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UAM Smart City Indicators Framework

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SAFIR-Med project

SAFE AND FLEXIBLE INTEGRATION OF ADVANCED U-SPACE SERVICES FOCUSING ON MEDICAL AIR MOBILITY

This Project Management Report is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 101017701 under European Union's Horizon 2020 research and innovation programme.

Abstract

This document provides a first approach to the development of a UAM Smart City Indicators Framework. This report consists of an assessment on the effectiveness and implications of UAM adoption for the urban spatial structure focusing on the mid-term timeline and the significance of changes that will be brought about in the city context. It is based on the Sustainable Urban Mobility Indicators (SUMI) framework outlined by the European Commission and gathers additional parameters necessary for the impact assessment of UAM by cities and local authorities in their respective areas. The current document aims to present a coherent analysis for the creation of a joint framework for urban ground and air mobility where it can act as a basis for future operations.

Table of Contents

1 Introduction

1.1 Purpose of the document

The present document summarizes the research conducted during the SAFIR-Med project regarding the development of an Urban Air Mobility (UAM) Assessment Framework for smart cities. The present document aims to set the basis of an impact assessment method so that public authorities can keep track and evaluate the implementation of UAM in their respective areas.

1.2 Scope

Currently UAM implementation progresses in a chaotic way. Drone technology and its use is ahead of relevant city level regulation. This is the case for planning and monitoring activities of UAVs in most cities of the world. The aim of the present study is to develop an assessment framework that would be able to capture the impact of medical UAM implementation via developing a set of sustainable UAM indicators. Therefore, the aim is to use this framework in order to:

1. assess the impact of various UAM implementation options on the city **before** launching UAM at scale and prepare a good plan

2. track the implementation progress

3. establish city level regulation processes

4. monitor and evaluate the impact on the city **after** the UAM implementation

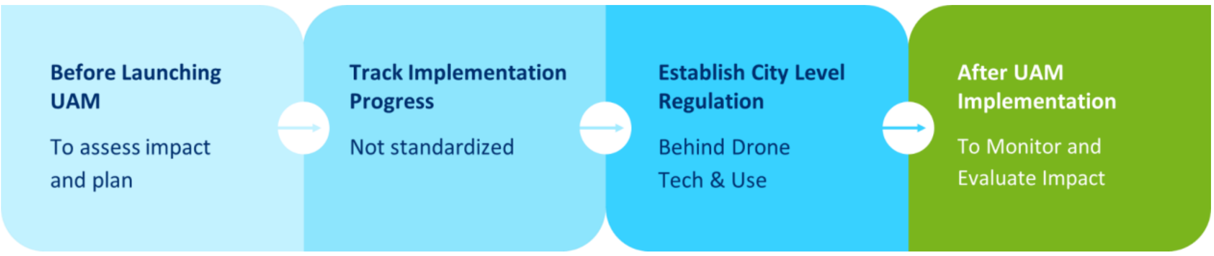

Figure 1 When and why to use indicators

The practitioner's briefing report from UIC2[1] regarding UAM and Sustainable Urban Mobility Plans (SUMP) emphasised on the importance of integrating UAM into the SUMP process. Moreover, in the

[1] https://www.eltis.org/sites/default/files/practitioner_briefing_urban_air_mobility_and_sump.pdf

same report it is mentioned that "(...) the SUMI[2] framework is expected to be updated to capture aviation-driven UAM-metrics. Taking into account the iterative character of the SUMP cycle, one should make distinction between high-level indicators from the SUMI framework that should be treated as 'fixed', and lower-level indicators which could be developed to address UAM-related activities". Sustainable Urban Mobility Indicators (SUMI) framework was a project funded by European Commission (DG MOVE) that lasted 2 years. Within the SUMI project 46 European urban areas tested the sustainable urban mobility indicator set based on the "SMP2.0 Sustainable Mobility Indicators" developed by the World Business Council for Sustainable Development (WBCSD).

Taking into account the aforementioned points, the present research is aligned with the SUMPs methodology already being implemented by cities in Europe for other modes of transport to enable faster acceptance and operationalization of the indicators. In a nutshell, using an assessment framework that smart cities are already familiar with from other modes of transport and expanding for UAM applications is important for the usability, applicability of the current work and the more efficient facilitation of UAM implementation. In this way, cities and urban areas will have a tool able to identify the strengths and weaknesses of their mobility system and to focus on areas for improvement.

1.3 Structure of the Document

The first chapter consists of the introduction and purpose of the document while the detailed overview and explanation of each existing indicator along with the introduction of new metrics for UAM impact assessment follow in chapter two. The third chapter consists of the conclusions and summary of the previous discussion while the fourth and fifth chapter contain the acknowledgments and the annex with the SUMI equations respectively.

1.4 Intended readership

This document is referred to SESAR 3 participants in performance-related tasks, to the Members of the SESAR Development Programme that participate of make use of the performance elements, to cities personnel and public servants working on Innovation, Transportation, Logistics or Environmental Departments, to any entities active in the field of UAM.

1.5 List of Acronyms

Table 1 List of Acronyms

Acronym	Definition
AED	Automated External Defibrillator

[2] https://transport.ec.europa.eu/transport-themes/clean-transport-urban-transport/sumi_en

ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATM	Air Traffic Management
CISP	Common Information System Provider
DoS	Denial of Service
eVTOL	electric Vertical Take-Off and Landing
GHG	Greenhouse gas
KPI	Key Performance Indicator
MAHHL region	the cities of Maastricht, Aachen, Hasselt, Heerlen and Liège
MRO	Maintenance, Repair & Operations
SUAMI	Sustainable Urban Air Mobility Indicators
SUMI	Sustainable Urban Mobility Indicators
SUMP	Sustainable Urban Mobility Plan
UAM	Urban Air Mobility
UAS	Unmanned Aerial Systems
UAV	Unmanned Aerial Vehicle
UIC2	Urban-Air-Mobility Initiative Cities Community

USSP	U-space Service Provider

1.6 About SAFIR-Med

The SAFIR-Med project's vision is to achieve safe, sustainable, socially accepted and socially beneficial urban air mobility. SAFIR-Med represents all value chain actors and stakeholder as either project partner (ATC, USSPs, Operators, UAS Manufacturers, cities) or formal associate partner (major customers, technology & service providers) at a representative international level. Five unmanned UAV platforms (passenger eVTOL, Hydrogen fuel cell VTOL, eVTOL, AED medical drone, X8 medical transport) are combined with manned aviation in real life exercises validating technology in a real urban environment. Our demonstrations are taking place in the city of Antwerp and the MAHHL cross-border region in tri-border region between the Netherlands, Belgium and Germany, and a de-risking exercise that took place at the DronePort test-facility in Sint-Truiden, Belgium. We further validated results achieved by enhancing the real demonstrations through large-scale simulations in order to test the maximum airspace capacity and then further validating our results by simulating demonstrations in two additional locations in Europe, namely Athens, Greece and Prague, Czech Republic. Lessons learnt are documented in a Performance Assessment and Recommendations report, providing refinements to the current U-space architecture principles and creating measurable indicators for UAM which will enable Smart Cities to include UAM in their Transport Roadmaps and set relevant measurable goals aligned with the current Smart City concept and standards.

1.7 Methodology

The methodology followed for the conduction of the present work includes background research, interviews with experts in each field and validation with the city of Aachen. Specifically, desk research was conducted. Through the literature review process, inspiration from other approaches in defining key performance metrics was taken and gaps in existing frameworks were identified. The SUMI framework, on which the present work is based, was examined in detail both as a holistic approach but also in the context of individual metrics. Then, consultations with experts in each field took place. Their opinions and insights were gathered and validated with existing literature. Finally, the city of Aachen engaged in the validation of the current work as the end user of the framework.

2 Overview of UAM Smart City Indicators

2.1 Introduction to SUAMI

While the Sustainable Urban Mobility Indicators (SUMI) Framework[3] provided a comprehensive set of practical indicators that can support cities during the evaluation of their mobility system, it is true that Urban Air Mobility and the use of Unmanned Air Vehicles (UAVs) were not included as a transportation means for the creation of the framework. The present work attempts to act as an addition to the SUMI as an existing framework that is already being used by cities for other modes of transport in order to enable faster acceptance and operationalization of UAM indicators for impact assessment, increasing their applicability and usability at the same time. Our framework will be referred to as **Sustainable Urban Air Mobility Indicators (SUAMI) Framework**, and although in principle applicable to all types of UAM applications, in our study we focus on indicators suitable to measure the impact of medical applications, which include medical package deliveries and passenger transportation (patients or medical staff).

Moreover, it is useful to mention that while a technical approach to a U-space performance framework, as an adaption from PJ19.04 Performance Framework for ATM[4], was presented in SESAR's PJ19-W2 CI project, the societal and economic aspects of U-space implementation were not addressed. The aforementioned research has different objectives and targets different readership than SUMI and SUAMI, since it refers to the technical aspects of UAM and U-space deployment and can be utilized by the appropriate technical personnel. While the inclusion of some socioeconomic dimensions in the PJ19-W2 CI performance framework would not satisfy the objectives of SUAMI, it would be useful and beneficial to include these dimensions of UAM in future versions of the document for a more holistic approach of performance assessment. These points have been communicated with the contact persons of the PJ19-W2 CI project and more adaptations are expected in future editions.

It is important to make clear that SUAMI is intended to be a user friendly and practical framework addressed to cities and local authorities in order to help them make future decisions in the context of UAM implementation in their respective areas, in the same way as SUMI was created for ground modes of transport.

2.2 Examination of SUMI applicability to UAM

An analysis of SUMI's applicability to UAM by Tojal & Paletti (2022) has ranked the indicators in classes of high, medium and low applicability to UAM[5] as shown in Table 2.

[3] https://transport.ec.europa.eu/transport-themes/clean-transport-urban-transport/sumi_en

[4] https://www.sesarju.eu/sites/default/files/documents/awards2021/SESAR%20Performance%20Framework%20ed_%2001_00_01%20-%202019.pdf

[5] Tojal, M., & Paletti, L. (2022). Is Urban Air Mobility Environmentally Feasible? Defining the Guidelines for a Sustainable Implementation of its Ecosystem. Transport Research Arena (TRA) Conference

Table 2 Ranking of SUMI applicability to UAM

SUMI Indicator	Definition	Applicability
Affordability of public transport for the poorest group	Share of the poorest quartile of the population's household budget required to hold public transport (PT) passes (unlimited monthly travel or equivalent) in the urban area of residence.	High
Accessibility of public transport for mobility-impaired groups indicator	This indicator determines the accessibility of public transport services to persons with reduced mobility.	High
Air pollutant emission indicator	Air pollutant emissions of all passenger and freight transport modes (exhaust and non-exhaust for PM2.5) in the urban area	High
Noise hindrance	Hindrance of population by noise generated through urban transport.	High
Road deaths	Road deaths by all transport accidents in the urban area on a yearly basis.	Medium
Access to mobility services	Share of population with appropriate access to mobility services in their area (public transport).	High
GHG Emissions	Well-to-wheels GHG emissions by all urban area passenger and freight transport modes	High
Congestion and delays	Delays in road traffic and in public transport	Medium
Energy efficiency	Total energy use by urban transport per passenger km and tonne km (annual average over all modes).	Medium
Opportunity for Active Mobility	Infrastructure for active mobility, namely walking and cycling	Low
Multimodal integration	The more modes available at an interchange, the higher the level of multimodal integration.	High
Satisfaction with public transport	The perceived satisfaction of using public transport.	Medium
Traffic safety active modes indicator	Fatalities of active modes users in traffic accidents in the city in relation to their exposure to traffic	High

This ranking includes all core indicators as defined by SUMI framework, but non-core indicators were not examined in the above study.

In the next chapters a discussion about each indicator from SUMI and how they can be implemented (or not) in the context of UAM impact assessment will follow. The existing indicators will be examined, while new additions will be suggested wherever it's suitable. The detailed definition of each indicator and their respective equations can be found in the Annex A.

2.3 Affordability of public transport for the poorest group

Affordability of public transport for the poorest group is defined as the share of the poorest quartile of the population's household budget required to hold public transport (PT) passes (unlimited monthly travel or equivalent) in the urban area of residence.

At this stage of UAM deployment in which air taxis or similar services are not available for the public and thus the price of a monthly PT pass including the use of UAV as transport modes for the general public cannot be calculated. However, **if and when such service becomes available the indicator of affordability can be used in the same way as current modes of transport.**

A rough estimation of the cost to fly an air taxi ranges from 1,5€/km to 6,5€/km. This information comes from estimates of organisations such as NASA[6], Joby aviation[7], Lilium[8], Archer aviation[9] etc. For drone delivery services the estimated cost per delivery is around 1€. The cost estimations are based on the assumption that the package weighs less than 2,2kg and the delivery distance is less than 16km (distance of warehouse to delivery site)[10]. Nevertheless, before a large-scale deployment of these services, we can't tell with certainty what the actual cost would be in each case but we can make more and more educated guesses as more data becomes available.

2.4 Accessibility of public transport for mobility-impaired groups

Accessibility of public transport for mobility-impaired groups determines the accessibility of public transport services to persons with reduced mobility. Such vulnerability groups include those with visual and audial impairments and those with physical restrictions, such as pregnant women, users of wheelchairs and mobility devices, the elderly, parents and caregivers using buggies, and people with temporary injuries.

In order to capture the real-life accessibility for a person with reduced mobility, this indicator combines the accessibility levels of three elements:

1) accessibility of moving assets (vehicles)
2) accessibility of stops and stations

[6] https://www.nasa.gov/sites/default/files/atoms/files/bah_uam_executive_briefing_181005_tagged.pdf
[7] https://www.youtube.com/watch?v=pyrTfUrwxZE
[8] https://www.flyingmag.com/evtol-air-taxi-passenger-prices/
[9] https://mashable.com/article/archer-maker-evtol-reveal
[10] https://www.itskrs.its.dot.gov/its/benecost.nsf/ID/4df3f3f4a1bf2a0d8525858f006842a3

3) accessibility of ticket machines and offices

For UAM, accessibility of stops, stations, ticket machines and offices can be treated, more or less, in the same way as other modes of transport. The use of web portals and mobile applications where the user will be able to purchase an e-ticket online and provide it at the time of using the service when asked, is not a new concept. Moreover, buying a ride through a physical ticket machine or ticket office is something that the public is already familiar with. Accessibility of these aspects is not expected to change with the deployment of UAM. The same goes for stops and stations. They should be designed in a way that is inclusive and accessible to all and utilise all accessibility features of modern stations of other transport modes such as train stations and bus stations. Specifically, designs of vertiports are considering access for wheelchairs to all parts of the facilities and especially to the boarding area in case stairs are present. Most elevated vertiports will have either ramps or an elevator to comfortably reach the take-off platform.

The accessibility of moving assets (vehicles) can be a more complex concept in the use of UAVs than other mainstream mobility systems. The limited space in an air taxi, for example, can be shown to be less accommodating for some part of the population with reduced mobility. However, accessibility to vehicles is being considered in some eVTOL designs where the wheelchair or person with limited mobility can be moved near the open door of the flying vehicle and then with the help of some crew, be lifted up manually as there are no ramps. Larger vehicles for over 4 passengers will likely consider using a ramp for easier boarding. For ill patients, it will not be easy to board standard eVTOLs, so adapted vehicles or medical ones will have to be used instead.

2.5 Air pollutant emissions

Air quality is an important topic for urban environments since air pollution can lead to major health problems and can even be one of the leading causes of premature deaths[11,12,13]. While air quality can be estimated using indexes like the European Air Quality Index[14], these metrics lack information regarding the source (urban mobility, industrial activities, domestic fuel burning etc.) and the degree that each source contributes to air pollution. Around 25% of total air pollution is sourced in urban mobility[15] (traffic, public transport, urban logistics, etc.). For ground modes of transport different methods of quantifying the impact of air pollution have been developed such as the Air Pollutant Emissions Indicator from the Sustainable Urban Mobility Indicators (SUMI) framework which calculates the Emission Harm equivalent Index (EHI) for fine particulate matter (PM2.5) in the urban area. While

[11] V. A. Southerland et al., 'Global urban temporal trends in fine particulate matter (PM2·5) and attributable health burdens: estimates from global datasets', The Lancet Planetary Health, vol. 6, no. 2, pp. e139–e146, Feb. 2022, doi: 10.1016/S2542-5196(21)00350-8.

[12] D. A. Malashock et al., 'Estimates of ozone concentrations and attributable mortality in urban, peri-urban and rural areas worldwide in 2019', Environ. Res. Lett., vol. 17, no. 5, p. 054023, Apr. 2022, doi: 10.1088/1748-9326/ac66f3.

[13] M. W. Tessum et al., 'Sources of ambient PM2.5 exposure in 96 global cities', Atmospheric Environment, vol. 286, p. 119234, Oct. 2022, doi: 10.1016/j.atmosenv.2022.119234.

[14] https://airindex.eea.europa.eu/

[15] https://op.europa.eu/webpub/eca/special-reports/urban-mobility-6-2020/en/

this method can be used for the impact assessment of conventional modes of transport in air quality, the adaption of the specific metric in order to include UAM activities has not been realized. At the same time, it is well-established that aviation's air quality impacts differ from those of other sectors due to the unique altitude that the emissions are deposited in[16], which is something that is not captured in this indicator.

Another limitation of the SUMI's Air pollutant emissions is the impact assessment of only one type of pollutant ($PM_{2.5}$). $PM_{2.5}$ refers to particulate matter with a diameter of 2.5μm or less, which is an air pollutant harmful to human health. $PM_{2.5}$ are inhalable particles, but these are not the only harmful particles to human health. PM_{10} that are coarse particles with a diameter between 2.5 and 10 microns, Ultrafine Particles (UFPs) with a diameter less than 0.1 microns, the presence of Ozone (O_3) at ground level and Nitrogen Dioxide (NO_2) are some examples of different air pollutants having a negative effect on human health[17].

Different fuels and propulsion technologies of UAM will affect the associated air quality impacts both during direct operation, and from a life cycle perspective, and as such would also need to be addressed. At the same time, the infrastructure required by UAM[18] (e.g. development of vertiports and other facilities) would also have implications for air quality. All these items need to be addressed in a uniform and comprehensive manner with the appropriate adaptions. Finally, it can be the case that UAVs replace other existing mobility modes, which currently also impact air quality.

For all these reasons, in order to be able to assess the impact of UAM on air quality it is important to make the appropriate adaptations so that all the aforementioned points will be addressed sufficiently.

Regarding UAVs, the impact on air quality in cities is expected to be mostly positive. Since most drones are designed to be electrically powered by using batteries -such as lithium polymer (LiPo) or lithium ion (Li-ion) batteries- or hydrogen fuel cells, the air pollution in urban areas related to UAM will be close to zero. This will not be the case if UAVs powered by combustion engines are used extensively. In the case of gas-powered vehicles, the emissions of different pollutants affecting air quality should be calculated in similar ways as ground transport modes.

[16] Flávio D A Quadros, Mirjam Snellen and Irene C Dedoussi, Regional sensitivities of air quality and human health impacts to aviation emissions, Environmental Research Letters, Volume 15, Number 10, https://doi.org/10.1088/1748-9326/abb2c5

[17] A. Lammers, N.A.H. Janssen, A.J.F. Boere, M. Berger, C. Longo, S.J.H. Vijverberg, A.H. Neerincx, A.H. Maitland - van der Zee, F.R. Cassee, Effects of short-term exposures to ultrafine particles near an airport in healthy subjects, Environment International, Volume 141, 2020, https://doi.org/10.1016/j.envint.2020.105779.

[18] Pengli Zhao, Joseph Post, Zhiqiang Wu, Wenbo Du, Yu Zhang, Environmental impact analysis of on-demand urban air mobility: A case study of the Tampa Bay Area, Transportation Research Part D: Transport and Environment, Volume 110, 2022, https://doi.org/10.1016/j.trd.2022.103438.

2.6 Noise hindrance

This indicator measures the hindrance of population by noise generated through urban transport. The calculated parameter is the percentage of population hindered by urban transport noise, based on hindrance factors for noise exposure data of population by noise bands.

Previous research[19] reveals how the current regulation, noise metrics and evidence of health effects of aircraft noise is not a great fit for application to UAM noise. Several reasons are discussed, including that the noise produced by UAM aircraft is substantially different to conventional aircraft and rotorcraft, and that UAM aircraft will operate closer to communities traditionally not exposed to aircraft noise. The noise produced by UAM configurations, based on multiple propellers or ducted fans, is expected to have a significant content in tonal and high frequency noise, both factors with a strong correlation with noise annoyance[20]. The current metrics for aircraft noise certification (i.e., Effective Perceived Noise Level - EPNL, and Sound Exposure Level - SEL), and aircraft noise exposure (i.e., A-weighted Energy Equivalent Sound Pressure Level integrated over time t - LAeq,t) will likely be unable to account for these unconventional noise signatures of UAM aircraft[21]. There is a significant uncertainty of whether existing WHO recommendations for aircraft noise, based on LAeq,t metrics, will be appropriate for UAM noise, as there is no evidence supporting that communities will respond to UAM noise in a similar way to conventional aircraft noise.

Existing methods for aircraft noise certification, based on very well defined and standard aircraft operations during take-off and landing stages, or flyover operations for rotorcraft, will unlikely be of application for UAM air vehicles. UAVs will fly at relatively close distances from communities, and therefore, not only take-off and landing stages should be accounted for, but also flyovers. Moreover, transient operations in UAM aircrafts (e.g., transition from hover to forward flight) will require novel procedures for the measurement of UAM noise.

From a psychoacoustic point of view, in cases where vehicles are considered beneficial for the communities they operate in (e.g., delivery of emergency equipment, medical supplies or transportation of patients), the actual noise hindrance of the public is expected to minimize since priority will be given to more urgent matters. This is another point to take into consideration when expanding the metric for UAM operations. Moreover, it is important to take into account the timings of operations. The noise originating in UAM activities will be perceived differently in the morning and afternoon when a lot of urban noises are present in the city than the night time when everything tends to be quieter and calmer.

[19] Torija, A. J., & Clark, C. (2021). A psychoacoustic approach to building knowledge about human response to noise of unmanned aerial vehicles. International Journal of Environmental Research and Public Health, 18(2), 682.

[20] Torija, A. J., Roberts, S., Woodward, R., Flindell, I. H., McKenzie, A. R., & Self, R. H. (2019). On the assessment of subjective response to tonal content of contemporary aircraft noise. Applied Acoustics, 146, 190-203.

[21] Torija, A. J., & Nicholls, R. K. (2022). Investigation of metrics for assessing human response to drone noise. International Journal of Environmental Research and Public Health, 19(6), 3152.

To sum up, using SUMI's approach in order to include Noise hindrance for UAM in the existing framework seems like a viable solution for the future. However, at the current stage of UAM and U-space deployment not enough data is available in order to get a clear view with regards to the appropriate noise metrics. More testing and validation activities are necessary in order to be able to tell whether and to what degree the aforementioned limitations can be overcome or whether at the same time the introduction of completely new metrics for noise assessment is necessary.

2.7 Road deaths

This indicator refers to the road deaths by all transport accidents in the urban area on a yearly basis. The parameter value is the number of deaths within 30 days after the traffic accident as a corollary of the event per annum caused by urban transport per 100,000 inhabitants of the urban area.

While Urban Air Mobility refers to activities taking place in the air, UAM operations can affect the ground activities as well (e.g., a drone crash on an obstacle and falling to the ground). In the case of a drone activity being responsible for a death, the metric can be used in the same way as conventional modes of transport. At the same time it is important to note that UAM can also affect the indicator negatively, considering the reduction of traffic thanks to UAV use instead of car or van use (e.g., in the case of ambulances or organ transport). In this case UAVs replace a vehicle that would be speeding in the streets of the city, possibly causing accidents. On top of that studies have shown that drones can help deliver life-saving defibrillators to people with suspected cardiac arrest at the accident site faster than ambulances[22]. In this way a road death caused by conventional modes of transport can be prevented. Same goes, of course, for non-emergency traffic such as replacement of delivery vans or scooters in the stress of a city. Therefore, on one hand in order to better capture the risks of UAM, the measurement of accidents caused by UAM activities is necessary when talking about accumulative effect, while on the other hand a combined view of effects on traffic is needed to capture the negative influence of the indicators (road deaths avoided thanks to UAM introduction).

2.7.1 Accidents related to UAM

According to an EASA study on the social acceptance of UAM in Europe[23], safety was identified to be one of the main challenges for the successful deployment of UAM and also a factor that plays an important role in public acceptance. For this reason, it is important to develop the appropriate KPI in order to be able to quantify how safe UAM operations are and compare it with other modes of transport.

[22] Sofia Schierbeck, Jacob Hollenberg, Anette Nord, Leif Svensson, Per Nordberg, Mattias Ringh, Sune Forsberg, Peter Lundgren, Christer Axelsson, Andreas Claesson, Automated external defibrillators delivered by drones to patients with suspected out-of-hospital cardiac arrest, European Heart Journal, Volume 43, Issue 15, 14 April 2022, Pages 1478–1487, https://doi.org/10.1093/eurheartj/ehab498

[23] https://www.easa.europa.eu/en/full-report-study-societal-acceptance-urban-air-mobility-europe

Aside from deaths, it is important to consider accidents (lethal or not) that are caused by the use of drones in urban space in a direct or indirect way. For example, a drone flies over a residential area to deliver a package. A bus is driving in that area and the drone flies inside the driver's line of sight. The bus driver gets distracted and he crashes with the vehicle in front of the bus. In this scenario, the drone did not operate in a way that was unsafe for the citizens, but its presence caused an accident on the ground. Especially, in the early days of UAM deployment it is more possible that people's curiosity will lead to similar accidents. In another instance, a drone might crash on an obstacle and land on the ground resulting in a drone-related accident but not necessarily a lethal one. This can be the case with two drones colliding with each other or with a drone crashing on the ground etc.

Similarly with the indicator for road deaths, a new indicator for accidents related to UAM operations in the area needs to be defined. Following the same principles as "road deaths", but replacing the number of deaths with the number of accidents can be a useful and practical way to establish the new metric.

2.7.2 Accidents avoided because of UAM

As mentioned in the section "Road deaths", UAM can have a positive impact by reducing road deaths (less ground traffic, faster supply of medical equipment at the accident site, etc). In the same way, when UAM is deployed at a large-scale, less accident may occur because of its activities. For example, when less ground traffic is present at the urban area then the probability of an accident occurring decreases. **In the future UAM can replace many activities that are operated by ground modes of transport such parcel deliveries, emergency deliveries, remote inspection of infrastructure in the urban area etc. This can reduce the number of vehicles present in the city and thus reduce the number of accidents taking place annually. For this reason, a new indicator quantifying this benefit could be useful for cities in order to understand better the impact of UAM in their areas.**

2.8 Access to mobility services

This indicator refers to the share of the population with appropriate access to mobility services (public transport). The parameter calculated is the percentage of population with appropriate access to public transport (bus, tram, metro, train).

As this indicator mainly refers to physical mobility of people, it can be used for UAM in the case of air taxis. However, vertiports or similar infrastructure for citizen's mobility in the U-space cannot serve individuals with the same proximity as bus and tram stops. For this reason, the distance base value in order to assess how accessible is a service (e.g., 5 min walking for the case of bus and tram stops and 10 min walking for metro and train stops) should be adjusted appropriately for UAM services in order to represent as accurately as possible the level of accessibility offered in terms of distance and examined in combination with availability of bus/tram/metro stops nearby the vertiport.

In this way, the current metric can be adapted and expanded in order to include people's physical mobility in the context of UAM.

2.9 Greenhouse gas emissions

This indicator refers to Well-to-wheels GHG emissions by all urban area passenger and freight transport modes.

This indicator is appropriate for the assessment of UAM impact on GHG emissions. Carbon dioxide emissions can be calculated for UAM in a similar way with conventional means of ground transport. Adapting this indicator in way that includes UAM can be slightly more complex than conventional means of transport, since GHG emissions also depend on the altitude of UAVs' operations. When UAVs fly relatively close to the ground then it is indeed a good estimation to use similar metric as for ground modes of transport, since CO_2 is the main source of climate impact. However, for flights in substantially higher altitudes (e.g. aviation) CO_2 accounts for only a third of the total impact. In higher altitudes NOx also plays a significant impact on climate[24]. So, climate impacts of aviation are quite different for high altitude and ground level.
For the battery-powered UAVs the flight altitude does not play any role since no direct pollution is produced during the operation.
In this case the overall UAVs carbon footprint can be calculated by adding the following parts:

1. Emissions generated in the Vertiport process due to electricity consumption, "amortization" of the construction, battery recharge etc.
2. Emissions generated by the UAV: construction, operation and recycling
3. Emissions generated in the intermodal platform: construction and operation

Since most drones are designed to be electrically powered by using batteries -such as lithium polymer (LiPo) or lithium ion (Li-ion) batteries- or hydrogen fuel cells, the GHG emissions during operations will be close to zero. This will not be the case if UAVs powered by combustion engines are used extensively. In the case of gas-powered vehicles, the emissions should be calculated in similar ways as ground transport modes. However, other wastes associated with elements such as the batteries, are expected to occur and need to be recycled and managed to aim for a circular economy. Furthermore, the recharge of the batteries will generate a carbon footprint if the energy source used for powering the vehicles is not fully renewable. It is expected that vertiports and droneports will be designed in a sustainable way in order to be self-sufficient in terms of energy consumption. On the other hand, eVTOLS and some other UAV platforms require amounts of power (kW) to fly. If the power for the battery recharge is not generated by green energy plants, then a negative environmental footprint will be created. In this case, it is important to make comparisons of UAM activities with conventional urban logistics in order to assess the impact of each and make good use of the available modes of mobility. Taking into account the current EU 28 average a plugin-hybrid taxicab still has an advantage regarding the overall GHG emissions, but with the trend to

[24] D.S. Lee, D.W. Fahey, A. Skowron, M.R. Allen, U. Burkhardt, Q. Chen, S.J. Doherty, S. Freeman, P.M. Forster, J. Fuglestvedt, A. Gettelman, R.R. De León, L.L. Lim, M.T. Lund, R.J. Millar, B. Owen, J.E. Penner, G. Pitari, M.J. Prather, R. Sausen, L.J. Wilcox, The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018, Atmospheric Environment, Volume 244, 2021, https://doi.org/10.1016/j.atmosenv.2020.117834.

lower greenhouse gas emmission for the generatrion of electric energy the air taxi will soon be cleaner than the plugin-hybrid taxicab.[25]

2.10 Congestion and delays

Pollution and congestion in cities are on the rise and this is a major problem that requires the restructuring of mobility, which involves reducing the high rates of pollution without harming last-mile transport activity. New resilient infrastructures are needed to provide a new safe, sustainable and connected mobility and to help cities reduce the level of pollution and congestion in urban centres in last-mile transport.

By making good use of the vertical dimension and utilising direct air routes, the necessary travel time and distance for mobility of people and goods in an urban context can be reduced significantly. In the case of UAM the risk of traffic congestion is minimised. In conventional land transport, deviations are high as queueing theory predicts[26]. The capacity to offer premium urgent transport services, in which the reduction of transport times represents a clear competitive advantage. For the calculation, a journey time based on standard traffic situations in the urban center is the base reference. Thus, UAM is expected to have a positive impact with regards to congestions. In the context of delays, considering that many UAV platforms are designed to operate electrically, the recharge of batteries can lead to limitations to the pace of operations. The size of batteries (in terms of energy capacity) and fast-charging capabilities can influence the number of delays experienced[27]. Swapping batteries when possible can decrease delays and make operations more efficient. Lastly, stable weather conditions are a requirement for smooth operations.

This indicator from SUMI framework refers to the delays in road traffic and in public transport during peak hours compared to off peak travel (private road traffic) and optimal public transport travel time (public transport). The parameter calculates the weighted sum of delays over representative corridors for road private and public transport. For road private transport, sum of weighted averages over 10 representative corridors for car trips as a ratio of peak period travel times to off-peak travel times. For (road) public transport, sum of weighted averages over 10 representative corridors for public transport trips as a ratio of peak period travel times to estimated optimal travel time.

In the future when the density of air traffic is increased the indicator can be used to describe congestion in the same way as ground modes of transport. Currently, what is important is to quantify

[25]Donateo, T.; Ficarella, A. & Surdo, L. Energy consumption and environmental impact of Urban Air mobility IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2022*, 1226*, 012065
doi: 10.1088/1757-899x/1226/1/012065

[26] Sundarapandian, V. (2009). "7. Queueing Theory". Probability, Statistics and Queueing Theory. PHI Learning. ISBN 978-8120338449.

[27] Laurie A. Garrow, Brian J. German, Caroline E. Leonard, Urban air mobility: A comprehensive review and comparative analysis with autonomous and electric ground transportation for informing future research, Transportation Research Part C: Emerging Technologies, Volume 132, 2021, https://doi.org/10.1016/j.trc.2021.103377.

delays which may originate in different sources than other modes of transport, but the result is the same as the travel time will be affected similarly with conventional modes.

2.11 Energy efficiency

This indicator refers to the total energy use by urban transport per passenger km and tonne km (annual average over all modes).

Note:

- The passenger-kilometre (pkm) is a unit of measurement that is equivalent to transporting a passenger over a distance of one kilometre[28].
- A tonne-kilometre, abbreviated as tkm, is a unit of measure of freight transport which represents the transport of one tonne of goods (including packaging and tare weights of intermodal transport units) by a given transport mode (road, rail, air, sea, inland waterways, pipeline etc.) over a distance of one kilometre[29].

Air vehicles that will be used in UAM operations will be powered mainly by batteries, hydrogen fuel cells or combustion engines. Through this indicator the amount of electricity or fuel used will be calculated per pkm and tkm in order to explore how efficient UAM operations are. A comparison with other modes of transport would be a good idea in order for cities to assess the impact of each mode. In this way, smart cities will be able to make better decisions regarding the more sustainable use of different transport modes in their areas. The indicator "Energy efficiency" is suitable for this assessment with minor adjustments so that all UAM air vehicles and power options are included in the calculation. All in all, as Tojal & Paletti mention UAM should aim to be as energy efficient as possible[30]. From the design of vehicles and hubs to the selection of routes, it is important to make UAM as sustainable as possible. Still the energy consumption of airborne transport solution will be higher than the comparable ground-based solutions.[31] This disadvantage must be compensated by other advantages.

2.11.1 Sustainability

Except from energy efficiency in order to be able showcase how sustainable the mobility system of a city is, it is important to get a better understanding of the origin of the energy used among other things. Both for conventional modes of transport and UAM implementation, it is necessary to track the whether the electricity used was produced from wind and solar power or natural and coal for example. While a mixture of different production plants is expected, it is a good idea to understand

[28] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Passenger-kilometre

[29] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Tonne-kilometre_(tkm)

[30] Tojal, M., & Paletti, L. (2022). Is Urban Air Mobility Environmentally Feasible? Defining the Guidelines for a Sustainable Implementation of its Ecosystem. Transport Research Arena (TRA) Conference

[31] Donateo, T.; Ficarella, A. & Surdo, L. Energy consumption and environmental impact of Urban Air mobility IOP Conference Series: Materials Science and Engineering, IOP Publishing, **2022**, *1226*, 012065 DOI: 10.1088/1757-899x/1226/1/012065 URL: https://iopscience.iop.org/article/10.1088/1757-899X/1226/1/012065/pdf

better the percentage of clean energy sources used and make a ranking on the sustainability of the city's mobility system. This is applied both for energy needs of the used vehicles used and the infrastructure. **Another aspect to be examined is waste management and recycling in vehicle parts and equipment. Making ground and air mobility in urban areas as sustainable as possible should play a big role in future decisions with regards to mobility**. For these reasons, more research is required in order to define and benchmark the appropriate indicator for sustainability.

2.12 Opportunity for active mobility

This indicator refers to the infrastructure for active mobility, namely walking and cycling. The parameter calculation takes into account the length of roads and streets with pavements, bike lanes, 30 km/h (20 mp/h) zones and pedestrian zones related to total length of city road network (excluding motorways).

This indicator does not seem to be affected by future UAM activities. Thus, no extensions or adaptations are recommended for SUAMI at this stage, since this metric will not be the most helpful one for smart cities who wish to assess the impact of UAM in their areas. However, similarly with other city infrastructure, it is important to consider the opportunities for active mobility when building vertiports and other UAM related infrastructure.

2.13 Multimodal integration

An interchange is any place where a traveller can switch from one mode of travel to another, with a minimum/ reasonable amount of walking or waiting. The more modes available at an interchange, the higher the level of multimodal integration. The indicator is designed to capture the availability of multimodal interchanges and hubs, not the level of connectivity of the transport network. As such, while multimodal connections from metro to bus, or bus to tram (for example) are included, interchanges between distinct lines of the same transport mode are not (such as metro-metro, tram-tram, or bus-bus).

Regarding the definition of an interchange, the urban area can choose one of the 3 available options:

a) All interchange points, where the traveller can switch between the pre-defined modes of transport in the urban area.
b) Large hubs, where at least half of the urban area's transport modes can be found.
c) Long-distance interchanges, where at least one of the modes available must be primarily used to travel outside the geographical boundaries of the urban area studied. Using the list of modes included in the calculation, long-distance modes are: 1. Long-distance bus (coach), 2. Railway, 3. Park&Ride.

The list of all the transport modes in the urban area is predefined, and for each interchange a percentage will be calculated of the number of modes available at the interchange, divided by the total number of modes. The possible transport modes are:

1. Long-distance bus
2. Railway (all types of services)
3. Metro

4. LRT/tram
5. Local bus
6. Bicycle (bike sharing station)
7. Car sharing (station or reserved parking place)
8. Bicycle parking (specially designated and protected facility)
9. Park&Ride
10. Reserved taxi rank
11. Ferry

In order to include Urban Air Mobility in the assessment of multimodal integration in a city, it is important to make some additions to the list of possible transport modes. Since this indicator refers to people's mobility, the inclusion of air taxi as a transport mode is necessary to cover this new mode in the future. However, since the deployment of air taxis at a large-scale is estimated to take place at the last stage of UAM implementation, the calculation of this indicator for UAM might not be of great use for the cities until a few years into the future. Moreover, it is expected that along vertiports/droneports, logistic and transport hubs will be built as well as parking lots, charging stations, bus stations, e-bikes and scooters pick up stations or even metro and train stations. To measure the extent of multimodal integration in these transport hubs, the presented indicator can be used in the same way as described in the SUMI framework with minor adjustments.

2.14 Satisfaction with public transport

This indicator refers to the perceived satisfaction of using public transport. Specifically, the average reported satisfaction of moving in the urban area by public transport is measured.

In order to calculate this indicator, the city has to conduct a survey (with around 500 respondents) with the following questions:

1) Generally speaking, please tell me if you are [1] satisfied, [2] rather satisfied, [3] rather unsatisfied, [4] not at all satisfied, or [5] don't know/ not applicable (do not read out), with public transport (for example the bus, tram or metro) in your city or area.

2) Thinking about public transport in your city, based on your experience or perceptions, please tell me whether you [1] strongly agree, [2] somewhat agree, [3] somewhat disagree, [4] strongly disagree, or [5] don't know/ not applicable (do not read out), with each of these statements.

Public transport in your city is:

- Affordable
- Safe
- Easy to get
- Frequent (comes often)
- Reliable (comes when it says it will)

Satisfaction with public transport is an indicator that would be suitable in the assessment of UAM activities as part of the public transport network. In order to assess other elements of UAM operations that are not taken into consideration in this case (such as transportation of goods), rephrasing or adding questions to the survey would be a nice way of getting more accurate results. In general, the adjustment of this indicator to include UAM seems as a pretty straightforward process with minimal complexities in comparison to the aforementioned metrics.

2.15 Traffic safety active models

This indicator refers to fatalities of active modes users in traffic accidents in the city in relation to their exposure to traffic. In SUMI there are two indicators related to the number of fatalities (this one and the indicator "Road deaths"). The two indicators follow a different rationale:

1. According to the SUMI explanation "Road deaths" aims at providing urban areas with insights in the extent of the road safety problem, independent of urban area population size. It allows areas to identify whether or not road safety has reached a level which requires local measures, independent of the provenance of fatalities. As measures are concerned, it may be that urban areas can take full problem ownership (and implement their own measures) or could be required to contact other areas or administrative levels. This indicator helps identify such cases.

2. The present indicator (Traffic safety active models) aims at providing urban areas with insights into the extent to which a specific road safety problem exists for active modes (cycling, walking), independent of the number of active mode trips. It allows areas to gain insights regarding the safety/danger associated in particular to active modes. The choice to make a relative estimation over the number of trips stems from the correlation between (active mode) unsafety and the presence of few active mode trips. For example, unsafe biking infrastructure does not invite people to bike, hence leading to fewer biking trips. It is exactly this bias which is mitigated in indicator "Traffic safety active models ".

As presented above (section with regards to "Road deaths") in order to capture more accurately the risks of UAM in the assessment framework, the measurement of accidents caused by UAM activities is necessary. This can be done through the newly introduced indicator "Accidents related to UAM". Since, any type of accidents can be measured in the "Accidents related to UAM" metric, it is not recommended to use a specialized indicator such as "Traffic safety active models" for UAM activities. However, it is encouraged to include accidents of active mode users caused by UAM operations in the "Accidents related to UAM" metric.

2.16 Quality of public spaces

This indicator addresses the perceived satisfaction of public spaces.

In order to calculate this indicator, the city has to conduct a survey (with around 500 respondents) with the following questions:

Generally speaking, please tell me if you are [1] satisfied, [2] rather satisfied, [3] rather unsatisfied, [4] not at all satisfied, or [5] DK/NA (do not read out), with each of the following issues in your city or area.

1. Public spaces such as markets, squares, pedestrian areas.
2. Green spaces such as parks and gardens.

This indicator might fluctuate depending on the location and size of the infrastructure that will be built to accommodate UAM operations. For example, people previously satisfied with the quality of public spaces might change their opinion if a vertiport replaces a park in their area. Similarly with the indicator "Satisfaction with public transport", the implementation of this indicator to a UAM assessment framework is recommended, as it shows low complexity in its integration.

In the context of UAM it is important to take into account whether citizens will feel safe and at ease when drones are flying over public space. Questions regarding whether drone presence will cause them anxiety or stress are necessary in order to assess individuals' overall health. These questions can be either included in the "Quality of public spaces" indicator or a new indicator may be needed. More studies are needed in order to assess whether a new metric is necessary and how it should be defined.

2.17 Urban functional diversity

Functional diversity refers to a mix of spatial functions in an area, creating proximity of mutual interrelated activities. For the parameter calculation the territory of the city is divided in grids of 1 km x1 km.

The examined functions in each grid are:

1) Business (industry, offices, logistics, etc.)
2) Hospital and medical services
3) General services (post, administration, etc.)
4) Schools
5) Commercial (shops, supermarkets)
6) Sports and recreation
7) Residential (families)
8) Residence for elderly people
9) Parks and greens

In the context of UAM, this indicator does not seem essential for the assessment of UAM impact on a city. This is the case since not any specific information or comparison about the effect of UAM activities or other modes of transport is provided. As a non-core indicator, it can act as a complementary element of the framework. Through this indicator more information about the type of activities that take place in certain parts of the city. This can be a useful guide when planning for mobility services and infrastructure placement. Consequently, the indicator "Urban functional diversity" can be used as it is in SUAMI with almost zero adjustments.

2.18 Commuting travel time

This indicator refers to the duration of commute to and from work or an educational establishment, using any types of modes.

In order to calculate this indicator, the city has to conduct a survey (500 respondents recommended) with the following questions:

1. What were your modes of transport for your commute? (Car, Motorcycle, Public Transport, Ferry, Bike, Walking, Car & PT, Bike & PT, Walk & PT)
2. Could you please give us the following details about your main commute that you described above:
    - What was the average travel distance (one way) in km (per mode)
    - What was the average travel time to work in minutes (per mode)
    - What was the average travel time to return home in minutes (per mode)

Alternatively, the city can use data available in a published report following a mobility survey, where daily trips have been aggregated and reported according to the main mode of travel used, and the reported purpose of the trip.

This indicator would be useful in the case that air taxis or even air buses become a service available at a large scale and is accessible to the majority of citizens. Since this scenario can be only a vague hypothesis at this stage of UAM implementation it is recommended for cities not to examine this indicator at this early stage of deployment. However, in the future if it is needed it could be an appropriate metric to quantify the commuting travel time in the same way as conventional modes of transport.

2.19 Mobility space usage

This indicator addresses the proportion of land use, taken by all city transport modes, including direct and indirect uses.

This indicator aims to capture all transport space. Hence, other aspects, such as tram tracks, bus lanes, logistics centres, etc. shall be included, if not already accounted for in the road space surface. With respect to "roads", if there is no precise data on street surfaces, standard widths can be assumed. Urban areas are encouraged to consider at least parking lots and petrol stations for representative results. To estimate the parking space usage, it is possible to multiply the number of parking spaces by their surface (~13 to 18 m^2/car). To estimate the space used by petrol stations, it is possible to consider the average surface of a petrol station (e.g., in Brussels it is 800 m^2) and multiply it by the number of petrol stations registered. On-street parking is considered direct use, and is already included in the road space, unless you have more precise data on streets that differentiates between parking usage and mobility usage. All parking provided for public use is considered public parking, and accounted by parking space surface, even on multi-storey car parks. Private parking is all parking that is not open to the public, such as residential and office parking garages. Similarly, it is accounted by parking space surface. "Stations" are all stations that are not already accounted for when calculating the direct use. This depends on the available data. In some cases, the surface area for roads might already include mass rapid transit stations, tram stations and railways might already include stations.

This indicator can be expanded in order to include the land taken for the implementation of U-space and UAM activities, as well. Similarly with other modes of transport in order for UAM activities to take place in the air, the necessary ground infrastructure has to be established. The amount of land that UAM infrastructure occupies such as vertiports, stations, parking near the vertiports, take-off and landing areas etc will need to be taken into account. The impact of UAM infrastructure can be shown both with "Mobility space usage" and "Quality of public spaces" indicators. Another point would be the inclusion of vertical space in the "Mobility space usage" and "Quality of public spaces" indicators. Considering how much space in the air UAVs occupy and the amount of visual pollution caused by UAM activities is another important topic for UAM impact assessment.

2.20 Security

This indicator refers to the perceived risk of crime and passenger security in urban transport. The calculated parameter measures the reported perception about crime-related security in the city transport system (including freight and public transport, public domain, bike lanes and roads for car traffic and other facilities such as car or bike parking).

The questions cover the reported perception about crime-related security in city transport by general population based on the following topics:

- In public transport
- In public transport in the evening
- Walking
- Walking on the street at night
- Cycling
- Cycling at night
- Car theft
- Risk of crime in car traffic

All these aspects of security are important issues for the wellbeing of citizens. In the context of UAM it is important to take into account whether citizens will feel safe when drones are flying over their cities. Questions regarding whether drone presence will cause them anxiety or stress are necessary in order to assess individuals' overall health. On top of physical security it is crucial to expand the current metric into the categories of cybersecurity and privacy, since with the implementation of UAVs concerns arise regarding cyberattacks and data protection. In this way, the appropriate precautions can be taken from both industry's side and public authorities in order to prevent these types of violations.

2.20.1 Cybersecurity

According to Tang (2021) UAVs may be vulnerable to different cyberattacks such as jamming, spoofing, man-in-the-middle, deauthentication, eavesdropping, DoS, etc. In order to deal with such attacks a combination of anti-jamming technology, secondary systems and encryption should be used to allow for secure operations of a scalable UAM environment[32].

At this stage of UAM implementation it is essential to assess the level of cybersecurity provided by the available technologies. For this reason, the addition of a new indicator that addresses these issues is suggested. This indicator could be defined in many ways. An example would be the calculation of security incidents or intrusion attempts. At this stage more research is necessary in order to be able to tell what would be the most practical way to quantify the level of cybersecurity present at any given moment. In any case, the latest industry KPIs for cybersecurity should be taken into account in order to be able to adequately identify the level of cybersecurity provided.

2.20.2 Privacy

Privacy is another important issue that needs to be quantified. Cameras will be required to remotely secure and supervise the vertiports, so some data protection rights (e.g. GDPR) may be infringed. Moreover, the presence of drones with cameras flying close to private properties (e.g., for delivering goods) raise concerns regarding the privacy implications of their use. For smart cities it is important to ensure the privacy of their citizens during UAM and U-space operations. A metric regarding the privacy violations reported is essential in order to assess the impact of UAVs presence in urban areas. Similarly with cybersecurity, this indicator can be defined in various ways. More research is needed in order to be able to quantify this aspect of UAM in the most suitable way.

2.21 Maturity

This new indicator is related to the readiness of new emerging technologies. It is key in order to confirm or predict accurately when the service is ready with regards to:

1. Regulation (e.g., flight authorizations)
2. Infrastructure (e.g., CNS equipment, vertiports) & Technology (e.g. batteries, engines, software)
3. Personnel (e.g., flight crew, ANSP, CISP, USSP, supervisors)

The idea behind this indicator is the creation of a checklist of necessary elements in each category in order for a city to easily assess its readiness to deploy UAVs in the urban space.

2.21.1 Regulation

The UAM regulatory framework will play a significant role in the UAS operations in urban airspace. EASA has taken some steps towards establishing some building blocks towards the creation of the UAM regulatory framework[33]. These include airworthiness, operations and pilot testing, airspace integration

[32] Anthony C. Tang. A Review on Cybersecurity Vulnerabilities for Urban Air Mobility. AIAA 2021-0773. Cybersecurity for Intelligent Aerospace Systems II. https://doi.org/10.2514/6.2021-0773

[33] https://www.easa.europa.eu/en/domains/urban-air-mobility-uam

and R&D through projects like SAFIR-Med. Without the proper regulation, UAM activities cannot take place. However, bureaucracy can make things more complicated especially for those with limited experience in relevant fields.

Since SUAMI is a framework addressed to city employees it is important to provide practical tools for the assessment of UAM maturity in their area. A checklist containing all necessary certifications for all different components of UAM value chain (staff, equipment, UAV certification), and flight permit steps (authorisation, coordination with ATM, clearance based on meteorological suitability) could be of great help in cities attempting to realize whether their area is ready to deploy such services. The value of the indicator would declare the level of the city's maturity in terms of regulation (e.g., not ready for deployment, close to deployment, ready for deployment).

2.21.2 Infrastructure

In the same way a checklist for infrastructure and necessary equipment could include:

1) Infrastructure for take-off and landing of drone
2) 4G-5G coverage
3) GNSS (global navigation services)
4) Navaids (navigations aids)
5) Visual aids (lights, airground lights, QR code or any image pattern)
6) HD cameras for secure area and operation
7) Warehouse for MRO, hangar for large eVTOLs
8) Power distribution for recharge and operations
9) Local meteorological data (AWOS, EG wind sensors)
10) Waste management for recycling batteries
11) Proximity sensors (basic radar) for landing area and surveillance of UAS also non-collaborative
12) Communication with ATM for coordination and data exchange

2.21.3 Personnel

1) This indicator aims to assess the availability of trained and certified resources (pilots, MRO, supervisors, etc). The list of necessary personnel could include:
2) maintenance and repair staff
3) operators
4) ground operators
5) remote pilots
6) supervisors
7) flights planners and authorisers

2.22 Availability of service

Another useful indicator for UAM deployment could be the "Availability of service". In this metric, the downtime to recharge the UAV, the time to reserve the airspace and to issue a flight plan and receive authorization, the availability of take-off/landing slots, the ground handling and the reparations and exchange of spare parts and similar situations can be included. In cases of medical emergencies, it is essential to offer fast, reliable and precise services. This includes both personnel mobility (doctors, nurses etc) and transfer of supplies (AEDs, medicine, blood etc). For this reason, it is important for city employees to understand when a UAV can be used based on the shown availability.

2.23 Modal split

The modal split, also known as modal share or mode choice, is a common and widespread indicator in transportation engineering to evaluate transportation behaviour. In brief, the modal split shows the percentage of travellers using a particular mode of transport compared to the ratio of all trips made.

Definition
For passenger mobility: Modal split according to passenger kilometres ran Modal split according to vehicle kilometres ran Modal split according to the number of trips ran Modal split according to the number of vehicle kilometres per trip ran
For freight: Modal split according to goods vehicles kilometres ran Modal split according to freight tonnes kilometres ran

Since UAVs can be used both for goods and people's mobility it is important to include the relevant data and conduct the appropriate calculations for the modal split indicator in order to include UAM operations.

3 Discussion

According to the analysis conducted above, it would be safe to say that the applicability table of SUMI framework to UAM activities (introduced by Tojal & Paletti[34]) can be modified as shown in Table 3.

Table 3 Summary of SUMI applicability to a UAM context

SUMI Indicator	Definition	Applicability to SUAMI
Core indicators		
Affordability of public transport for the poorest group	Share of the poorest quartile of the population's household budget required to hold public transport (PT) passes (unlimited monthly travel or equivalent) in the urban area of residence.	High
Accessibility of public transport for mobility-impaired groups	This indicator determines the accessibility of public transport services to persons with reduced mobility.	High
Air pollutant emissions	Air pollutant emissions of all passenger and freight transport modes (exhaust and non-exhaust for PM2.5) in the urban area	High
Noise hindrance	Hindrance of population by noise generated through urban transport.	High
Road deaths	Road deaths by all transport accidents in the urban area on a yearly basis.	Medium
Access to mobility services	Share of population with appropriate access to mobility services in their area (public transport).	High
GHG Emissions	Well-to-wheels GHG emissions by all urban area passenger and freight transport modes	High
Congestion and delays	Delays in road traffic and in public transport	Medium
Energy efficiency	Total energy use by urban transport per passenger km and tonne km (annual average over all modes).	High

[34] Tojal, M., & Paletti, L. (2022). Is Urban Air Mobility Environmentally Feasible? Defining the Guidelines for a Sustainable Implementation of its Ecosystem. Transport Research Arena (TRA) Conference

SUMI Indicator	Definition	Applicability to SUAMI
Opportunity for Active Mobility	Infrastructure for active mobility, namely walking and cycling	Low
Multimodal integration	The more modes available at an interchange, the higher the level of multimodal integration.	High
Satisfaction with public transport	The perceived satisfaction of using public transport.	High
Traffic safety active modes	Fatalities of active modes users in traffic accidents in the city in relation to their exposure to traffic	Low
Non-core indicators		
Quality of public spaces	The perceived satisfaction of public spaces.	High
Urban functional diversity	Functional diversity refers to a mix of spatial functions in an area, creating proximity of mutual interrelated activities.	Medium
Commuting travel time	Duration of commute to and from work or an educational establishment, using any types of modes.	Medium
Mobility space usage	Proportion of land use, taken by all city transport modes, including direct and indirect uses.	High
Security	The perceived risk of crime and passenger security in urban transport.	Medium
Modal split	The percentage of travellers using a particular mode of transport compared to the ratio of all trips made	High

Except for the discussion regarding the applicability, modifications, and adjustments of existing indicators that are necessary in order to perform a UAM impact assessment, the introduction of new KPIs was also examined. The summary of the new framework that includes UAM activities is shown in Table 4.

Table 4 SUAMI framework summary

Sustainable UAM Indicators
Affordability of public transport for the poorest group

Sustainable UAM Indicators
Accessibility of public transport for mobility-impaired groups
Air pollutant emissions
Noise hindrance
Road deaths - Accidents related to UAM - Accidents avoided because of UAM
Access to mobility services
GHG Emissions
Congestion and delays
Energy efficiency - Sustainability
Opportunity for Active Mobility
Multimodal integration
Satisfaction with public transport
Traffic safety active modes
Quality of public spaces
Functional diversity
Commuting travel time
Mobility space usage
Security - Cybersecurity - Privacy
Maturity - Regulation

Sustainable UAM Indicators
- Infrastructure - Personnel
Availability of service
Modal split

Future Work

The next steps going forwards would be the research on gaps or points missing in the presented framework. It is important to continue the research in order to provide cities with a holistic approach of KPIs that cover all the important aspects of their mobility system. Moreover, large-scale testing and validation is necessary in order to increase the robustness of SUAMI and its reliability. More elaboration is crucial for each indicator with precise definition and examples so that the proposed adjustments are included and the framework's improvement. Newly-introduced indicators should include calculation instructions in order to be easily measurable. Lastly, in order for the framework to become as user friendly as possible it is important to develop an easy-to-use digital tool, such as a web app, so that city employees will be able to extract the information provided by the framework in a more effective manner.

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5 Annex

A. SUMI framework

- **Affordability of public transport for the poorest group**

Share of the poorest quartile of the population's household budget required to hold public transport (PT) passes (unlimited monthly travel or equivalent) in the urban area of residence and is calculated as presented below.

$$SCORE = \frac{(Price\ monthly\ PT\ pass * average\ household\ size)}{income\ of\ the\ 25\%\ poorest\ residents\ of\ the\ urban\ area}$$

Additionally, the share of Public Transport passes out of the reported expenditure for transport services (and transport-related insurance) should be calculated. The data on transport services expenses is normally also available with the household expenditure survey.

- **Accessibility of public transport for mobility-impaired groups**

This indicator determines the accessibility of public transport services to persons with reduced mobility.

Such vulnerability groups include those with visual and audial impairments and those with physical restrictions, such as pregnant women, users of wheelchairs and mobility devices, the elderly, parents and caregivers using buggies, and people with temporary injuries.

The proportion of total public transport services where accessibility has been facilitated for individuals who would otherwise be unable to use them.

$$ARMG = \frac{\sum_i modal\ weight_i * ACC_i}{100}$$

With:
$i = mode$
$modal\ weight_i = \frac{users\ of\ mode_i}{total\ users} * 100$
$ACC_i = accessibility\ of\ mode\ i = \underline{features}_{ij}$
$\underline{features}_{ij} = average\ of\ accessibility\ feature\ j\ of\ mode\ i$
With
$feature_j = \%\ of\ feature\ which\ is\ accessible = \frac{\#\ accessible}{total}\ irrespective\ of\ operator$

- **Air pollutant emissions**

This indicator shows air pollutant emissions of all passenger and freight transport modes (exhaust and non-exhaust for PM2.5) in the urban area.

$$EHI = \frac{\sum_{s} \quad Eeq_s * \left(\sum_{ij} \quad A_{ij} * \left(NE_i + \sum_{ck} \quad S_{ck} * E_{ijkcs} * I_k\right)\right) * 1000}{cap}$$

EHI = Emission harm equivalent index [kg PM2.5 eq./cap per year]
Eeqs = Emission substance type PM2.5 equivalent health impact value [factor]
Eijkcs= Emission of pollutants per vkm driven by transport mode i and vehicle type j for fuel type k, emission class c (g/km)
Aij= Activity volume (distance driven by transport mode i and vehicle type j) [million vkm per year]
Sijk = Share of fuel type k per vehicle type j and per transport mode i [fraction]
Cijkc = Share of emission class c per fuel type k per vehicle type j and per transport mode i [fraction]
NEsi = Non-exhaust emissions of pollutant i per distance driven [g/km] (=0 for NOx)
cap = Capita or number of inhabitants in the urban area [#]
k = Energy type (petrol, diesel, bio-fuel, electricity, hydrogen, etc.) [type]
i = Vehicle type transport mode (passenger car, tram, bus, train, motorcycle, inland vessel, freight train, truck, etc.) [type]
j = Vehicle class (if available specified by model (e.g. SUV, etc.) [type]
s = Type of substance [type] limited to NOx and PM2.5
c = Emission class (euro norm) [type]
multiplication by 1000 to transform units from g to kg

- **Noise hindrance**

This indicator measures the hindrance of population by noise generated through urban transport.

The calculated parameter is the percentage of population hindered by urban transport noise, based on hindrance factors for noise exposure data of population by noise bands.

$$NI = \frac{\left(\sum_{i} \quad HFLden_i\right) * \left(\sum_{m} \quad W_{im} * P_{im}\right)}{\sum_{im} \quad W_{im} * P_{im}}$$

NI = Noise hindrance index [% of population]
i = Average noise Lden of noise band [#]
Pim = Population exposed to noise band i for mode m (road, rail, airplane) [#]
Wim = High Annoyance weight factor for mode m and noise band i [%]
HFLDeni = Hindrance factor at average Ldeni of the related noise band i
LDen= Average sound pressure level over all days, evenings and nights in a year (in this compound indicator the evening value gets a penalty of 5 dB and the night value of 10 dB).

- **Road deaths**

This indicator refers to the road deaths by all transport accidents in the urban area on a yearly basis.

The parameter value is the number of deaths within 30 days after the traffic accident as a corollary of the event per annum caused by urban transport per 100,000 inhabitants of the urban area.

$$FR = \frac{\sum_i K_i * 100\,000}{Cap}$$

FR = Fatality rate [# per 100,000 urban area population per year]
Ki = Number of persons killed in transport mode i [# per year]
Cap = Capita or number of inhabitants in the urban area [#]
i = Transport mode

- **Access to mobility services**

This indicator refers to the share of population with appropriate access to mobility services (public transport).

The parameter calculated is the percentage of population with appropriate access to public transport (bus, tram, metro, train).

$$AccI = \frac{\sum_i PR_i * W_i}{cap}$$

AccI = Appropriate access index [% of population]
PRi = Number of people living within the access typology zone i, identified by combination of PT accessibility level.
"Wi = Weight to identify if the accessibility to mobility services is appropriate (depending on the combination of PT accessibility level). The weight is differentiated for small (i.e. less than 100,000 inhabitants) or large urban areas.
The weight Wi is predefined (not modified by the user) and identifies if the accessibility is appropriate as follows:
- it is = 1 where it is fully appropriate
- it is = 0.5 where it isn't fully appropriate
- it is = 0 where it isn't appropriate"
Cap = Capita or number of inhabitants in the urban area [#]

- **Greenhouse gas emissions**

This indicator refers to Well-to-wheels GHG emissions by all urban area passenger and freight transport modes.

$$G = \frac{\left(\sum_{ij} A_{ij} * \left(\sum_{ck} S_{ijk} * C_{ijkc} * I_{jk} * (T_k + W_k) * (1 + F_{ijk})\right)\right) * 1000}{cap}$$

G = Greenhouse gas emission [tonnes CO2(eq.) /cap. Per year]
Tk = Tank to wheel CO2 emission per energy type unit considered [kg/ℓ or kg/kWh]
Wk = Well to tank CO2 equivalent emission per energy type unit considered [factor]

Aij= Activity volume (distance driven by transport mode i and vehicle type j) [million vkm per year]
Sijk = Share of fuel type k per vehicle type j and per transport mode i [fraction]
Cijkc = Share of emission class c per fuel type k per vehicle type j and per transport mode i [fraction]
Ijk = Energy intensity per distance driven for vehicle type j and fuel type k [ℓ/km or MJ/km or kWh/km]
Cap = Capita or number of inhabitants in the urban area [#]
Fijk = Non-CO2 GHG correction (CO2 equivalent) [factor]
k = Energy type (petrol, diesel, bio-fuel, electricity, hydrogen, etc.) [type]
i = Transport mode (passenger car, tram, bus, train, motorcycle, inland vessel, freight train, truck, etc.) [type]
j = Vehicle class (if available, specified by model (e.g. SUV, etc.) [type]
multiplication by 1000 to transform unit from kg to tonnes

- **Congestion and delays**

This indicator refers to the delays in road traffic and in public transport during peak hours compared to off peak travel (private road traffic) and optimal public transport travel time (public transport).

The parameter calculates the weighted sum of delays over representative corridors for road private and public transport. For road private transport, sum of weighted averages over 10 representative corridors for car trips as a ratio of peak period travel times to off-peak travel times. For (road) public transport, sum of weighted averages over 10 representative corridors for public transport trips as a ratio of peak period travel times to estimated optimal travel time.

$$CD_{ij} = (MS_{road} * (\frac{\sum_{i=1}^{10} \quad (\frac{CT_i * PHT_i}{FFT_i}))}{\sum_{i=1}^{10} \quad CT_i} + MS_{PT} * \frac{\sum_{j=1}^{10} \quad \left(\frac{PT_j * PTPHT_j}{PTOT_j}\right)}{\sum_{j=1}^{10} \quad PT_j}$$

CDij = Congestion and delay index (percentage delay during peak hours) [% of delay]
CTi = Number of car trips during peak hours on main road corridor i [#]; If this information is missing, the number of lanes could be used as an alternative weighing factor
PHTi = Car travel time during peak hours on main road corridor i [minutes]
FFTi = Off-peak car travel time on main road corridor i [minutes]
PTj = Number of public transport trips during peak hours on transit corridor j [#]
PTPHTj = Public transport travel time during peak hours on main road corridor i [minutes]
PTOTj = Optimal Public Transport travel time on main road corridor i [minutes]
MSroad = Modal share road [%] (modal share as the number of persons which are travelling, modal share when only considering private car and PT as possible modes)
MSpt= Modal share public transport [%] (modal share as the number of persons which are travelling, modal share when only considering private car and PT as possible modes)

- **Energy efficiency**

Total energy use by urban transport per passenger km and tonne km (annual average over all modes).

$$E = \frac{(\sum_{ij} \quad A_{ij}(\sum_{k} \quad S_{jk} * I_{jk} * EC_{k}))}{TV_{pass} + \left(\frac{TV_{fre}}{8}\right)}$$

E = Energy consumption rate [MJ/km]
TVpass = Transport volume passenger transport (passenger km) [million passenger km]
TVfre = Transport volume freight transport [million tonne km]
Sjk = Share of fuel type k per vehicle type j [fraction]
Ijk = Energy intensity per distance driven for vehicle type j and fuel type k [l/km or MJ/km or kWh/km]
Aij= Activity volume (distance driven by transport mode I and vehicle type j) [million km per year]
ECk = Fuel energy content for fuel k [MJ/l or MJ/kg]
k = Fuel type [type]
i = Transport mode (passenger car, tram, bus, train, motorcycle, inland vessel, freight train, truck, etc.) [type]
j = Vehicle class (if available specified by model e.g. SUV, etc.) [type]

- **Opportunity for active mobility**

Infrastructure for active mobility, namely walking and cycling.

The length of roads and streets with pavements, bike lanes, 30 km/h (20 mp/h) zones and pedestrian zones related to total length of city road network (excluding motorways).

$$R_{am} = \frac{L_{pv} + L_{bl} + L_{z30} + L_{pz}}{L_{rn}}$$

Ram = Share of road length adapted for active mobility [n]
Lpv = Length of road network with pavements (not if in a pedestrian zone) [km]
Lbl = Length of road network with bike lanes (not if in a 30 km/h zone) [km]
Lz30 = Length of road network in 30 km/h zone [km]
Lpz = Length of pedestrian zone(s) [km]
Lrn = Total length of city road network (excluding motorways) [km]

- **Multimodal integration**

Index between 0 and 1 showing the average level of multimodal connection of the interchange points within an urban transport network.
The indicator is designed to capture the availability of multimodal interchanges and hubs, not the level of connectivity of the transport network. As such, while multimodal connections from metro to bus, or bus to tram (for example) are included, interchanges between distinct lines of the same transport mode are not (such as metro-metro, tram-tram, or bus-bus).

The data will be collected by analysing the network characteristics of the public transport operators, as well as information from the local urban area administration regarding the facilities available at interchanges in the urban area.
The list of all the transport modes in the urban area is predefined, and for each interchange a percentage will be calculated of the number of modes available at the interchange, divided by the total number of modes. The possible transport modes are:

> 1. Long-distance bus
> 2. Railway (all types of services)
> 3. Metro
> 4. LRT/tram
> 5. Local bus
> 6. Bicycle (bike sharing station)
> 7. Car sharing (station or reserved parking place)*
> 8. Bicycle parking (specially designated and protected facility)
> 9. Park&Ride**
> 10. Reserved taxi rank***
> 11. Ferry"

A place, or structure, can be considered an interchange if switching from one mode of travel to the other(s) can be done in a relatively smooth way, without having to overcome, cross, travel over undue barriers. Examples of such barriers include: rivers and other bodies of water without a nearby bridge, highways and heavy traffic roads without nearby safe crossing facilities, fences, etc. Switching from one mode of transport to another within the interchange should only require walking (including up/ down a flight of stairs in the case of multi-storey facilities). Furthermore, the walking distance should be ""designed"" to be short: as a guideline, the average distance between bus stops is approximately 500m, which should be considered a maximum threshold.
An interchange does not have to be (although in practice most often it is) a building especially built for this purpose, a good rule of thumb for the interchange selection and deciding which modes serve it is whether the names of the stops are identical for the different modes of transport."
*For the availability of car sharing services, there is a need to take into account the different business models available. The main 3 business models are station-based, free-floating and peer-to-peer. An interchange point is considered to have car sharing services available if at least 3 parking places are reserved for car sharing services. The focus here is the space reserved for car sharing, not whether each car sharing service is represented at the particular interchange, and additionally no evaluation should be made of whether the car sharing system is "easy to access" or not.
**A Park&Ride facility is a parking lot where a certain number of parking places are reserved for daily parking by commuters.
***A taxi rank is considered to be any area where "regular" cars are not allowed to stop and where only taxis are allowed to park while waiting for customers.

- **Satisfaction with public transport**

The average reported satisfaction of moving in the urban area by public transport.

$$\underline{SAT} = \frac{\sum_m \quad \underline{ASPECT_m}}{m} \; m\ being\ the\ number\ of\ aspects\ (dimensions)$$

$\underline{ASPECT_m} =$

$\sum_h \quad \underline{AGREE_{h,m}} h\ being\ the\ four\ replies\ on\ the\ perception\ of\ crime\ related\ security$

(Strongly agree, somewhat agree, somewhat disagree and strongly disagree)

$$\underline{AGREE_{h,m}} = \frac{\#\ times\ agreement\ h\ was\ used\ in\ sample\ for\ aspect\ m}{\#\ people\ sample\ of\ aspect\ m - \#\frac{DK}{NA}\ answers\ in\ sample\ m} x C_h$$

$C_{h=strongly\ agree} = 10;\ C_{h=somewhat\ agree} = 6.66;\ C_{h=somewhat\ disagree} =$
$3.33;\ C_{h=strongly\ disagree} = 0$

Q1.1 Generally speaking, please tell me if you are [1] satisfied, [2] rather satisfied, [3] rather unsatisfied, [4] not at all satisfied, or [5] don't know/ not applicable (do not read out), with public transport (for example the bus, tram or metro) in your city or area.

Q6 Thinking about public transport in your city, based on your experience or perceptions, please tell me whether you [1] strongly agree, [2] somewhat agree, [3] somewhat disagree, [4] strongly disagree, or [5] don't know/ not applicable (do not read out), with each of these statements.
Public transport in your city is:
Q6.1 Affordable
Q6.2 Safe
Q6.3 Easy to get
Q6.4 Frequent (comes often)
Q6.5 Reliable (comes when it says it will)

- **Traffic safety active models**

Number of deaths within 30 days after the traffic accident as a corollary of the event per annum caused by active modes of transport, per billion trips per annum (exposure).

$$RF = \frac{\sum_i \quad K_i * 1000}{Exp_i}$$

RFi = Risk factor for transport mode i [# per billion trips per year]
Ki = Number of persons killed within 30 days after the traffic accident as a corollary of the event in transport mode i [# simple average over the last 3 years for which data is available]
Expi = Exposure, defined as number of trips (in million) [# per year]
i = Transport mode (pedestrian, bicycle) [type]

- **Quality of public spaces**

The average reported satisfaction of green and non-green public spaces.

$\underline{SAT} = \frac{\sum_m \underline{\underline{ASPECT_m}}}{m}$ m $being$ the $number$ of $aspects$ $(dimensions)$

$\underline{ASPECT_m} =$

$\sum_h \underline{AGREE_{h,m}} h$ $being$ the $four$ $replies$ on the $perception$ of $crime$ $related$ $security$

(Strongly agree, somewhat agree, somewhat disagree and strongly disagree)

$\underline{AGREE_{h,m}} = \frac{\#\ times\ agreement\ h\ was\ used\ in\ sample\ for\ aspect\ m}{\#\ people\ sample\ of\ aspect\ m - \#\frac{DK}{NA}\ answers\ in\ sample\ m} x C_h$

$C_{h=strongly\ agree} = 10;\ C_{h=somewhat\ agree} = 6.66;\ C_{h=somewhat\ disagree} = 3.33;\ C_{h=strongly\ disagree} = 0$

Generally speaking, please tell me if you are [1] satisfied, [2] rather satisfied, [3] rather unsatisfied, [4] not at all satisfied, or [5] DK/NA (do not read out), with each of the following issues in your city or area.
Q1.6 Public spaces such as markets, squares, pedestrian areas.
Q1.7 Green spaces such as parks and gardens.

- **Urban functional diversity**

Functional diversity refers to a mix of spatial functions in an area, creating proximity of mutual interrelated activities.

Parameter
Average presence (value 1) or not (value 0) out of 10 spatial functions related to daily activities except for work in grids of 1 km x 1 km.

The territory of the city is divided in grids of 1 km x1 km.
The presence of 10 functions (see comments) is indicated in each of the grids and weighted with the population living in the urban area.

$$FDS = \sum_{ij} Pop_i(\forall Pres_{ij} > 0)$$

where:
FDS = Functional diversity score [%]
Popi = Fraction of population in the urban area in zone i [fraction]
Presij = Presence of functions j in zone i (it is equal to 1 if there is a presence; it is equal to 0 if there is not a presence) [binary]
9 functions are predefined as follows:
1) Business (industry, offices, logistics, etc.)
2) Hospital and medical services
3) General services (post, administration, etc.)

4) Schools
5) Commercial (shops, supermarkets)
6) Sports and recreation
7) Residential (families)
8) Residence for elderly people
9) Parks and greens

This indicator is complementary to indicator "commuting travel time". Additionally, it also measures the proximity from the home of other functions than workplaces, such as schools, services, shops.

- **Commuting travel time**

Duration of commute to and from work or an educational establishment, using any types of modes.

$$\underline{Tcom} = \sum_i \frac{Tout_i}{n} + \sum_i \frac{Treturn_i}{n}$$

Tcom: Average commuting travel time [minutes/day]
Touti: Commuting time to work/school by person i [minutes/day]
Treturni: Commuting time to home by person i [minutes/day]
n: number of persons in survey

- **Mobility space usage**

Proportion of land use, taken by all city transport modes, including direct and indirect uses.

Parameter
Square meters of direct and indirect mobility space usage per capita.

$$LUM = \frac{\sum_i \quad (LD_i + LI_i)}{Cap}$$

LUM = Land use for mobility applications [ha]
LDi = Direct Land use for category i [ha]
LIi = Indirect Land use for category i [ha]
i = Mobility mode [#]
Cap = Capita or number of inhabitants in the city [#]

- **Security**

Reported perception about crime-related security in the city transport system (including freight and public transport, public domain, bike lanes and roads for car traffic and other facilities such as car or bike parking).

$$\underline{SEC} = \frac{\sum_m \underline{SEC_m}}{m} \; m \; being \; the \; number \; of \; aspects \; (dimensions)$$

$$\underline{SEC_m} = \sum_h \underline{SEC_{h,m}} h \; being \; the \; four \; replies \; on \; the \; perception \; of \; crime \; related \; security$$

(Very safe, safe, unsafe and very unsafe)

$$\underline{SEC_{h,m}} = \frac{\# \; times \; agreement \; h \; was \; used \; in \; sample \; for \; aspect \; m}{\# \; people \; sample \; of \; aspect \; m - \# \frac{DK}{NA} \; answers \; in \; sample \; m} x C_h$$

$$C_{h=very\;safe} = 10; \; C_{h=safe} = 6.66; \; C_{h=unsafe} = 3.33; \; C_{h=very\;unsafe} = 0$$

Public Transport
Q1: Do you feel unsafe because of potential physical attacks in the following situations? [1] Very safe, [2] Safe, [3] Unsafe and [4] Very unsafe:
Q1.1: Waiting for public transport at the stop or at the station during daytime
Q1.2: Waiting for public transport at the stop or at the station during nighttime
Q1.3: Being on board public transport during daytime
Q1.4: Being on board public transport during nighttime
Cars
Q2 Do you feel unsafe because of potential physical attacks in the following situations? [1] Very safe, [2] Safe, [3] Unsafe and [4] Very unsafe:
Q2.1: Driving a car during daytime
Q2.2: Driving a car at night
Q3 How much do you feel afraid of the following situations that might happen? [1] Very safe, [2] Safe, [3] Unsafe and [4] Very unsafe:
Q3.1: Your car being stolen during the day?
Q3.2: Your car being stolen at night?
Q3.3: Your belongings being stolen from your car during the day?
Q3.4: Your belongings being stolen from your car at night?
Motorcycles
Q4 How much do you feel afraid of the following situations that might happen? [1] Very safe, [2] Safe, [3] Unsafe and [4] Very unsafe:
Q4.1: Your motorcycle/scooter being stolen during the day?
Q4.2: Your motorcycle/scooter being stolen at night?
Q4.3: Your belongings being stolen from your motorcycle/scooter during the day?
Q4.4: Your belongings being stolen from your motorcycle/scooter at night?
Q5 Do you feel unsafe because of potential physical attacks in the following situations? [1] Very safe, [2] Safe, [3] Unsafe and [4] Very unsafe:
Q5.1a: Driving a motorcycle/scooter during daytime
Q5.2a: Driving a motorcycle/scooter at night
Cycling
Q6 Do you feel unsafe because of potential physical attacks in city streets when doing the following? [1] Very safe, [2] Safe, [3] Unsafe and [4] Very unsafe:
Q6.1: Riding a bike during daytime
Q6.2: Riding a bike at night

Walking
Q7 Do you feel unsafe because of potential physical attacks in city streets when doing the following? [1] Very safe, [2] Safe, [3] Unsafe and [4] Very unsafe:
Q7.1: Walking during daytime
Q7.2: Walking at night

- **Modal split**

Modal split according to passenger kilometres ran: total number of passenger kilometres ran for each mode within an urban area compared to the total number of passenger kilometres ran for all modes within an urban area.
Modal split according to vehicle kilometres ran: total number of vehicle kilometres ran for each mode within an urban area compared to the total number of vehicle kilometres ran for all modes within an urban area.
Modal split according to number of trips: total number of trips for each mode within an urban area compared to the total number of trips for all modes within an urban area.
Modal split according to goods vehicles kilometres ran: total number of goods vehicles kilometres ran for each goods vehicles mode within an urban region compared to the total number of goods vehicles kilometres ran for all goods vehicles modes within an urban area.
Modal split according to vehicle tonnes kilometres ran: total number of goods tonnes kilometres ran for each goods transport mode within an urban area compared to the total number of vehicle tonnes kilometres ran for all goods transport modes within an urban area.