. 3 shows the Real Estate Register and Building Cadastre data provided by the Surveying and Mapping Authority of the Republic of Slovenia (GURS). There are 1,188,949 buildings in Slovenia, out of which 553,357 (46.5%) have a house number. Since each building is divided into parts, in Slovenia there are 1,888,107 building parts. Each part of a building has its own actual use and there are 59 different actual uses, such as: Residential (872,411), Business (35,584), Commercial (18,216), School and kindergarten (3,445), Museum and library (1,313), Restaurant (8,613), Religious (3,894), Hospital/medical center (553), Bank/post office/insurance company (2,368), Sports Hall (1,928), etc.

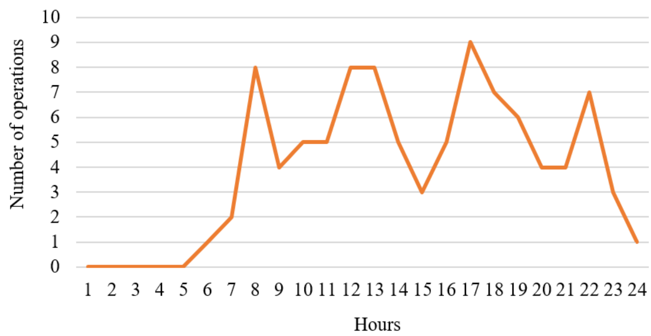

Figure 2. Hourly distribution of aircraft operations for year 2018

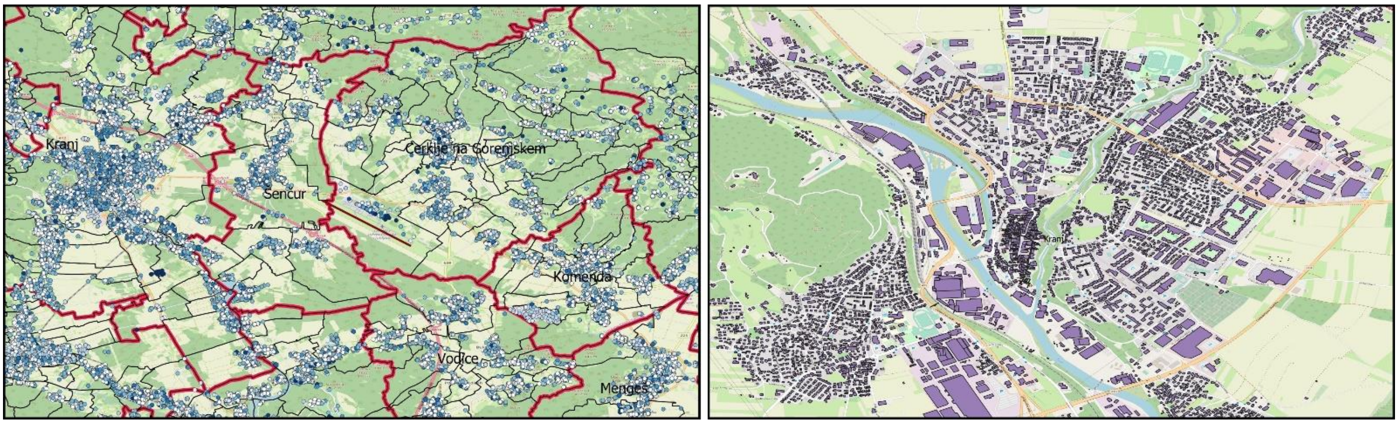

Figure 3. Real Estate Register and Building Cadastre data (source: GURS https://egp.gu.gov.si/egp/, validity date 22.08.2020)

In this case study, data on daily travel habits, movements and trips of residents aged 15–84 living near Ljubljana airport were collected from Daily Passenger Mobility Survey (TR-MOB 2017) conducted by the Statistical Office of the Republic of Slovenia. The survey examines how many and how (walking or by any other mode of transport) people travel, how much time they spend, and what the trip purpose is (work, education, leisure, shopping, etc.). Data collection took place during the last two weeks in September and in October 2017 which was considered representative period for the entire calendar year [32]. Equal distribution of working and non-working days was obtained. For more information about this survey, interested readers may refer to methodological explanations given in [32]. For this case study, we obtained the protected microdata containing detailed information about each trip on an individual level. The number of respondents was 8,842, out of which 1,355 (15.3%) survey participants stayed at home on a selected day, while the other 7,487 persons made 24,195 trips (3.2 trips per day). It is also relevant to mention that 296 (3.3%) persons started their first trip from the municipality other than the municipality where they live.

People tend to choose the start of their trip differently depending on the purpose of the trip. Therefore, there are time periods of the day with pronounced peaks (e.g., early, a.m. peak, midday, p.m. peak, and late) as shown in Figure 4. Most of the first-shift workers usually start their trip around 7 a.m. with the pupils and students following the similar trend. The majority of trips with the purpose of shopping start around 11 a.m. while leisure activities have their peak after 6 p.m.

Table 2 provides short descriptions of each trip purpose along with the number of trips for each purpose for the whole sample. There are seven different purposes of trips, with leisure being most frequent among participants.

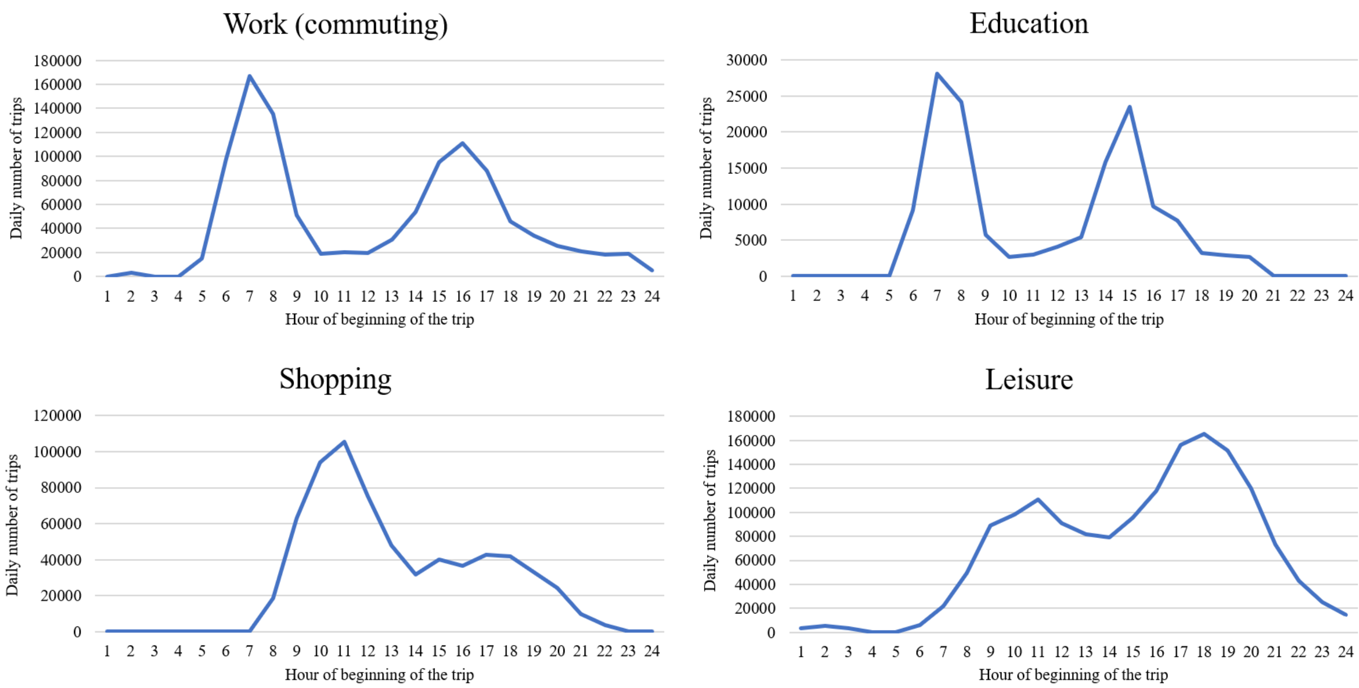

Figure 4. Daily number of trips by trip commencement hour and purpose (source: SURS https://www.stat.si/statweb)

TABLE II. DESCRIPTION AND FREQUENCY OF TRIP PURPOSES

Trip Purpose	Description	No. of trips
Work (commuting)	Going to work	5871
Professional, business	Business or official errands, business trip up to 300 km	640
Education	Going to school, faculty (education facility)	989
Escorting (of parents)	Driving / picking up/ accompanying a child or other person	2339
Shopping	Visiting stores	3544
Leisure	Visiting friends/relatives, going out to eat or drink, recreational activities (indoor or outdoor), hobbies, walking a pet, working in the garden, sightseeing, visiting cultural or sport events.	8620
Personal business	Health treatment, personal care (e.g. hairdresser), services (e.g. car maintenance), going to the bank, post, religious activities (also funerals).	2192

IV. RESULTS AND DISCUSSION

To assess the influence of daily mobility patterns of the population upon evaluation of aircraft noise effects, noise impact will be presented for each person (dynamic noise maps) and for each location (traditional noise maps). In the first scenario, census data are used to assess the distribution of population to the locations affected by noise, assuming that people stay at their homes for the whole day (24 hours). Since for all currently developed official noise maps such approach is used, this scenario is hereinafter referred to as the reference scenario. On the other hand, if daily mobility patterns of the population are considered, such movements will lead to different distribution of the population during the day and this scenario is hereinafter referred to as the dynamic scenario.

Since the assignment of location for each trip is a stochastic process, 1,000 iterations have been conducted, which improved the precision and statistical significance of the results. As each survey participant represents some portion of the population, we used weights already provided in the TR-MOB 2017 survey to scale up the results and to give a rough estimate of the expected impact on the population. The expected number of people annoyed by aircraft noise is calculated as a sumproduct of noise annoyance (based on the respondent's noise exposure) and weight for each survey respondent. Using the same approach, the results were obtained for highly annoyed, sleep-disturbed and highly sleep-disturbed people for both scenarios. The average results of 1,000 iterations along with descriptive statistics are presented in Table 3.

TABLE III. ANNOYANCE AND SLEEP DISTURBANCE FOR REFERENCE AND DYNAMIC SCENARIO

Statistics	Reference scenario				Dynamic scenario			
	NPA	*NPHA*	*NPSD*	*NPHSD*	*NPA*	*NPHA*	*NPSD*	*NPHSD*
Mean	5430	588	158	92	5588	529	158	91
Median	5435	589	156	90	5588	530	155	90
Min	4756	408	33	19	5058	386	37	22
Max	6227	810	301	174	6226	700	288	167
Range	1471	401	268	155	1168	313	251	145
Standard deviation	202	53	43	25	193	50	43	25

Table 3 shows that in the case of the Dynamic scenario, the total number of people annoyed by noise increases by 2.9%, while the number of highly annoyed people decreases by 10% compared to the Reference scenario. This implies that people spend less time during the day in the areas most affected by aircraft noise, while there are more people in less affected areas around the airport. As expected, sleep disturbance indicators do not differ significantly between the two scenarios, since the number of trips during the night is negligible. Reduced number of people who are sleep-disturbed implies that some of the survey participants spent at least some period of the night in the areas outside the noise contours (L_{night}>40 dB).

What cannot be seen from Table 3, however obvious from Fig. 5 and Fig. 6, is that different people are affected by aircraft noise then the ones expected. Fig. 5 shows the difference between the number of people annoyed by aircraft noise of the two scenarios for each residential location where the difference exists. The negative difference indicates that for those persons noise impact has been underestimated, since the L_{den} noise levels for the Dynamic scenario are higher than the ones obtained in the Reference scenario or higher than 37 dB if the person does not live within the L_{den} 37 dB noise contours. The positive values suggest that those persons spend more time outside the area of L_{den} 37 dB noise contours during the day and thus the noise impact has been overestimated. Consequently, there is no difference between scenarios for the persons staying home for the whole day.

The L_{den} noise contours caused by all arrival and departure operations are shown in Fig. 6, where the people affected by aircraft noise at each location are also indicated. At first glance, it can be observed that there are four different types of people in terms of their noise annoyance and location of their residence. The total number of people annoyed by noise (NPA) within the L_{den} noise contours higher than 37 dB for the Reference scenario (marked with red and white circles) is 5,430 as stated in Table 3. However, when movements of the people during the day are considered, only 4,884 of them (marked with red circles) are annoyed by noise based on the Dynamic scenario. These results lead to the conclusion that even though people live at locations enclosed in the noise contours, 10.1% of them (marked with white circles) are not annoyed by aircraft noise due to their daily mobility to locations far away from the airport.

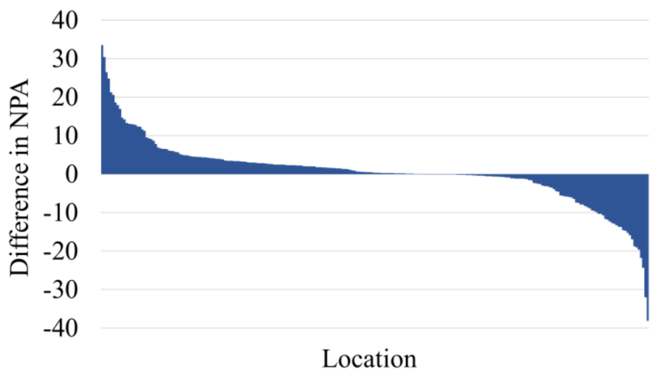

Figure 5. Difference in NPA per location

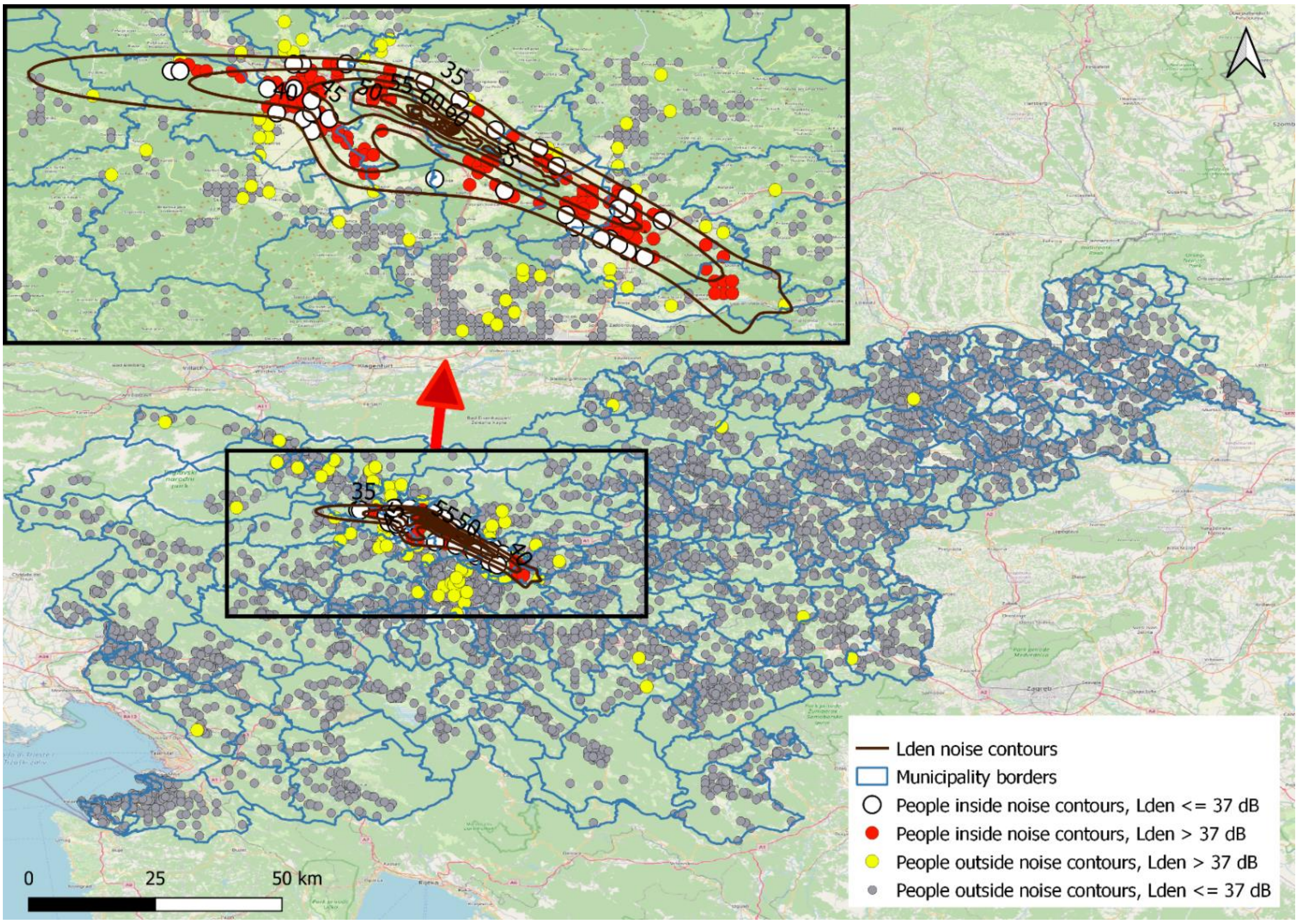

Figure 6. L_{den} noise contours and people affected by aircraft noise

Furthermore, in order to see how many noise annoyed people are located outside the L_{den} noise contours higher than 37 dB, the NPA based on the Dynamic scenario at all locations is evaluated. The results show that, apart from the 4,884 people living within the noise contours, there are additional 704 persons (14.4%) also experiencing noise annoyance (marked with yellow circles), which in total makes 5,588 people annoyed by noise for the Dynamic scenario (as shown in Table 3). This can be explained by considering that people who live outside the area affected by aircraft noise may work or study within these areas at some time during the day and are therefore affected by aircraft noise. The fourth group of people (marked with grey circles) resides outside the noise contours and is not affected by aircraft noise, even when the daily mobility patterns are considered.

V. Conclusion

In this work we have considered a particular case study for which we have detailed records for a full Slovenia population sample coming from a mobility survey. The noise impact levels generated by the average Ljubljana airport traffic have been calculated by the hour and the expected noise annoyance upon the population has been measured considering both only the residents and the actively present individuals. The estimated noise annoyance showed that a portion of the most affected population does not spend the whole day in the affected areas. In this case, the neighborhoods around the airport are mostly residential and few people enter them during working hours. This implies that without taking into account the population’s mobility, the number of people annoyed is either overestimated or underestimated. The airport is 20 km away from the capital, where most of the services, educational centers and jobs are concentrated. The population, therefore, travels in and out of the annoyed areas during the day, thus changing their daily noise impact. As expected, if only night disturbance is considered, the difference is much lower, and it is due to the small fraction of the population who move during the night.

As future research, these results must be validated in urban areas that are more diverse in terms of land use. For instance, if logistic, industrial, or commercial areas are concentrated close to an airport, the annoyance may even increase if mobility is considered, since these will be the areas of concentration of the population during the day. Secondly, we divided the time into hour intervals to calculate the noise contours. As long as very detailed mobility data are available, we can refine this calculation to the impact of individual flights. Thirdly, the sample of the population considered must be widened to prevent uncertainty in the metrics and statistical errors. This will be done by including data from other sources, larger surveys or synthetic population, over which models could be run to study what-if scenarios including mitigation policy actions.

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