Bauhaus Luftfahrt
Neue Wege.

Technische Universität München

Technische Hochschule Ingolstadt

Gefördert durch

Bayerisches Staatsministerium für
Wirtschaft, Landesentwicklung und Energie

Erforschung des langfristigen Anwendungspotenzials von Urban Air Mobility als Ergänzung zum öffentlichen Personennahverkehr am Beispiel Oberbayern (OBUAM)

K. O. Ploetner, C. Al Haddad, C. Antoniou, F. Frank, M. Fu, S. Kabel, C. Llorca, R. Moeckel, T. Moreno Chou, A. Pukhova, R. Rothfeld, M. Shamiyeh, A. Straubinger, H. Wagner, Q. Zhang

OBUAM Final Project Review
Munich, 17.12.2019

Hintergrundinformation: OBUAM Projekt

Zielsetzung:

- Definition und Simulation von vielversprechenden Urban Air Mobility Missionsprofilen und Transportnetzwerken für die Region Oberbayern
- Quantifizierung der Transportleistung und Rückkopplung auf die Verkehrssituation
- Ableitung von Technologieanforderung auf Vehikel, Infrastruktur und Luftraumebene sowie vielversprechenden Geschäfts- und Betreibermodellen
- Mögliche Regulierungsmaßnahmen zur effektiven Einbindung von UAM in den öffentlichen Personennahverkehr
- Analyse der Vor- und Nachteile sowie möglicher Auswirkungen von UAM auf sozialer, ökonomischer und ökologischer Ebene
- Identifikation des Forschungsbedarfs im Bereich Technologie und Infrastruktur, Operation, Regularien und Gesellschaft

Partner

- Bauhaus Luftfahrt e.V.
  (Projektkoordinator)
- Technische Universität München
  (Professur für Modellierung räumlicher Mobilität)
  (Lehrstuhl für Vernetzte Verkehrssysteme)
- Technische Hochschule Ingolstadt
  (Professor für Automotive & Mobility Management)

Laufzeit: 2019 (12 Monate)

Gefördert durch
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Publikationen und weitere Kommunikation

- Publikationen (siehe übernächste Folie)
- Pressemitteilungen
- Workshops/Initiativen in denen OBUAM Ergebnisse vorgestellt wurden
  - OECD International Transport Forum, Drones in Transportation, 16.04
  - Munich Aerospace Summer School 08.-09.07
  - IHK Denkfabrik 19.11
  - IHK Forum 17.10.2019
  - Bauer AG 12.11
  - UAM Initiative Ingolstadt 22.7 & 19.11
  - ACARE Working Group 1, 14.11
  - Verkehr aktuell Deutsches Museum 09.1.2020

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Publikationen und weitere Kommunikation

- Interviews Vertiportstandorte
  - 19.02: Workshop Flughafen München
  - 26.03: Stadt München
  - 20.05: IHK Oberbayern
  - 04.07: Stadt Ingolstadt

- Interviews Geschäftsmodelle und rechtliche Rahmenbedingungen
  - FLUTR, DFS, DLR, NLR, EUROCONTROL
  - Toulouse, Regionalmanagement Nordhessen, Hamburg Aviation, Bonner Stadtplanung, Stadt München
  - SRTI-BAS (BG), Robots Expert (FI), RAI (NL)
  - Zangano & AeroSolutions (S), TEZ (BG)
  - Drone Think Do (B), Becker Büttner Held (D)
  - AIRBUS (F), Firmennetzwerk Aviation München (D),
  - UDE, Fraunhofer, DG Move, Fraport, IMA

Publikationen (1/4)

Journal papers

- Al Haddad, C., Chaniotakis, E., Straubinger, A., Ploetner, K.O., & Antoniou, C. (2019). Factors Affecting the Adoption and Use of Urban Air Mobility. Transportation Research Part A: Policy and Practice. Sent to production.

Conference contributions

- R. Rothfeld, M. Fu, C. Antoniou, "Analysis of Urban Air Mobility's Transport Performance in Munich Metropolitan Region", mobil.TUM 2019, Munich, 2019.
- A. Straubinger, M. Fu, "Identification of Strategies How Urban Air Mobility Can Improve Existing Public Transport Networks", mobil.TUM 2019, Munich, 2019.

Publikationen (2/4)

- Conference contributions
  - K. O. Ploetner,C. Al Haddad,C. Antoniou, F. Frank, M. Fu, S. Kabel,C. Llorca, R. Moeckel, A. T. Moreno Chou, A. Pukhova, R. Rothfeld, M. Shamiyeh, A. Straubinger, H. Wagner, Q. Zhang, "Long-term Application Potential of Urban Air Mobility Complementing Public Transport: an Upper Bavaria Example", Deutscher Luft- und Raumfahrtkongress 2019, Darmstadt, Germany, 2019.
  - Al Haddad, C., Fu, M., Straubinger, A., Ploetner, K.O., & Antoniou, C. (2020). Multi-Criteria Analysis for the Assessment of Future Transport Systems. A Case Study of Urban Air Mobility in Upper Bavaria, Germany. In the 99th Annual Meeting of the Transportation Research Board, January 2020, Washington, D.C.

Publikationen (3/4)

- Conference contributions
  - Al Haddad, C., Chaniotakis, E., Straubinger, A., Ploetner, K.O., & Antoniou, C. (2019). Towards Understanding User Adoption of Urban Air Mobility. Proceedings of 8th Symposium of the European Association for Research in Transportation (hEART), 4-6 September 2019, Budapest, Hungary.
  - Al Haddad, C., Chaniotakis, E., Straubinger, A., Ploetner, K.O., & Antoniou, C. (2019). Identifying the factors affecting the use and adoption of urban air mobility. Proceedings of the International Scientific Conference on Mobility and Transport (Mobil.TUM), 11-12 September 2019, Munich, Germany.

Publikationen (4/4)

Workshops

- Urban Air Mobility: Previous and ongoing research activities. Presented at: The Future of Shared Mobility and Public Transport Workshop, organized by the Chair of Transportation Systems Engineering of the Technical University of Munich, May 14th 2019.
- Options for Low-Noise & Safe Urban Air Mobility Vehicle Operations within the OBUAM project, Taufkirchen, 16.09-17.09.2019

Hochschultagung 2019

- Factors affecting users‘ engagement in future transport systems. Presented at the Universitätstagung Verkehrswesen, organized by the University of Armed Forces (Unibw), Lenggries, September 16th, 2019

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Publikationen und weitere Kommunikation

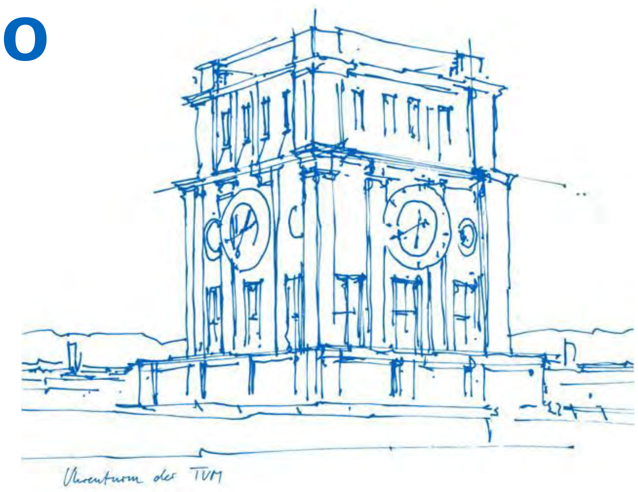
- Weitere Informationen zu der OBUAM Studie und den Simulationsergebnissen kann auf Anfrage an UAM@Bauhaus-luftfahrt.net zur Verfügung gestellt werden

Bavarian Ministry of Economic Affairs,
Regional Development and Energy

Institute for Advanced Study
Technical University of Munich

Study Area &
Munich Mobility 2030 Scenario

Carlos Llorca
Professorship for Modeling Spatial Mobility,
Technische Universität München
Ingolstadt, 19.11.19



Outline

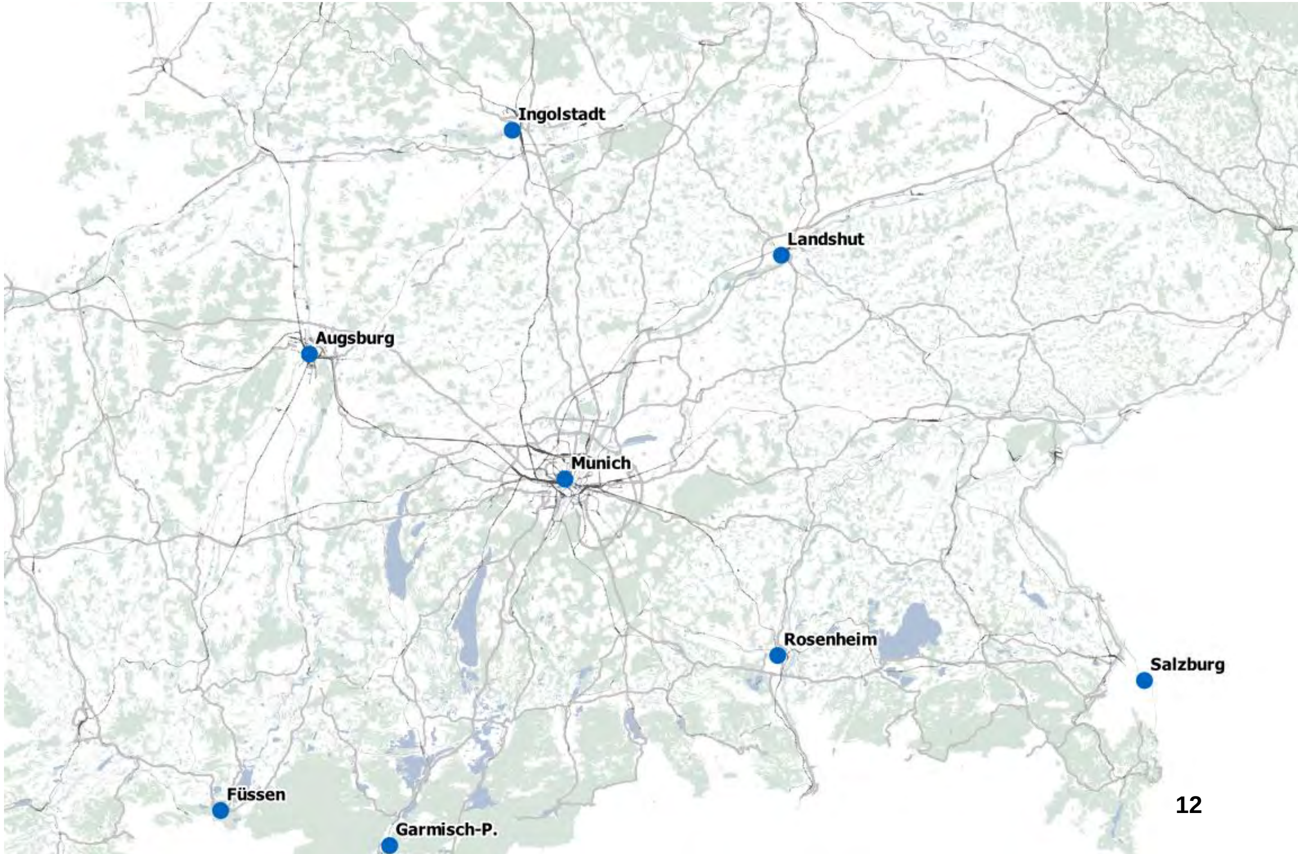
- Introduction
- Travel demand model
- Study area
- Model development
- Munich Mobility 2030 Scenario
- Introducing UAM

Introduction

Goal: forecast future **travel demand** of Urban Air Mobility (UAM) in Upper Bavaria

Travel demand:

- Number of trips
- Trip distance
- Trip destinations
- Modal shares
- Vehicle counts
- Passenger counts
- Travelers



Introduction

Predict UAM travel demand is challenging:

- Completely new mode without previous experience
- **No observations** available
- **Unknown** travelers' **behavior**

There are few available scientific methods:

- Stated preference travel **surveys**:
    - Would you travel by UAM if …?
- Travel demand **models**

OBUAM approach:

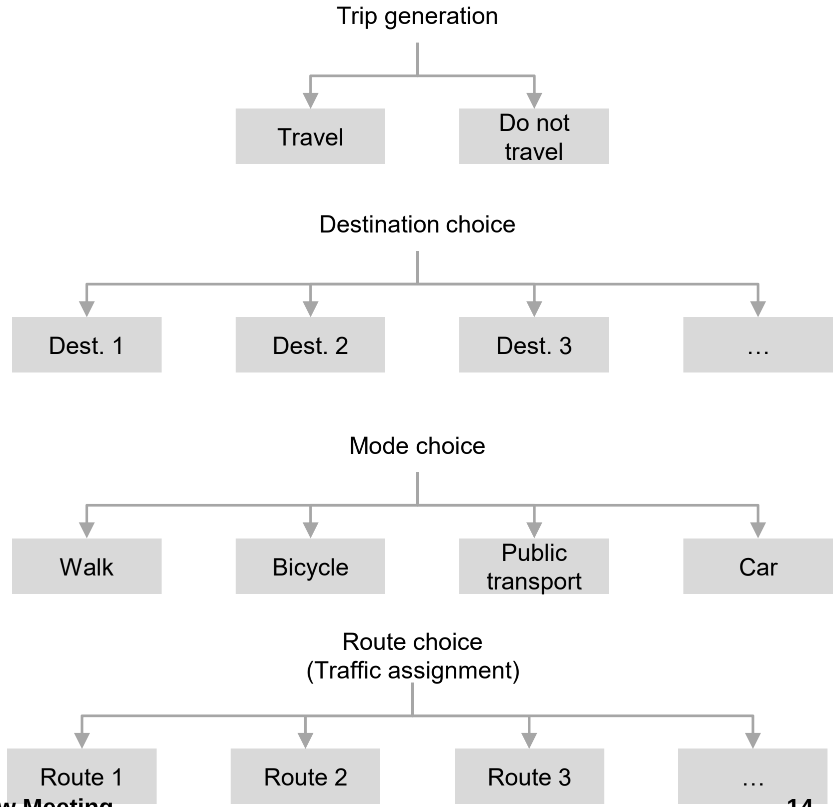
- Combine a **travel demand model** and a **stated preference survey** to forecast the future travel demand

Travel demand model

Microscopic Transportation Orchestrator (MITO)

- 4-step travel demand model

1) Trip generation • How many trips?
2) Destination choice • Where?
3) Mode choice • Which mode?
4) Traffic assignment • Which route?



Travel demand model

Microscopic Transportation Orchestrator (MITO):

- Agent-based model
  - o Represents individually each person and trip
  - o Model variables:

Person
- Age
- Gender
- Income
- Occupation

Household
- Size
- Economic status
- Car ownership
- Location
- Persons

Job
- Industry
- Location

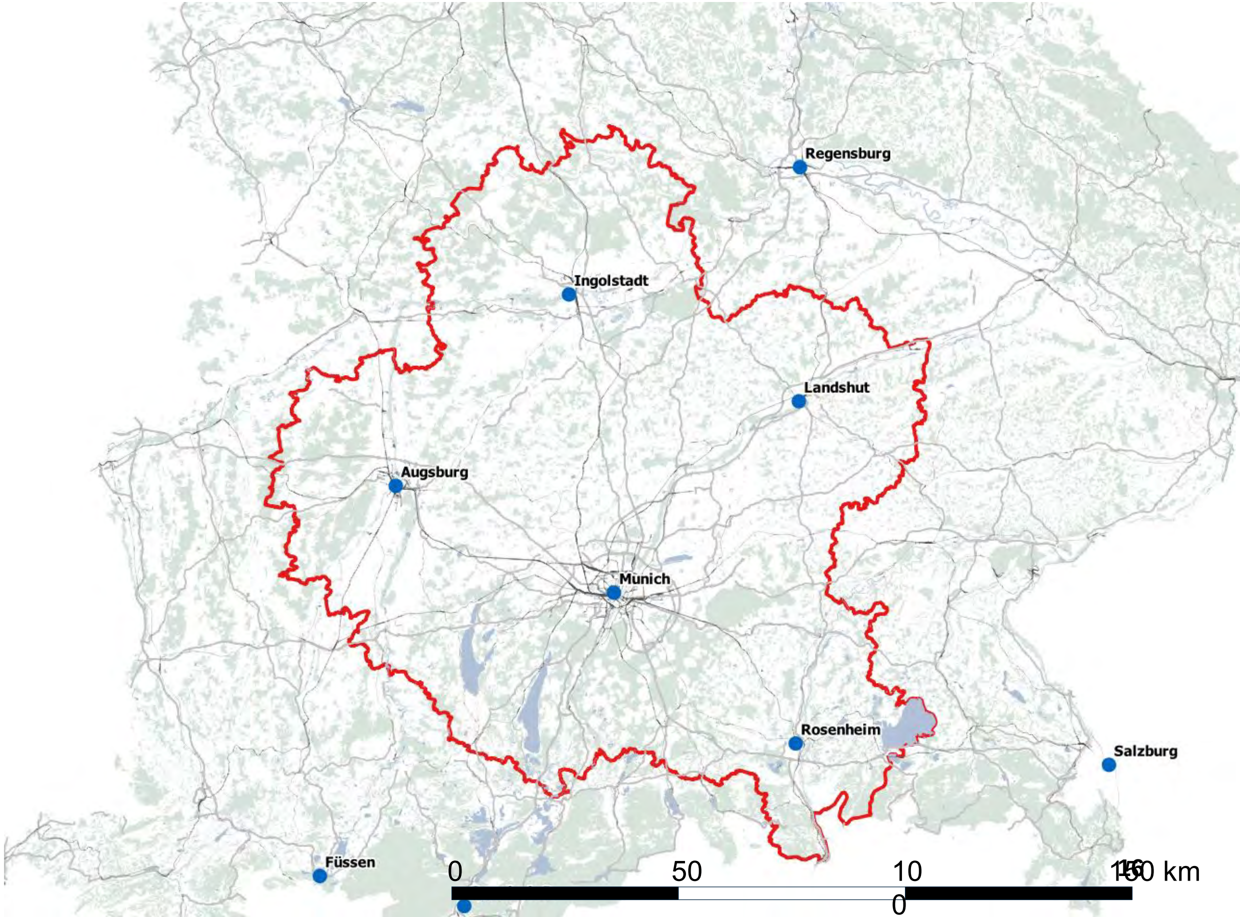
Location
- Coordinates

Trip
- Origin location
- Destination location
- Trip mode
- Time of day
- Purpose
- Route
- Cost
- Travel time
- Waiting time

Study Area

Definition criteria:

- Municipalities where at least 25% of workers commute to Munich, Augsburg, Ingolstadt, Rosenheim or Landshut



4,4 million inhabitants

444 municipalities

1,7 million jobs

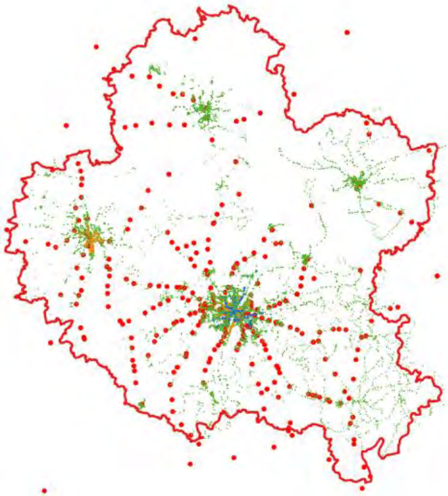
ca. 14 million trips/day

Model development

Data sources

- Network data: OpenStreetMaps
- Census data (2011) → population characteristics
- Household travel survey: Mobilität in Deutschland (2008, 2017) → travel behaviour

Road network (openstreetmaps.org)

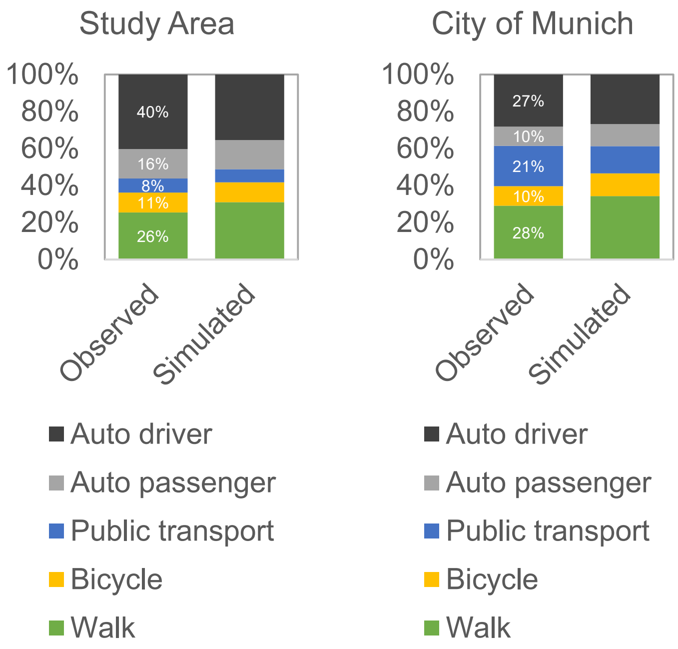

Public transport stops (openstreetmaps.org)

zensus2011
Wissen, was morgen zählt

Model development

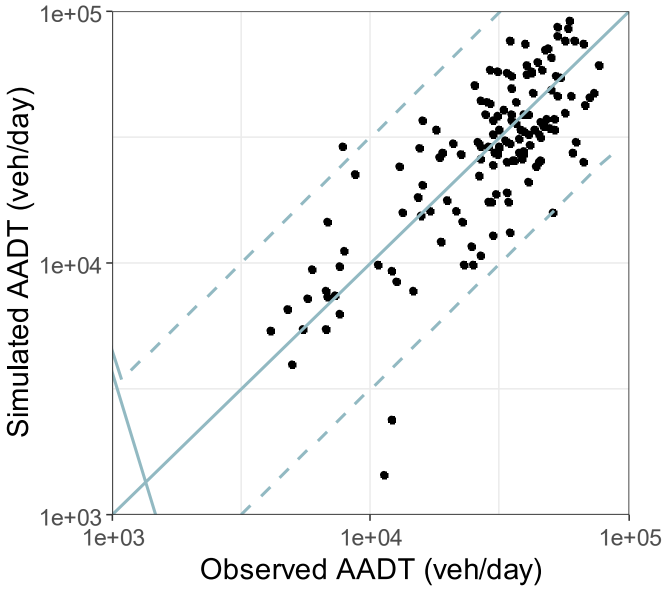
Calibration and validation of MITO at the base year 2011

Modal shares



Source (observed modal share): Mobilität in Deutschland (2008)

Traffic counts

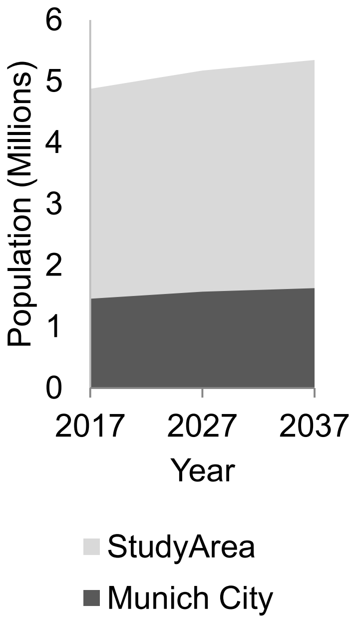


Source (traffic counts): Bundesanstalt für Straßenwesen (2011)

Munich Mobility 2030 Scenario

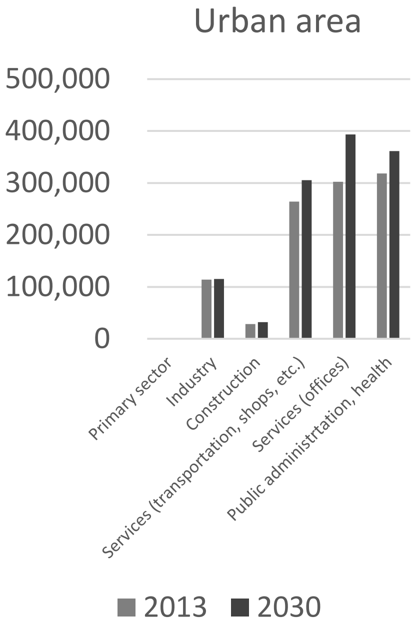
Simulation of travel demand at 2030 (without UAM)

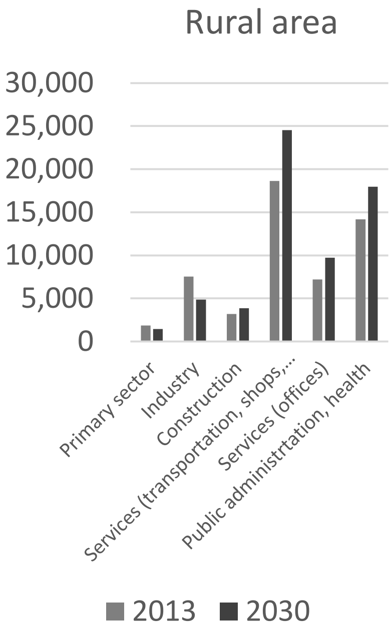
Demographic changes



Source: Bayerisches Landesamt für Statistik (2019)

Job market changes

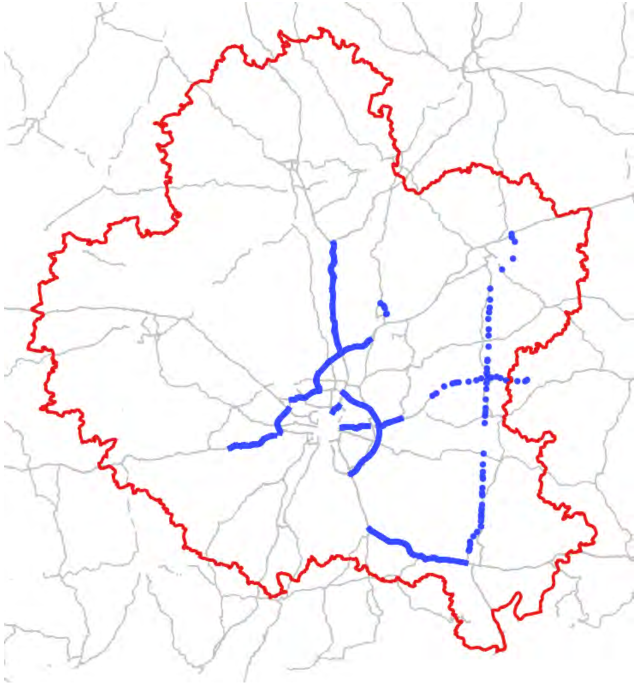




Sources: Bundesministerium für Arbeit und Soziales (2019), Referat für Arbeit und Wirtschaft and Referat für Stadtplanung und Bauordnung der Landeshauptstadt München (2019)

Munich Mobility 2030 Scenario

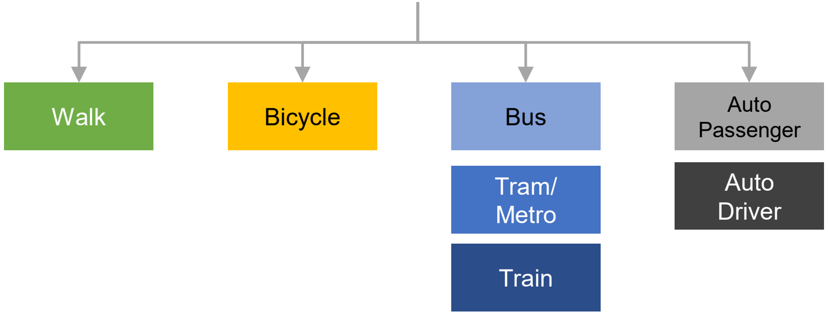
Road network changes



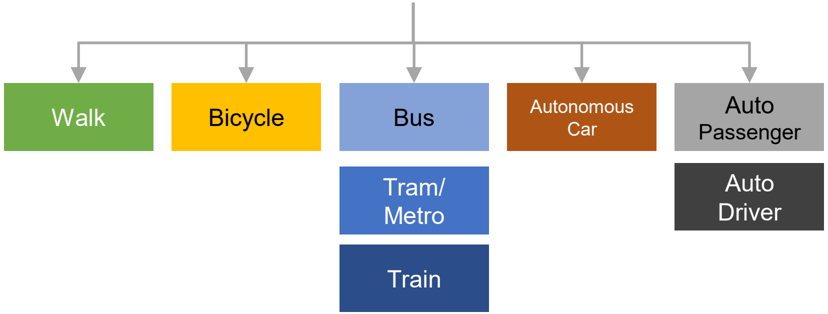
Source: Bundesverkehrswegeplan 2030 (BMVI, 2016)

New ground modes available

Modes available in 2011

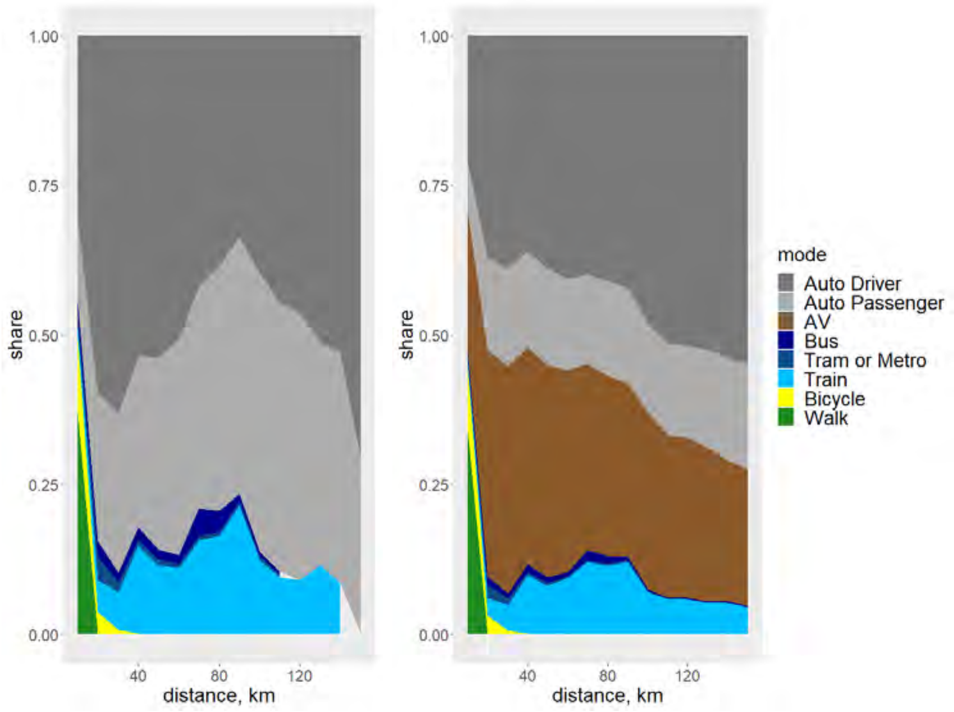


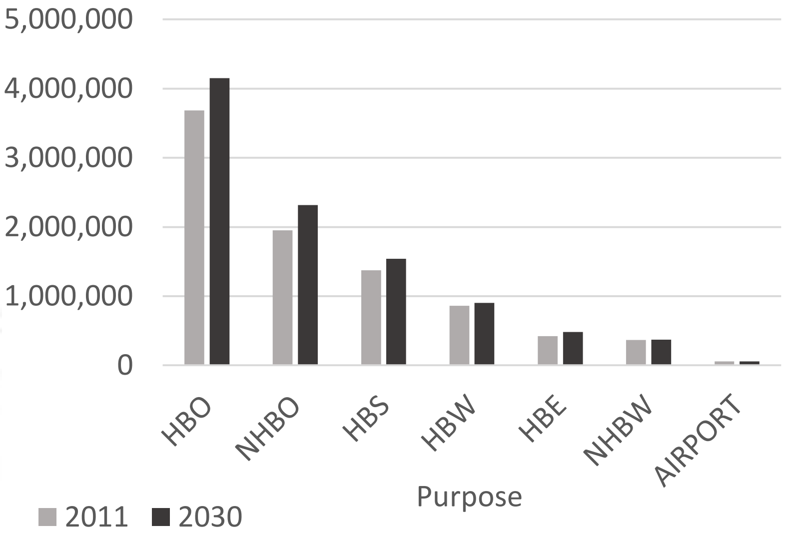
Modes available in 2030 (without UAM)



Munich Mobility 2030 Scenario

Number of trips by purpose and mode in 2011 and 2030 (no UAM)



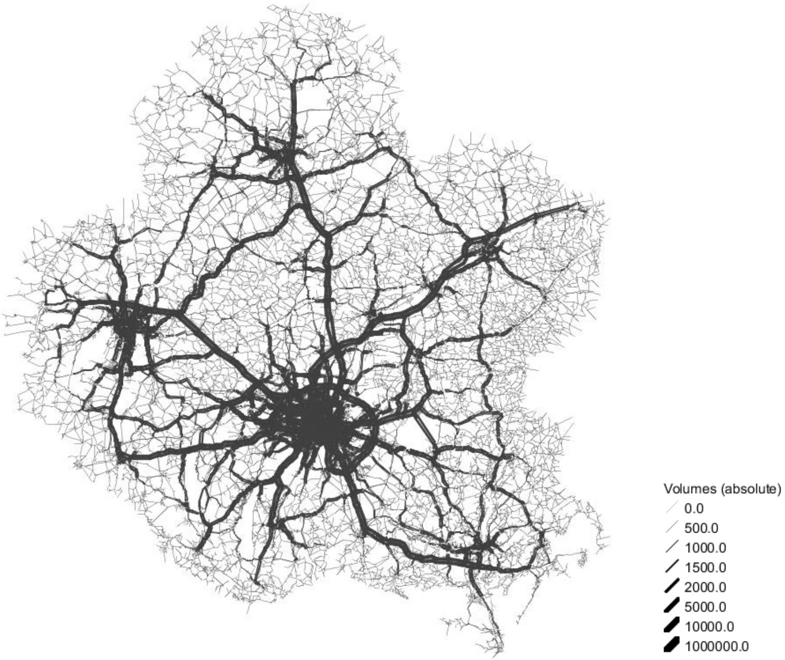


ca. 15 M legs in 2011

ca. 17 M legs in 2030

Munich Mobility 2030 Scenario

Road traffic in 2030



Traffic volumes (veh/day)

Volume/Capacity at 19:00 in Munich City center

Introducing UAM

How to use the MITO model to forecast UAM demand?

- Modify mode choice
- Modify available infrastructure (UAM vertiports)
- Modify available vehicles (UAM vehicles)
- Modify traffic assignment (route choice)

Bavarian Ministry of Economic Affairs, Regional Development and Energy

Institute for Advanced Study
Technical University of Munich

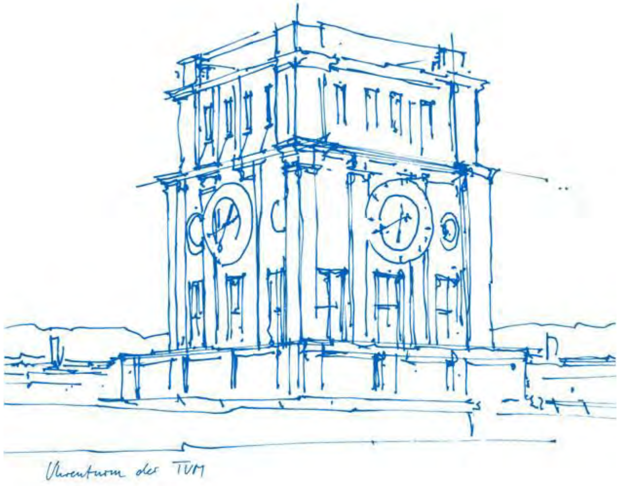
Mode Choice Modelling

Alona Pukhova

Technische Universität München

Professorship for Modeling Spatial Mobility

Ingolstadt, 19.11.19



Outline

- Travel Demand Model
- Mode Choice Modeling:
  - Utility-based Models
  - UAM Introduction
  - Survey-based Incremental Logit Model
- Base Scenario UAM 2030:
  - Settings
  - Modal Share by Distance
  - UAM Trip Purpose

Travel demand model

Microscopic Transportation Orchestrator (MITO)

- 4-step travel demand model

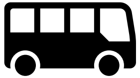
1) Trip generation
   - How many trips?
2) Destination choice
   - Where?
3) Mode choice
   - Which mode?
4) Traffic assignment
   - Which route?

Mode Choice Modelling

Utility-based Models

$$Utility_{MODE} = a \, * \textcolor{blue}{\boldsymbol{in\ vehicle\ time}} + b \, * \textcolor{green}{\boldsymbol{trip\ cost}} + c \, * access(egress)time + mode\ specific\ constant$$

a, b, c - coefficients



$Utility_{BUS}$

$Utility_{AUTO}$

The mode with higher utility is selected

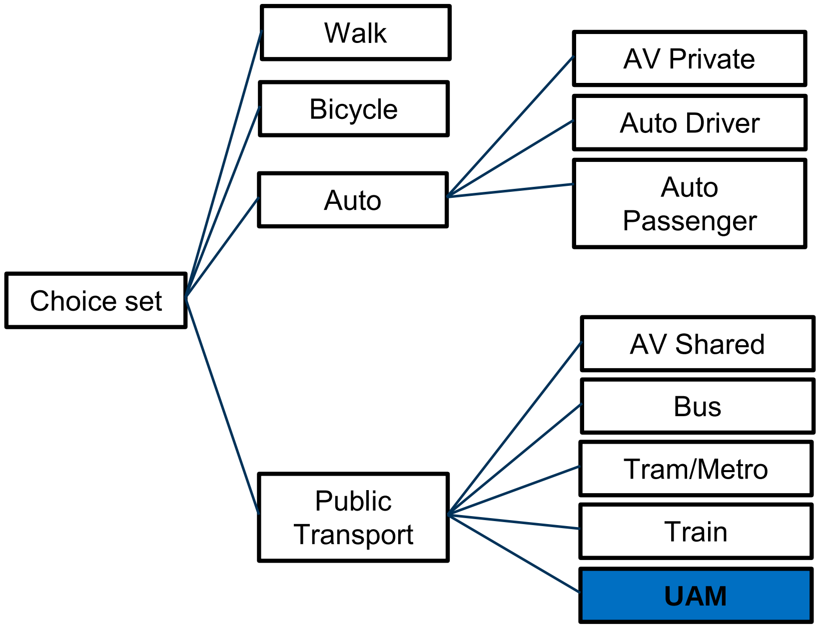
$Utility_{BUS} > Utility_{AUTO}$ → BUS

$Utility_{BUS} < Utility_{AUTO}$ → AUTO

Mode Choice Modelling

MITO. UAM Introduction

Incremental Logit Model



Stated Preference Survey

- travel cost
- travel time
- safety
- inconvenience
- multitasking possibility

Survey-based Incremental Logit Model

Mode Choice Modelling

Survey-based Incremental Logit Model

Adjustment of generalized cost coefficient(s) based on SP survey

Stated Preference survey coefficients:

Coefficient	Mode			
	Car	Public Transport	Autonomous Vehicle	UAM
Travel Cost	-1.98	-1.12	-3.13	-0.509
Travel Time	-0.893	-0.678	-1.16	-1.00

Generalized cost term of Train utility is: $-0.0012 \cdot \left(t_{Train} + \frac{c_{Train}}{VOT_{Train}} \right)$

UAM/Public Transport cost ratio: $\frac{-0.509}{-1.12} = 0.454$

UAM/Public Transport time ratio: $\frac{-1.00}{-0.678} = 1.475$

Generalized cost term of **UAM utility** is: $-0.0012 \cdot \left(1.475 \cdot \ time_{UAM} + 0.454 \cdot \frac{c_{UAM}}{VOT_{UAM}} \right)$

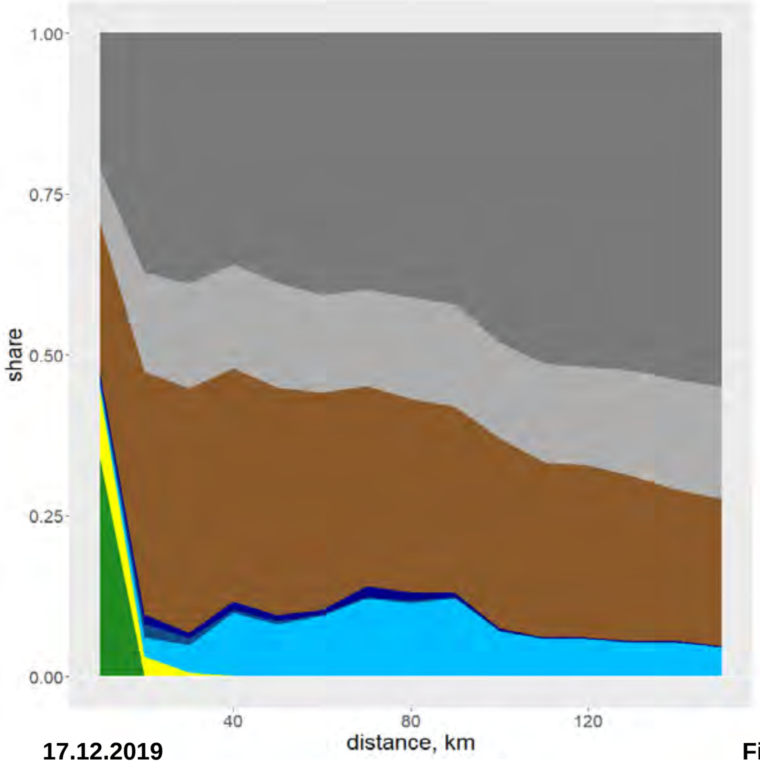
Base Scenario 2030

Settings

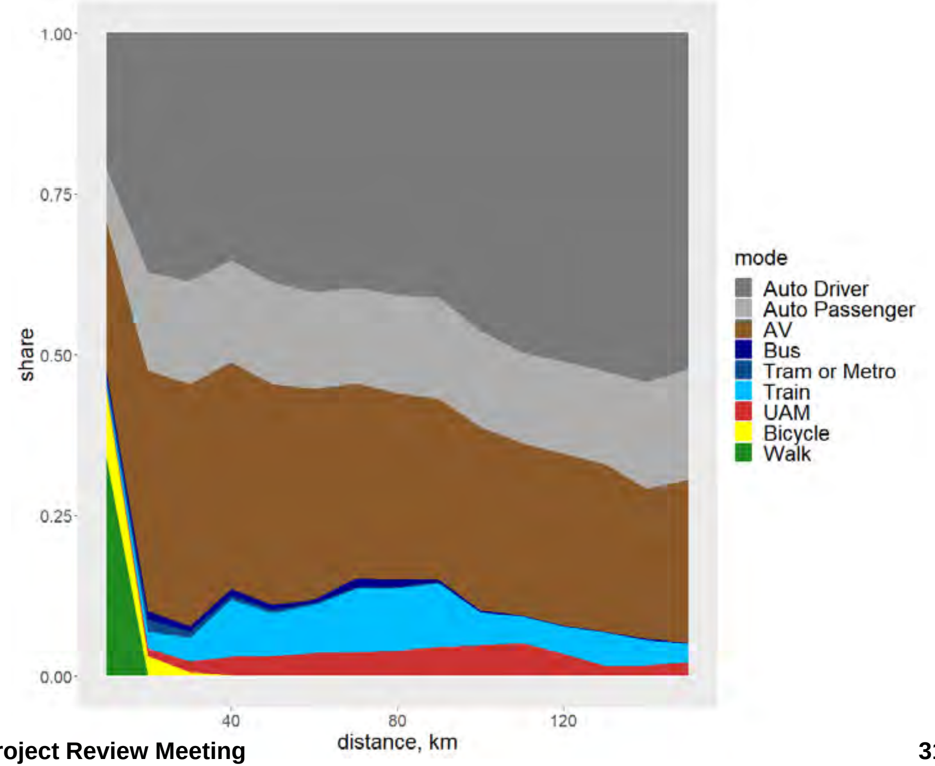
- Network of 74 vertiports
- Unlimited air vehicle fleet
- Air vehicle speed 100 km / h
- UAM cost 2 € / km
- UAM boarding cost 5 €

Base Scenario
Modal Shares by Distance

Year 2030 (Autonomous Vehicle)

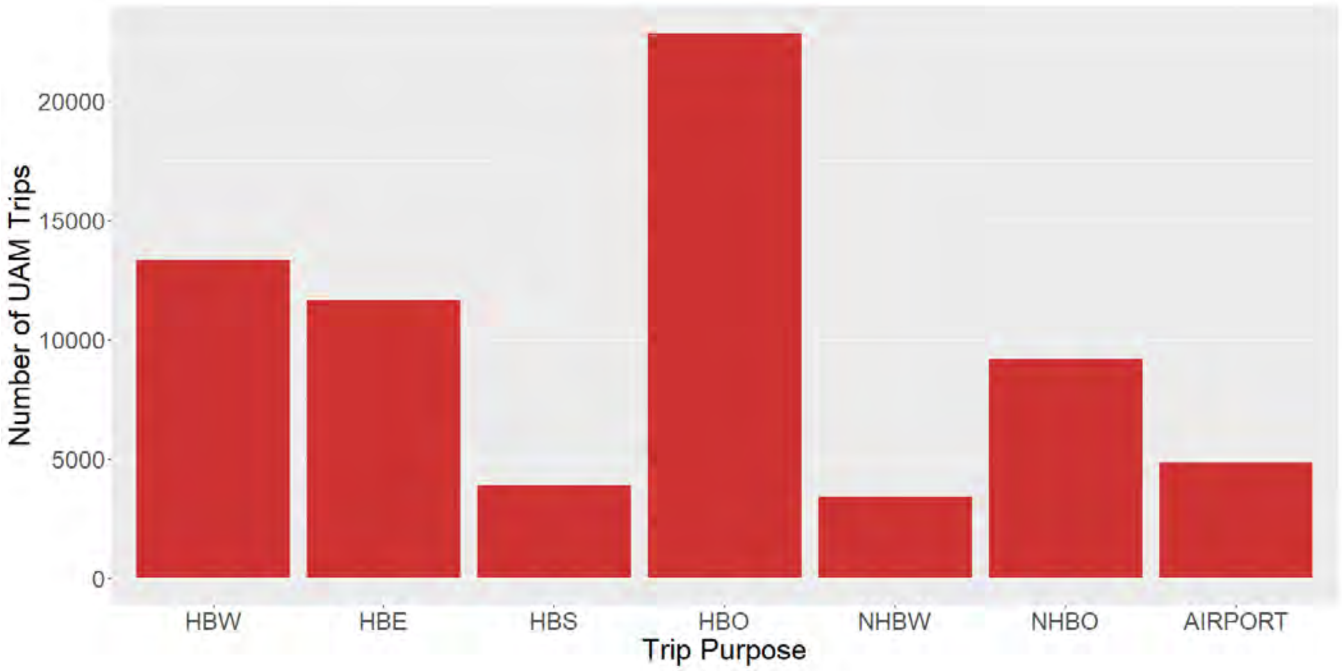


Year 2030 (Autonomous Vehicle + UAM)



Base Scenario

UAM Trip Purpose



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UAM Simulation Framework

Raoul Rothfeld

Gefördert durch
Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie

OBUAM Final Conference,
München, 30.01.2020

Travel Demand Model

- Microscopic Transportation Orchestrator (MITO)
  - 4-step travel demand model

1	Trip generation	• How many trips?
2	Destination choice	• Where?
3	Mode choice	• Which mode?
4	Traffic assignment	• Which route?

Bauhaus Luftfahrt
Neue Wege.

Travel Demand Model

Microscopic Transportation Orchestrator (MITO)

- 4-step travel demand model

1	Trip generation	• How many trips?
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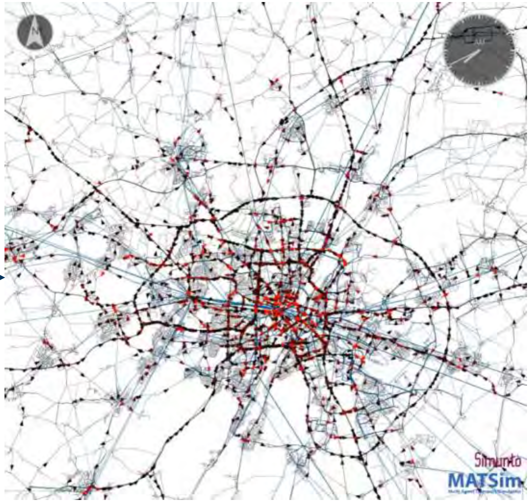
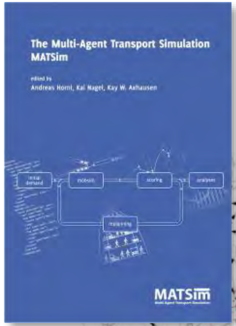
MATSim
Multi-Agent Transport Simulation



Simulation Results

UAM-enabled Transport Simulation using MATSim

- The Multi-Agent Transport Simulation
  - Java-based, open-source, community-driven simulation framework by Horni, Nagel and Axhausen (2016)
- Development of open source UAM extension
  - Co-development between ETH Zurich, TU Munich, and Bauhaus Luftfahrt e. V.
  - Features modelling capabilities for UAM vehicles, infrastructure, and aerial networks
  - Allows for simplistic passenger pooling and dynamic vehicle distribution



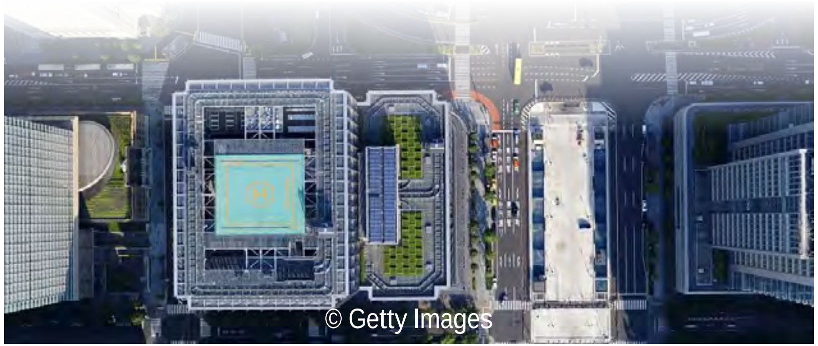
Simulation Results

From R. Rothfeld, M. Fu, C. Antoniou, "Analysis of Urban Air Mobility's Transport Performance in Munich Metropolitan Region", mobil.TUM 2019, Munich, 2019.

Infrastructure and Vehicle Modelling

Infrastructure properties

- Location and accessibility
- Access and egress options
- Capacity (simultaneous VTOL)



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Vehicle properties

- Cruising and vertical speeds
- Boarding and turnaround times
- Passenger capacity
- Fixed range (dynamic range desired)

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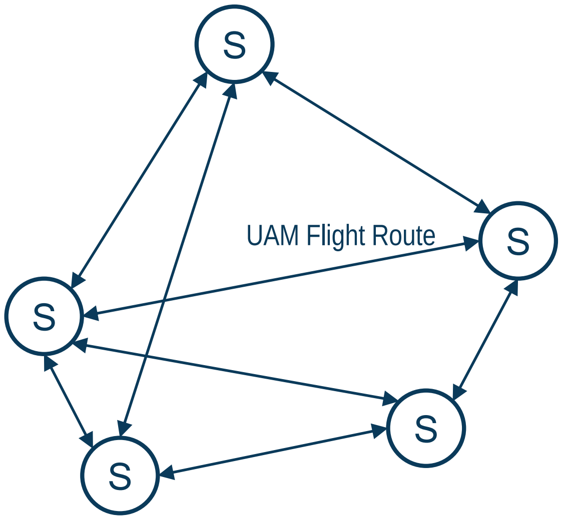
From R. Rothfeld, M. Fu, C. Antoniou, "Analysis of Urban Air Mobility's Transport Performance in Munich Metropolitan Region", mobil.TUM 2019, Munich, 2019.

Flight Modelling

- Flight along pre-defined paths
  - Beeline (direct) or
  - Routed (indirect) flight
- Simplified flight into three segments
  - Vertical take-off
  - Cruise flight
  - Vertical landing
- No acceleration modelled

Direct



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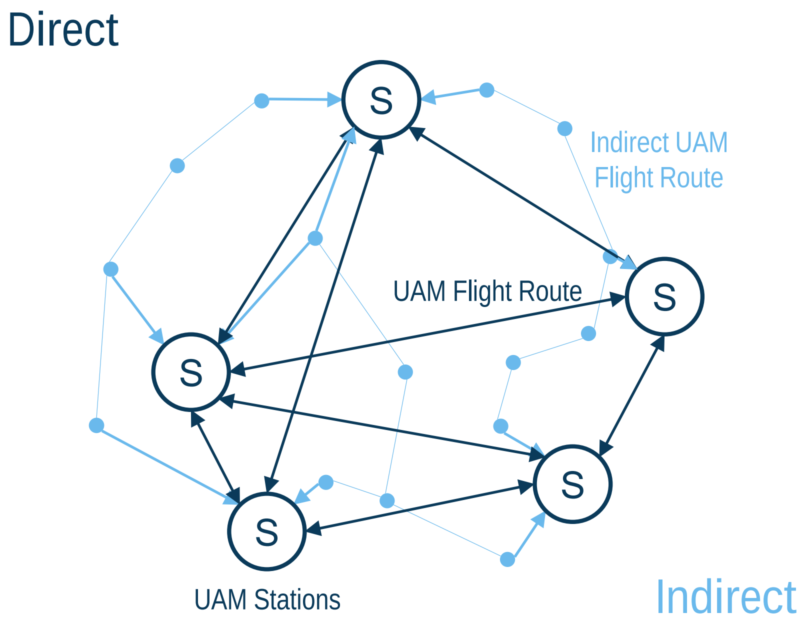

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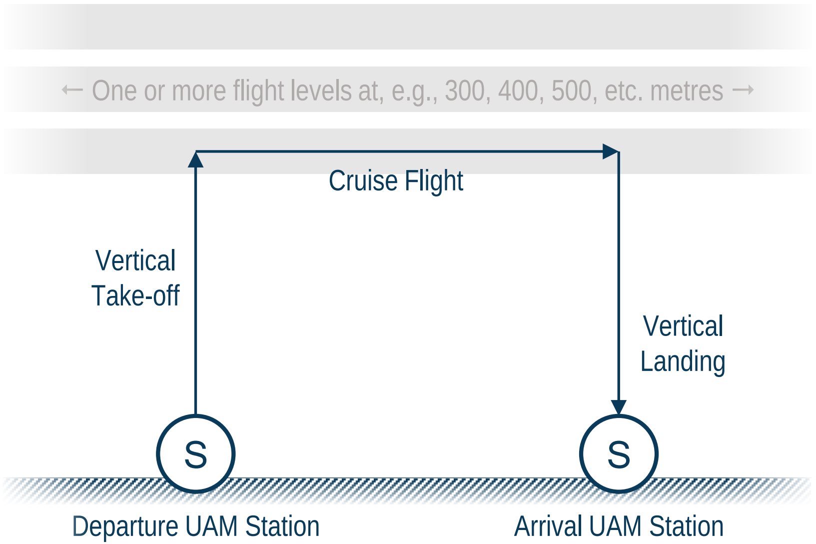

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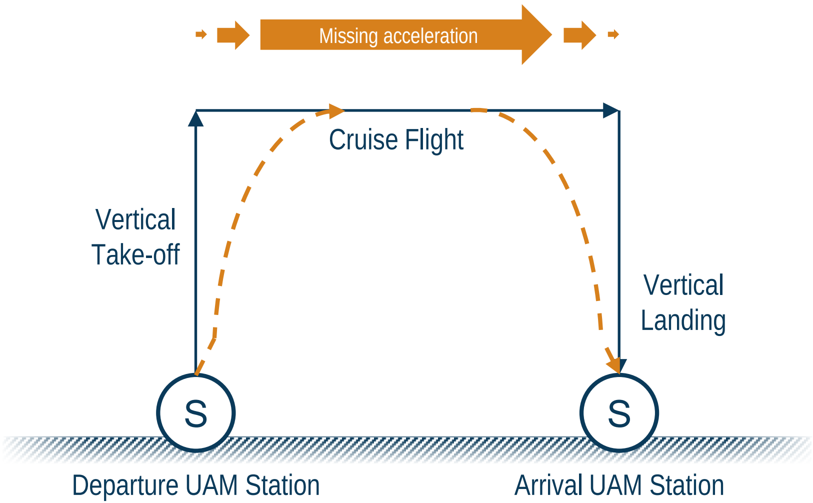
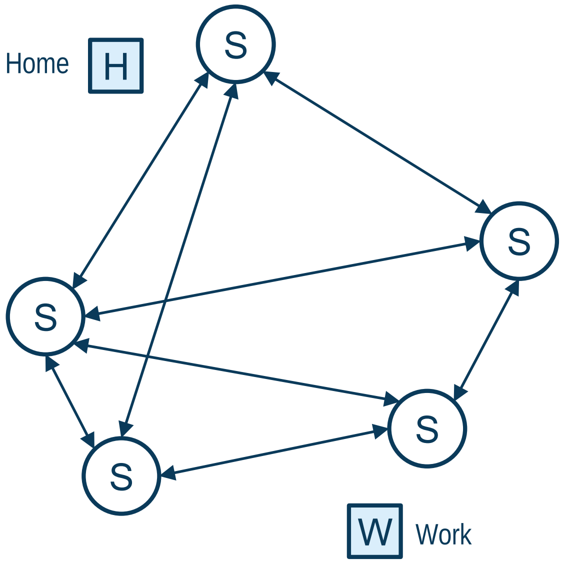


From R. Rothfeld, M. Fu, C. Antoniou, "Analysis of Urban Air Mobility's Transport Performance in Munich Metropolitan Region", mobil.TUM 2019, Munich, 2019.

Trip Routing

- UAM trip comprise five segments
  - Access leg (e.g. by car, walking, bike)
  - Departure processes
  - Flight leg (take-off, cruise, landing)
  - Arrival processes
  - Egress leg (e.g. by car, walking, bike)
- Provided strategies for routing, e.g.
  - MinAccessDistance, MinDistance, MinTravelTime, or MaxUtility



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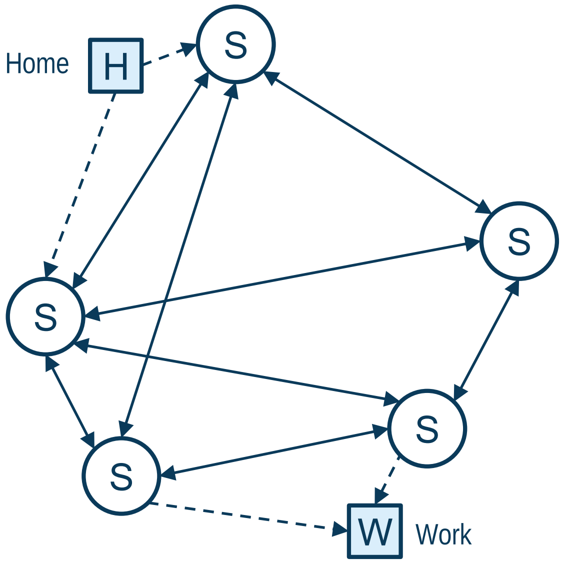
  - Flight leg (take-off, cruise, landing)
  - Arrival processes
  - Egress leg (e.g. by car, walking, bike)

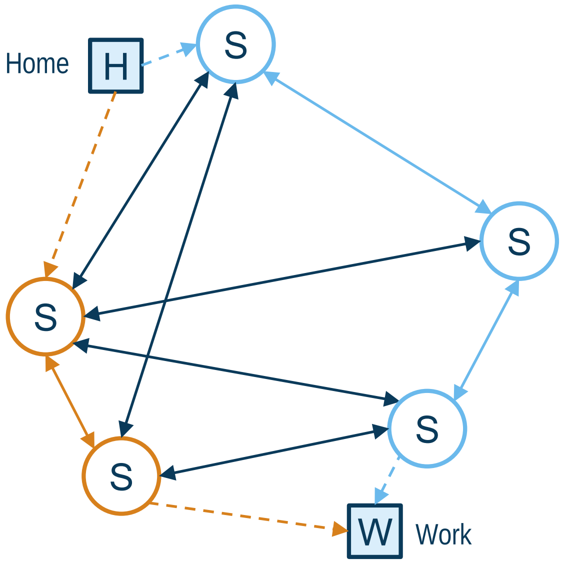
- Provided strategies for routing, e.g.
  - MinAccessDistance, MinDistance, MinTravelTime, or MaxUtility



From R. Rothfeld, M. Fu, C. Antoniou, "Analysis of Urban Air Mobility's Transport Performance in Munich Metropolitan Region", mobil.TUM 2019, Munich, 2019.

Trip Routing

- UAM trip comprise five segments
  - Access leg (e.g. by car, walking, bike)
  - Departure processes
  - Flight leg (take-off, cruise, landing)
  - Arrival processes
  - Egress leg (e.g. by car, walking, bike)



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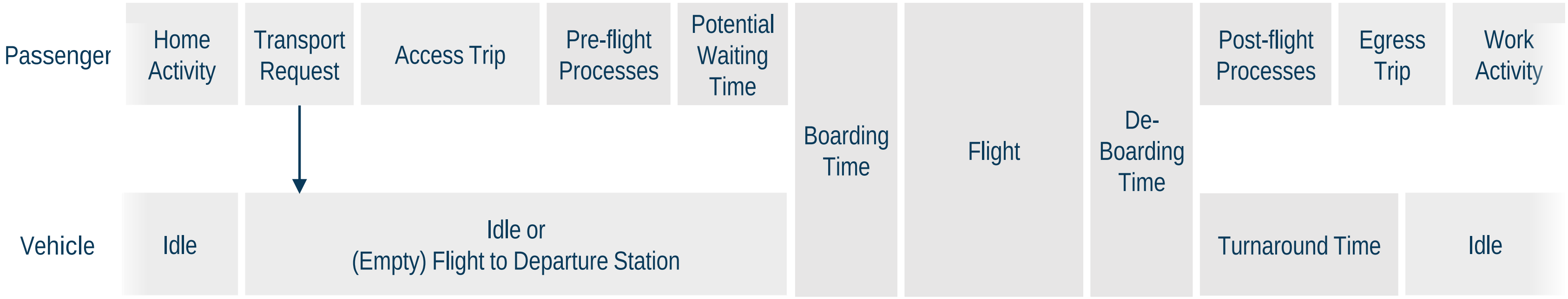
From R. Rothfeld, M. Fu, C. Antoniou, "Analysis of Urban Air Mobility's Transport Performance in Munich Metropolitan Region", mobil.TUM 2019, Munich, 2019.

Process Modelling

- Separated processes for on-demand vehicles and passengers



- Mixture of static and dynamic times
  - Pre-defined durations for all passenger and vehicle procedures
  - Dynamic passenger waiting time, dependent on vehicle availability

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Process Modelling

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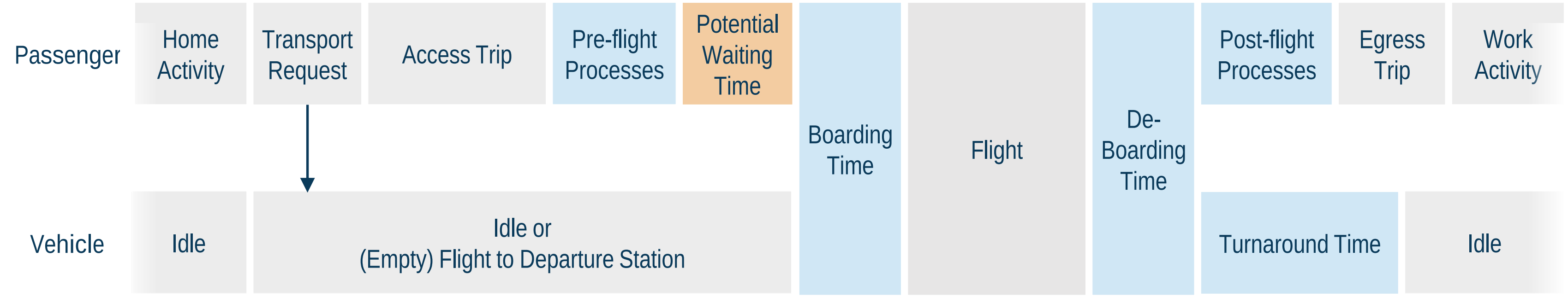

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Travel Demand Model with UAM Inclusion

- Microscopic Transportation Orchestrator (MITO)
  - 4-step travel demand model

1	Trip generation	• How many trips?
2	Destination choice	• Where?
3	Mode choice	• Which mode?
4	Traffic assignment	• Which route?

Travel Demand Model with UAM Inclusion

Microscopic Transportation Orchestrator (MITO)

- 4-step travel demand model

	Step	
1	Trip generation	How many trips?
2	Destination choice	Where?
3	Mode choice	Which mode?
4	Traffic assignment	Which route?

Introduction of MITO iterations:

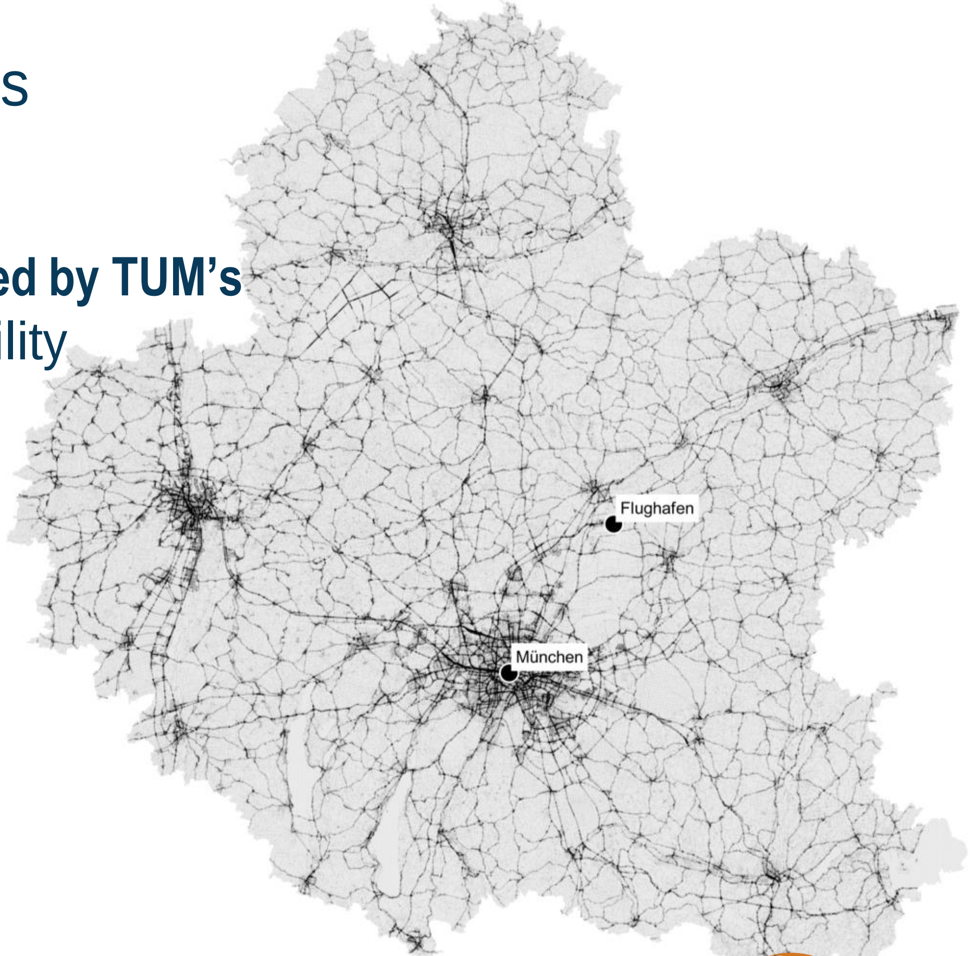
- Travel times (dependent on waiting times at UAM stations) are being updated
- Mode choice is being redone with updated travel times until waiting time equilibrium is reached

MATSim Multi-Agent Transport Simulation + UAM

Bauhaus Luftfahrt Neue Wege.

Detailed Transport Analyses

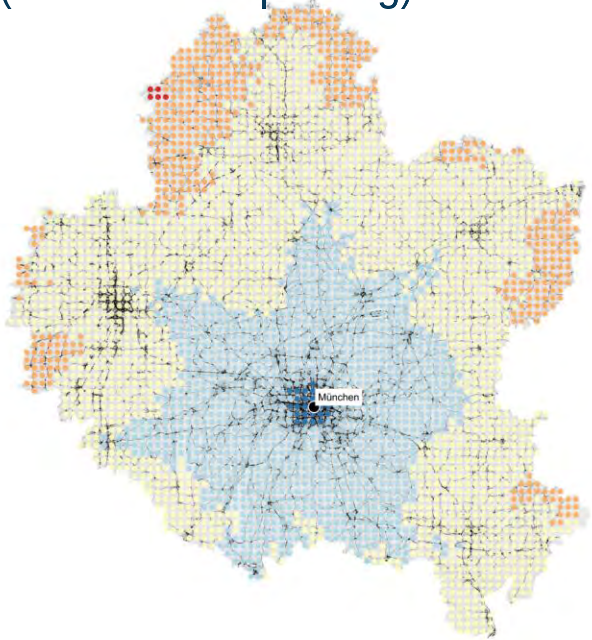
- Base MATSim **model maintained by TUM's** chair of Modelling Spatial Mobility under Prof. Moeckel
  - Model of larger Munich, Augsburg, Ingolstadt, Landshut, and Rosenheim region
  - Offers congestion-including car and schedule-based public transport travel times



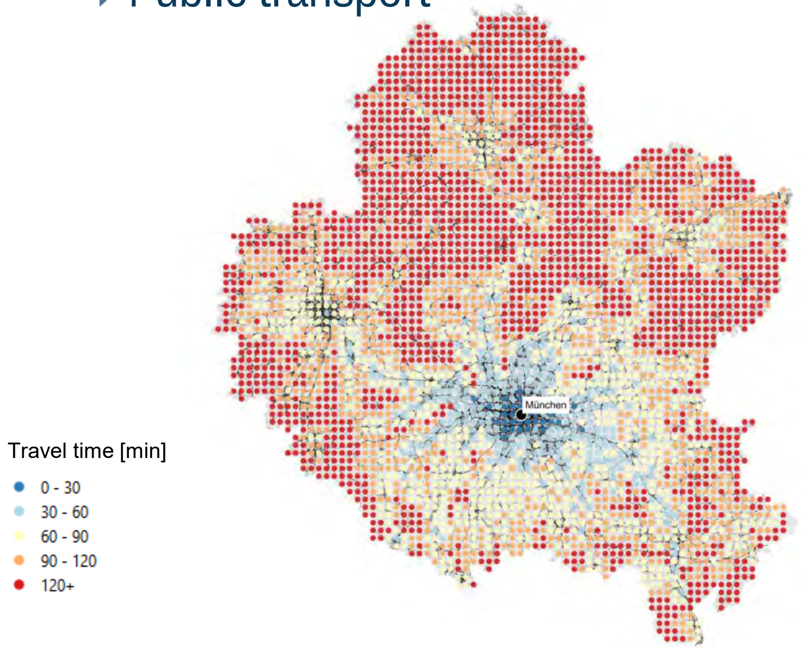
From R. Rothfeld, M. Fu, C. Antoniou, "Analysis of Urban Air Mobility's Transport Performance in Munich Metropolitan Region", mobil.TUM 2019, Munich, 2019.

Detailed Transport Analyses – Travel Times

- Car (incl. 15 mins parking)



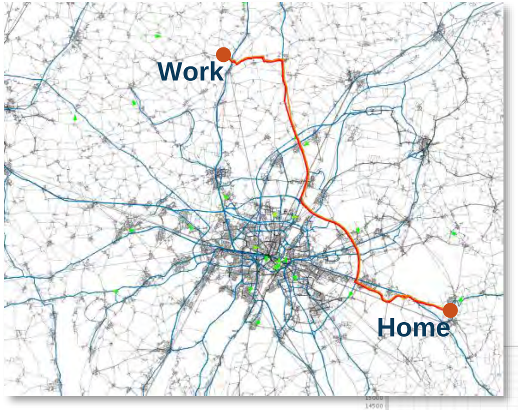
- Public transport

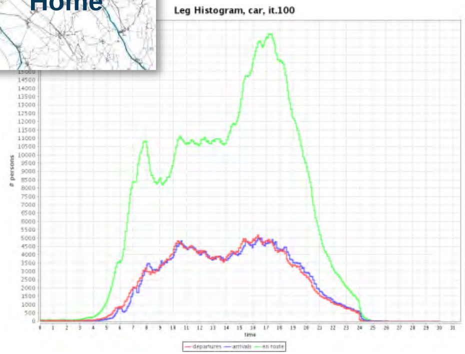


From R. Rothfeld, M. Fu, C. Antoniou, "Analysis of Urban Air Mobility's Transport Performance in Munich Metropolitan Region", mobil.TUM 2019, Munich, 2019.

Detailed Transport Analyses – Aggregated and Individual Trips

- Exemplary analyses of agent-based transport simulation results
  - Follow any agent or vehicle throughout the simulated day
  - Analyse vehicle utilization, idle times, and load factors
  - Congestion levels on any or all streets at any time
  - Results can be analysed from a holistic or very granular level





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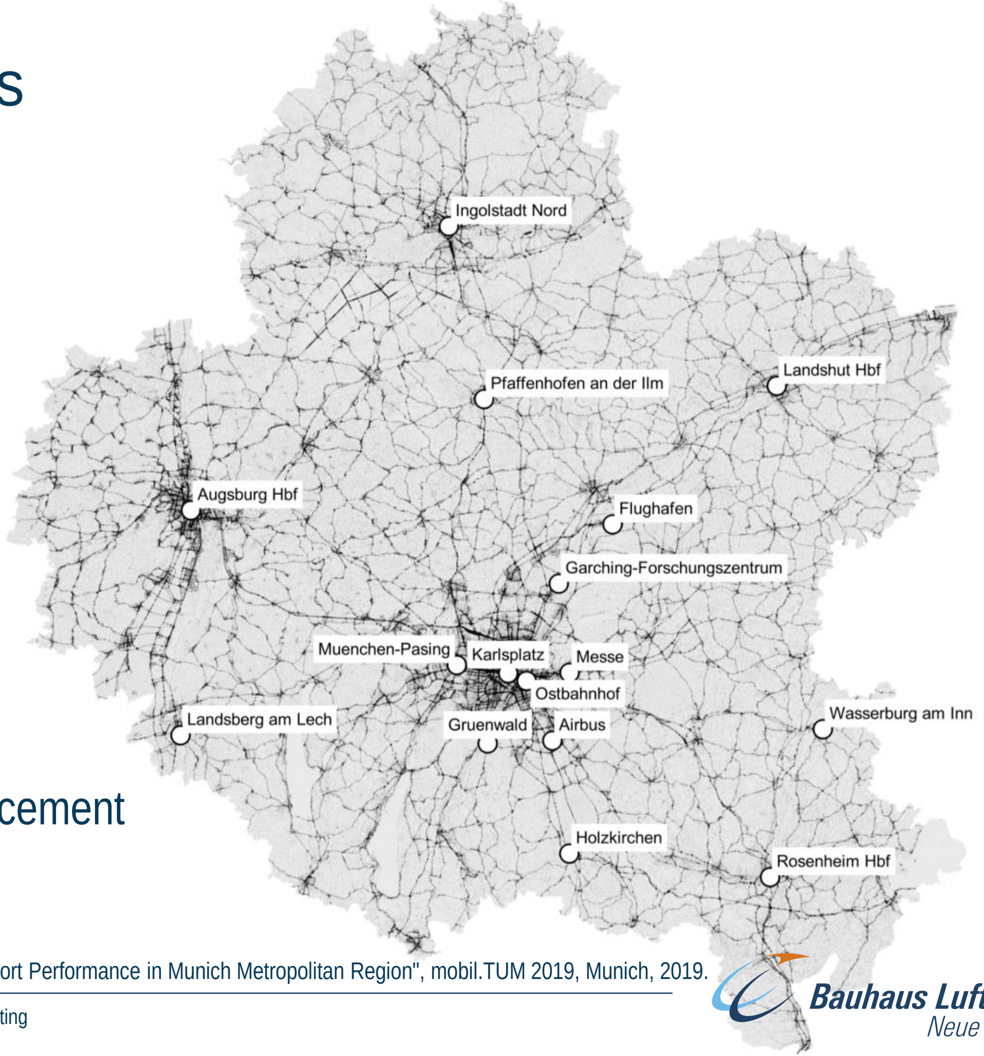
Detailed Transport Analyses

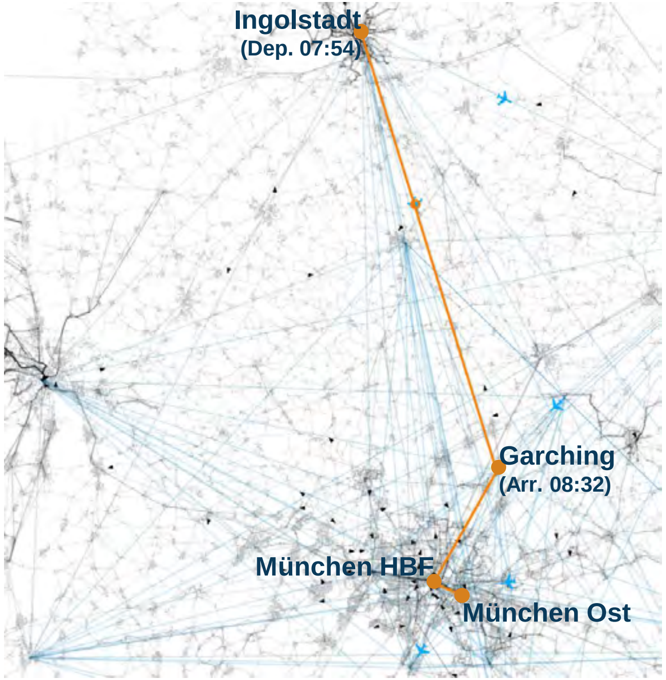
- Inclusion of MATSim-UAM
  - Provides UAM as additional transport mode
  - Requires UAM stations with vehicles, flight routes, process times, and access/egress options
  - Simulation with this, qualitative placement of UAM stations as an Example



From R. Rothfeld, M. Fu, C. Antoniou, "Analysis of Urban Air Mobility’s Transport Performance in Munich Metropolitan Region", mobil.TUM 2019, Munich, 2019.

Detailed Transport Analyses – Individual UAM Trips

- Agent-based UAM simulation allows granular analyses of UAM service operation and usage
  - Who is requesting UAM transport?
  - Which vehicle is serving which customer?
  - Which UAM stations generate the highest demand at what time of day?
  - How do waiting times develop over the day?
  - How to customers access and egress stations?
  - …



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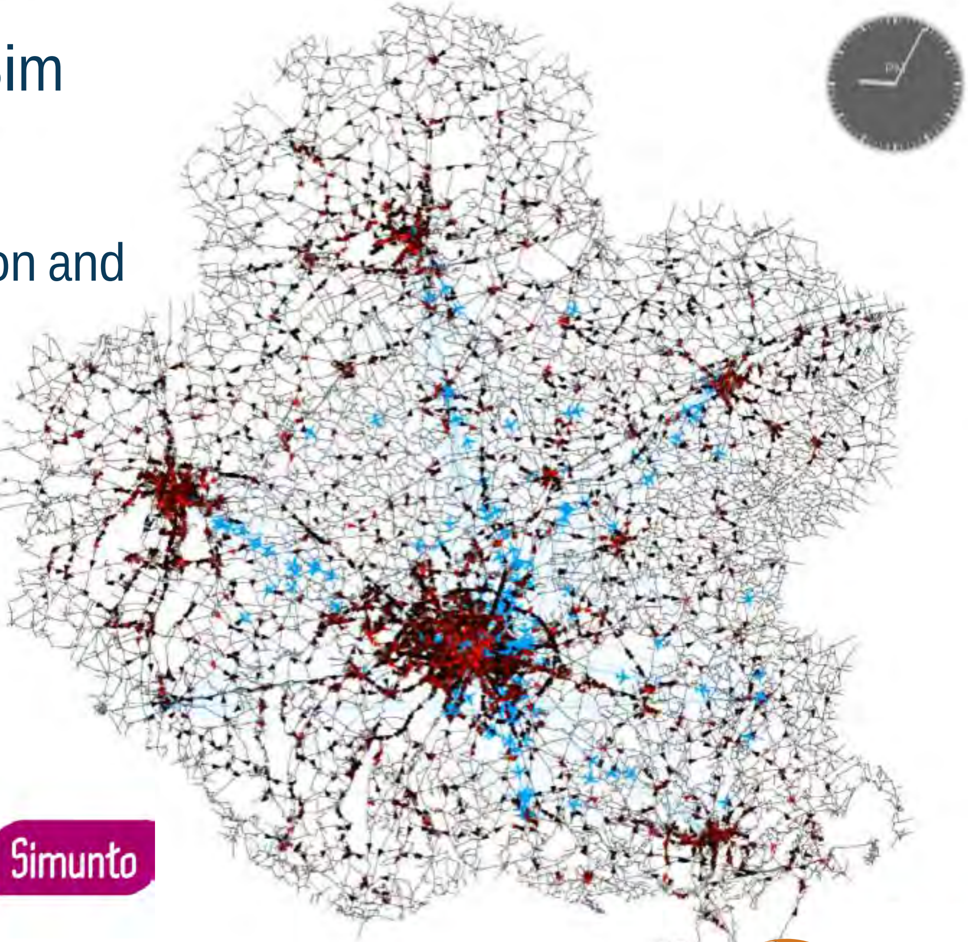
UAM Simulation with MATSim

- Inclusion of UAM into simulation and mode choice functions
  - Offers simulated agents the option to use UAM based on the mode’s availability, speed, and cost
  - Enables estimations on future transport scenarios which include novel air-borne transport concepts



From R. Rothfeld, M. Fu, C. Antoniou, "Analysis of Urban Air Mobility’s Transport Performance in Munich Metropolitan Region", mobil.TUM 2019, Munich, 2019.

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Vertiport Locations and Routing Strategies

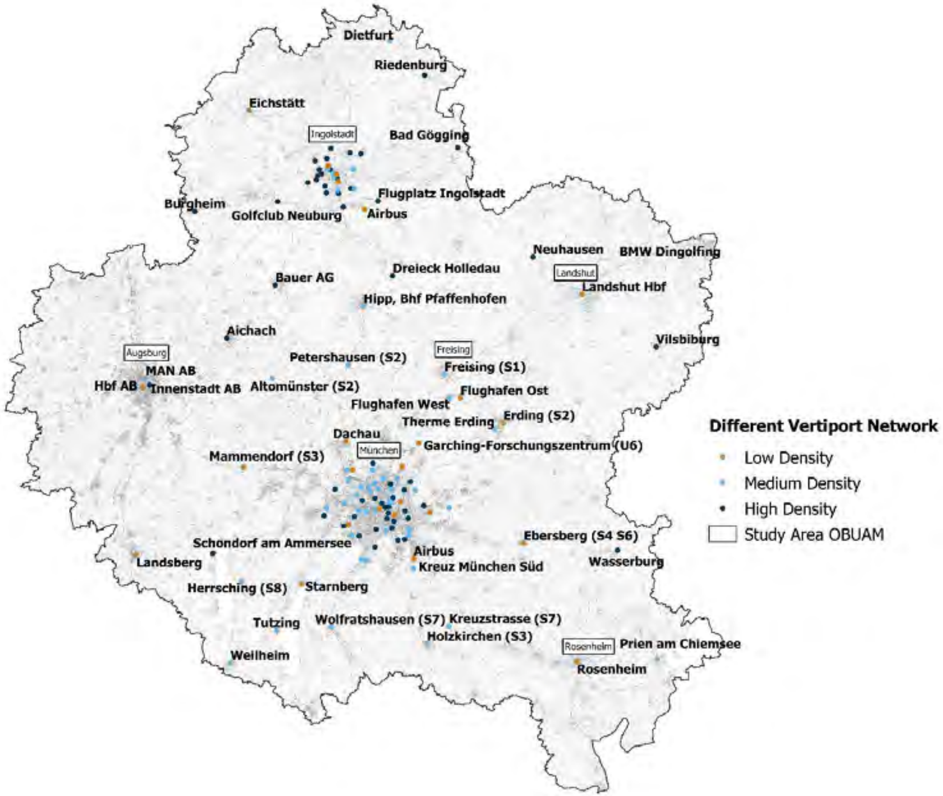
Mengying Fu

OBUAM Final Conference,
München, 19.11.2019

Gefördert durch
Bayerisches Staatsministerium für
Wirtschaft, Landesentwicklung und Energie

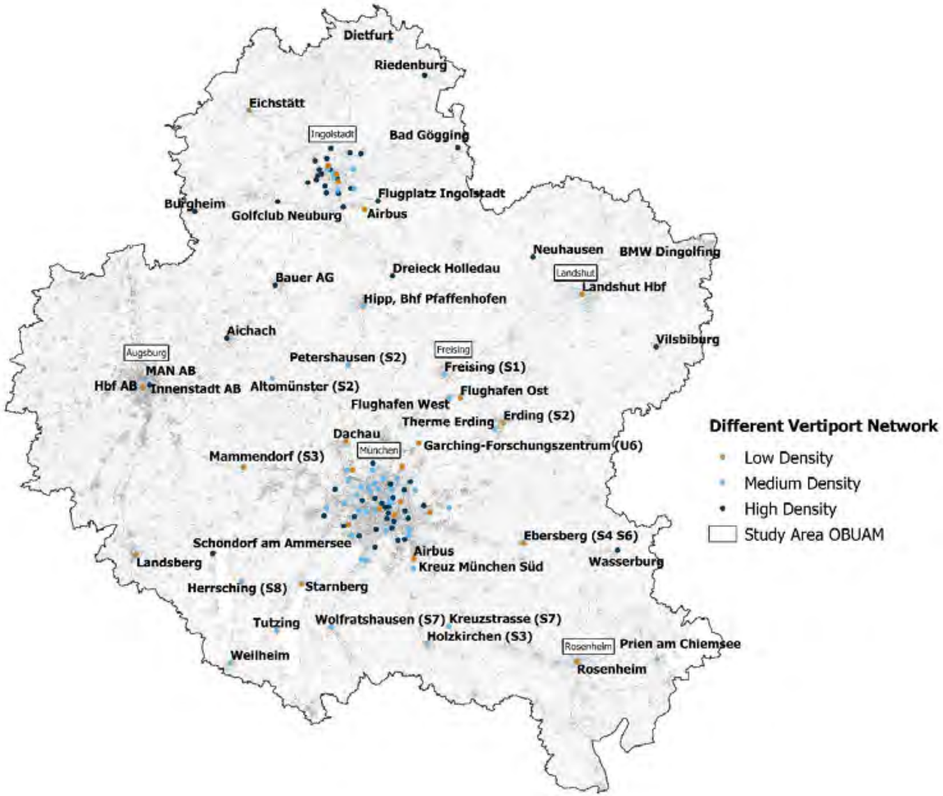
UAM Network

- Selection of vertiport locations
  - Four workshops with representatives from Munich Airport, Chamber of Industry and Commerce of Upper Bavaria (IHK), city of Munich and city of Ingolstadt
  - Four trip purposes, including commuting, business, tourism/leisure, improving accessibility, have been considered
  - Three levels of archetypes



UAM Network

- Three levels of archetypes
  - High density network – 130 vertiports, covers all relevant trip purposes and aims at capturing demand from various target group
  - Medium density network – 74 vertiports, includes all vertiports of the low density network and main subway and suburban lines, and all major employment centers
  - Low density network – 24 vertiports, covers large agglomerations, employment centers, transportation hubs and densely populated areas with a large share of high incomes



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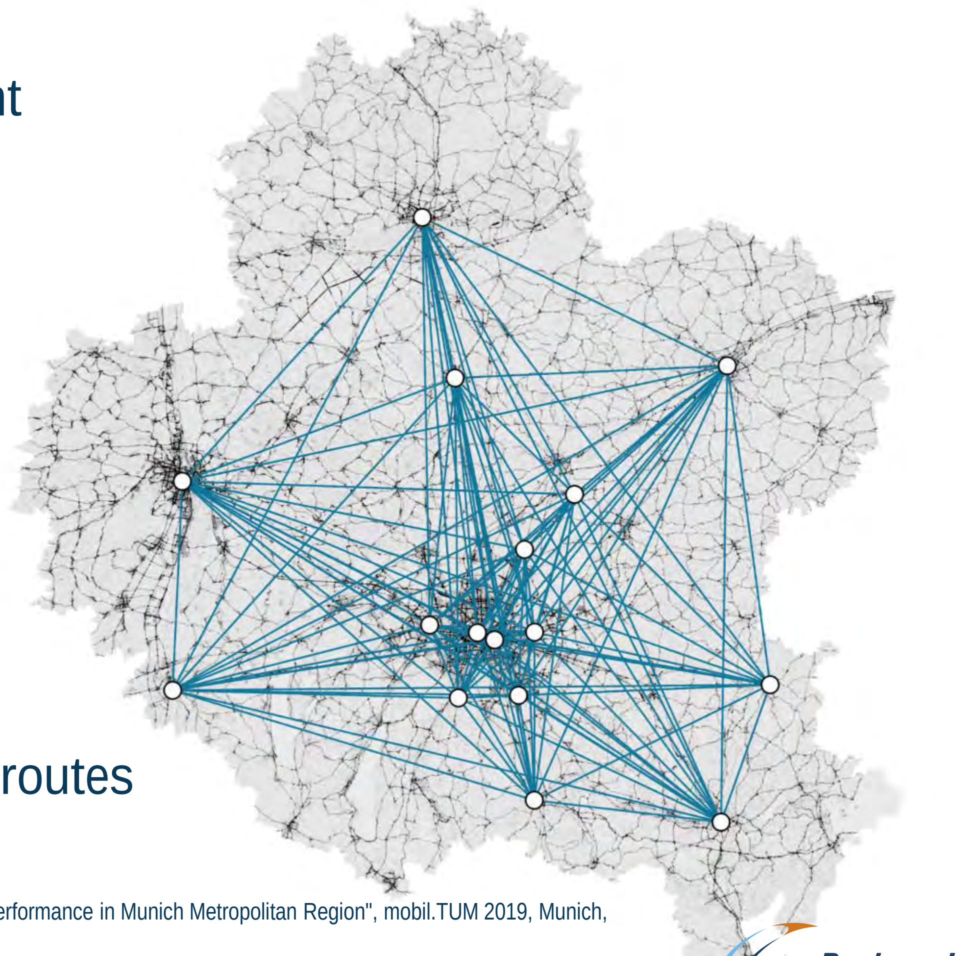
Routing strategies
Restricting Residential Overflight

- Direct Point-to-Point Flight
  - Shortest possible distances
  - Highest potential travel time savings

  - Overflight of residential areas
  - High impact of noise emissions

- Use routing algorithms to find routes that avoid residential areas

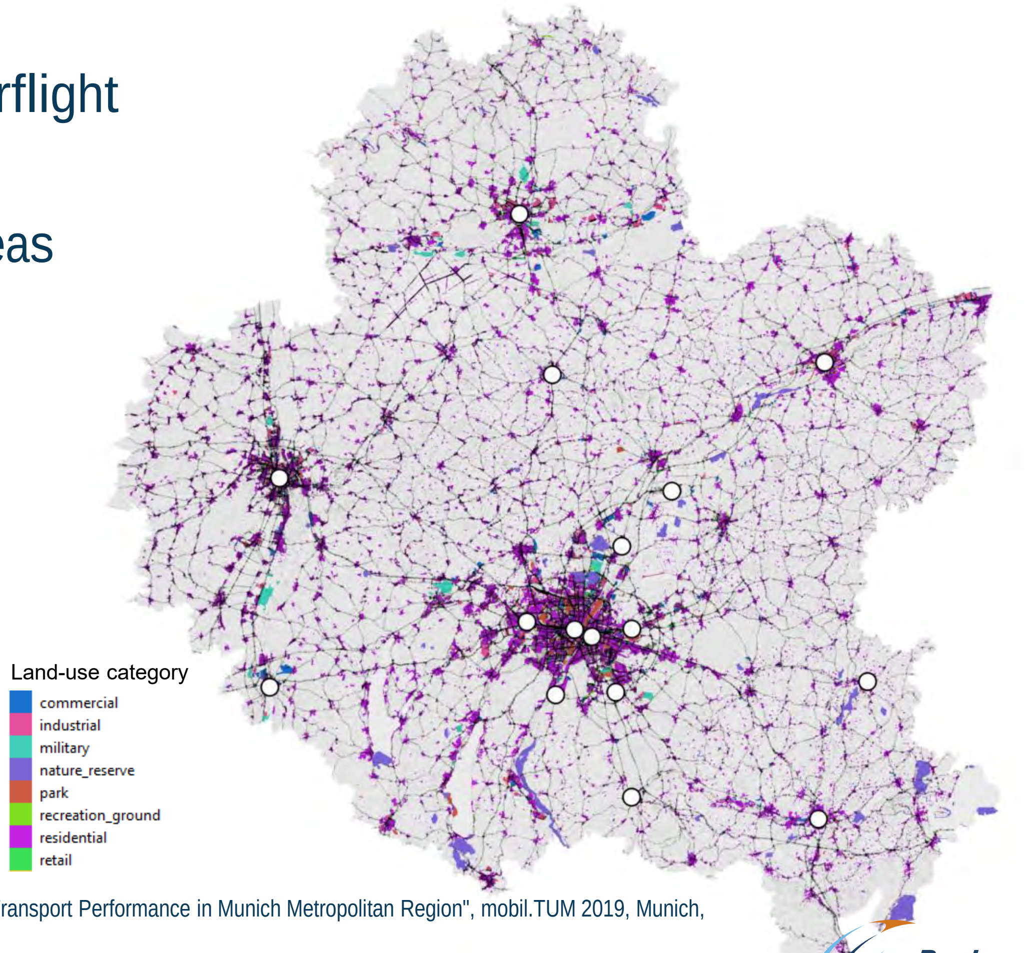


From R. Rothfeld, M. Fu, C. Antoniou, "Analysis of Urban Air Mobility's Transport Performance in Munich Metropolitan Region", mobil.TUM 2019, Munich, 2019.; methodology exemplified on a 16 vertiport network structure

Routing strategies

Restricting Residential Overflight

- Removal of residential areas
  - Data from OpenStreetMap
  - Removal of inhabited and protected areas (e.g. parks)
  - Overflight allowed over, e.g. lakes, forests, farm land



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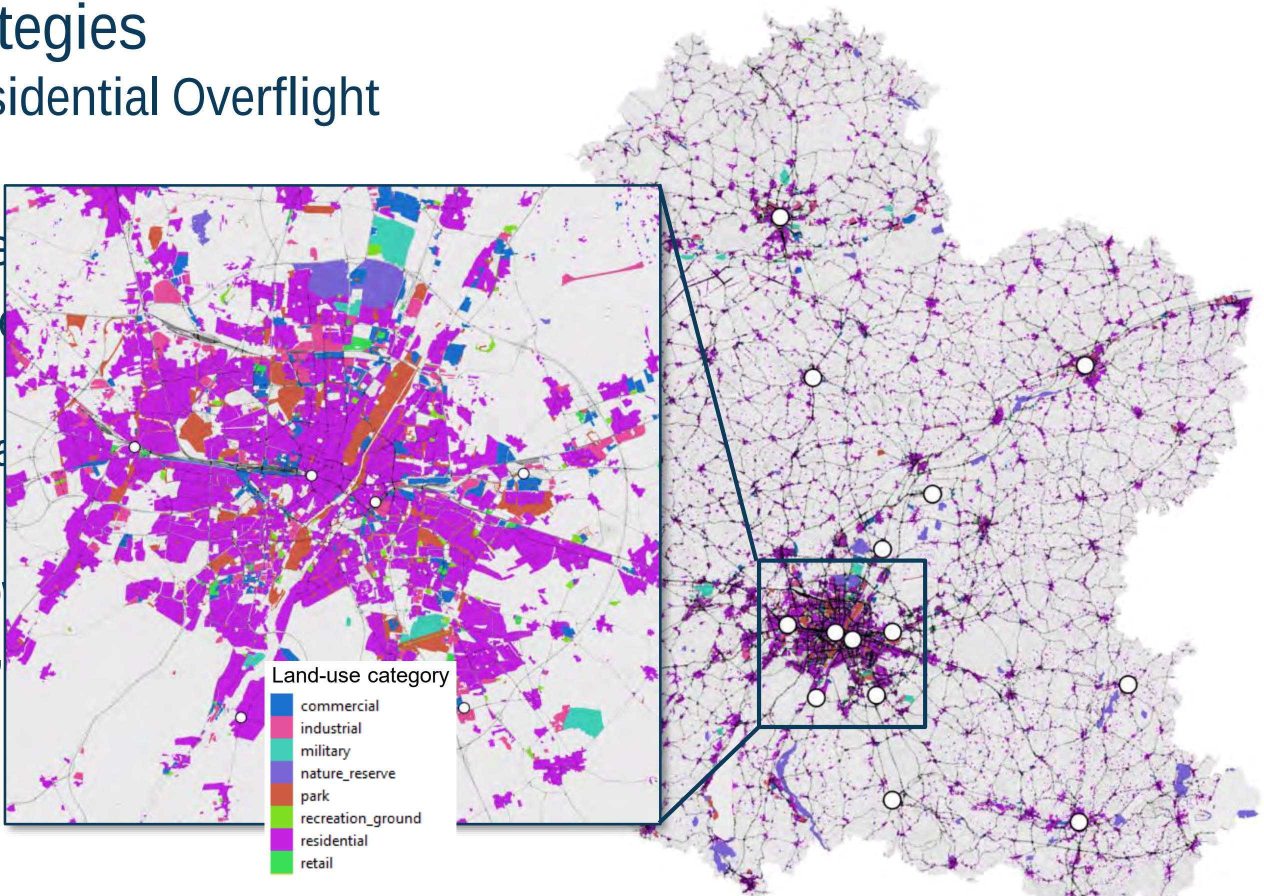

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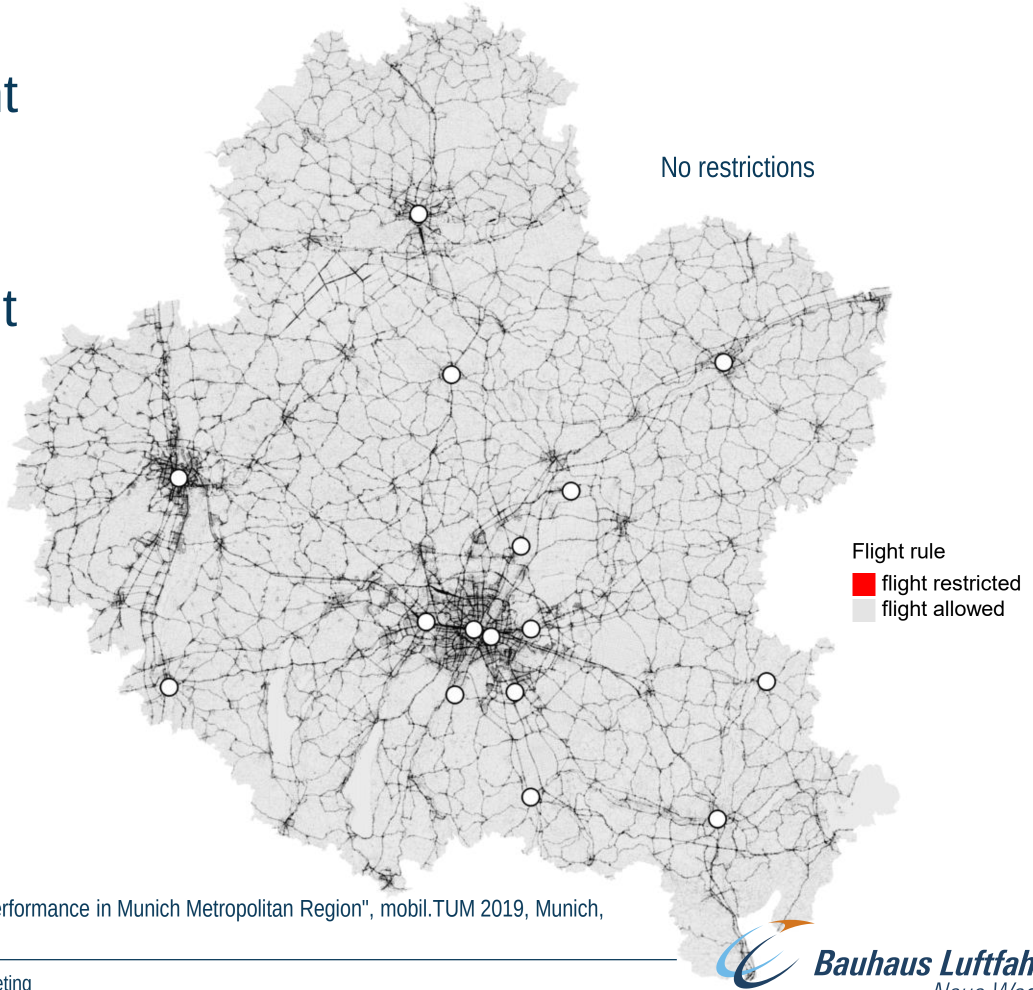
Routing strategies
Restricting Residential Overflight

- Remaining fly-able area when restricting residential overflight
  - No restrictions 100%



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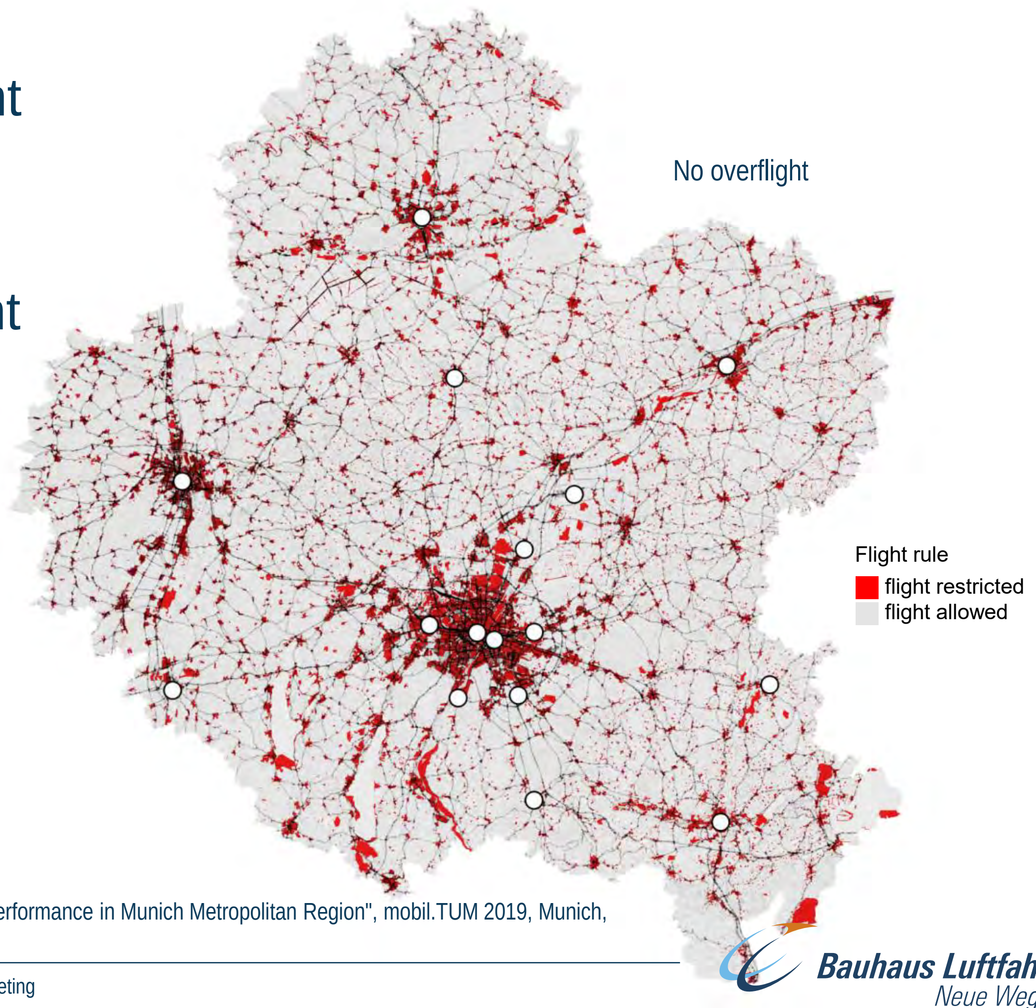
Routing strategies
Restricting Residential Overflight

- Remaining fly-able area when restricting residential overflight
  - No restrictions 100%
  - No overflight 89%



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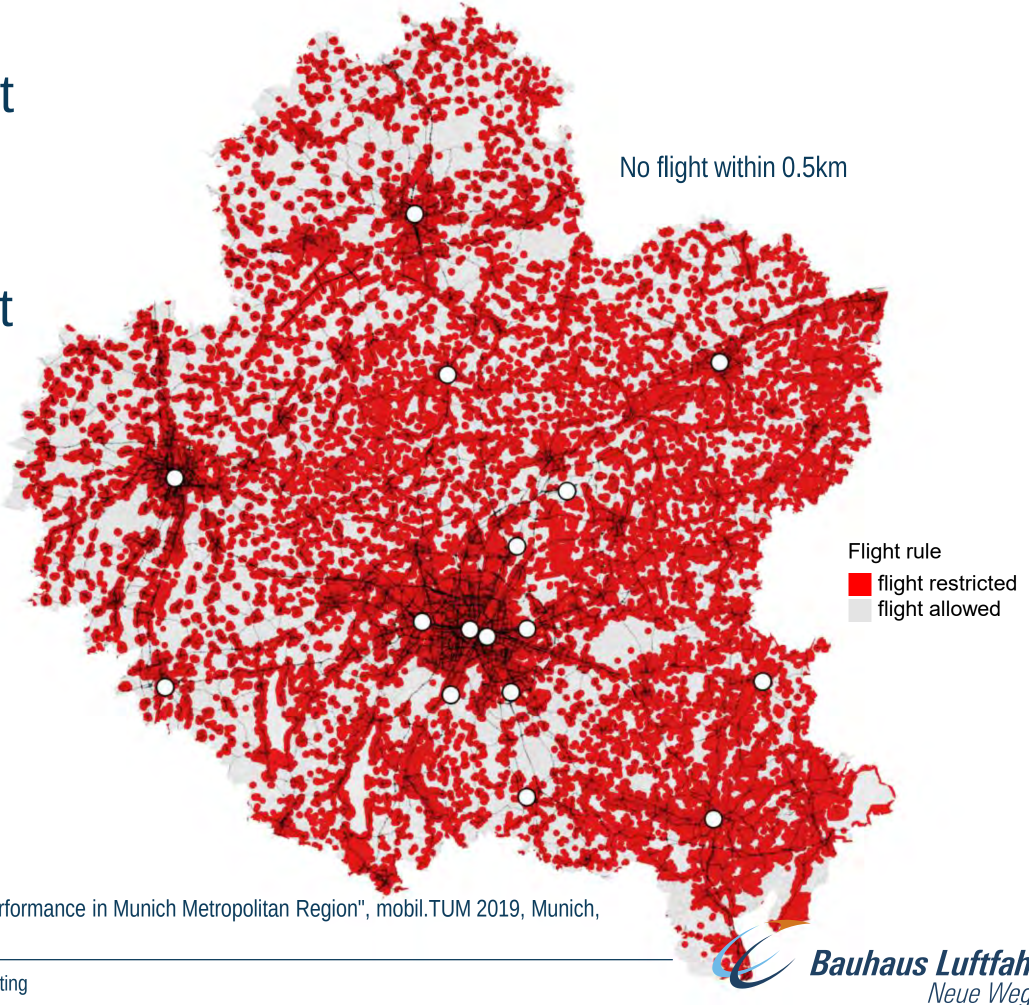
Routing strategies
Restricting Residential Overflight

- Remaining fly-able area when restricting residential overflight
  - No restrictions 100%
  - No overflight 89%
  - No flight within 0.5km 37%



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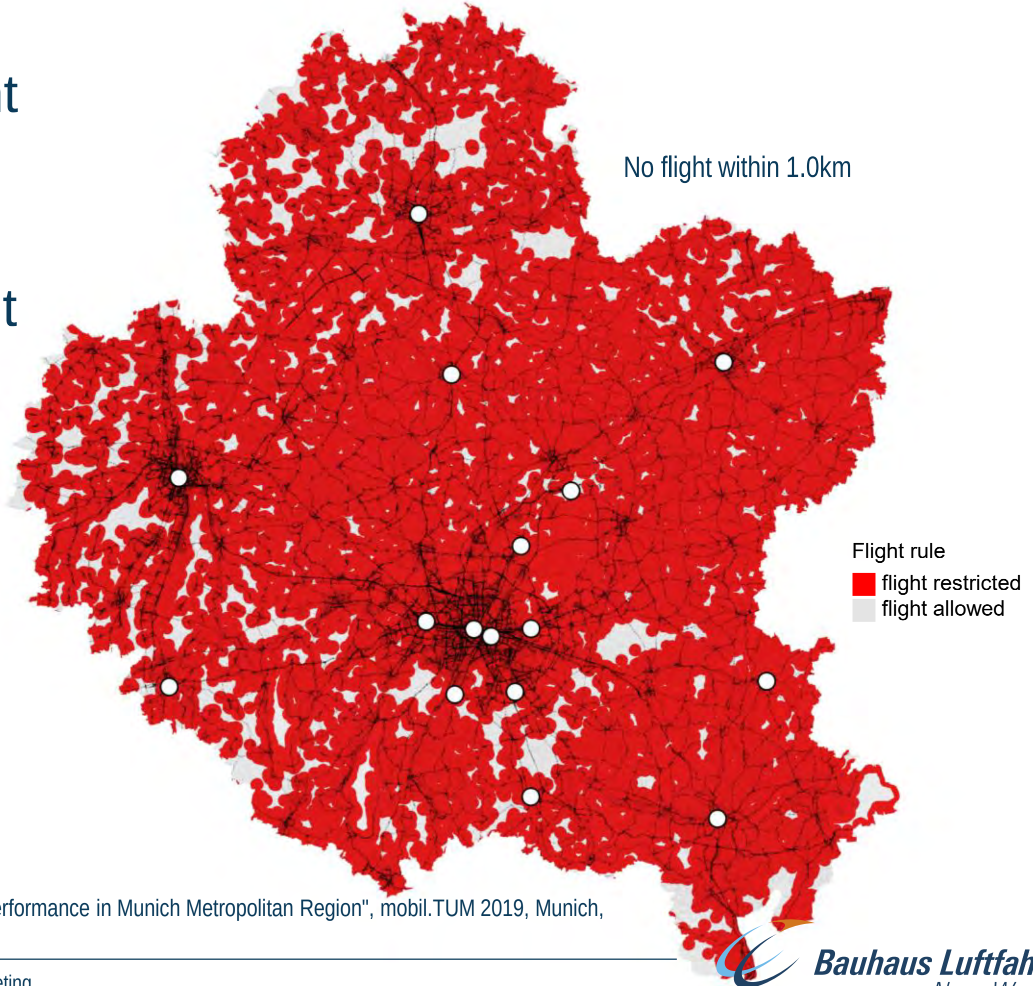

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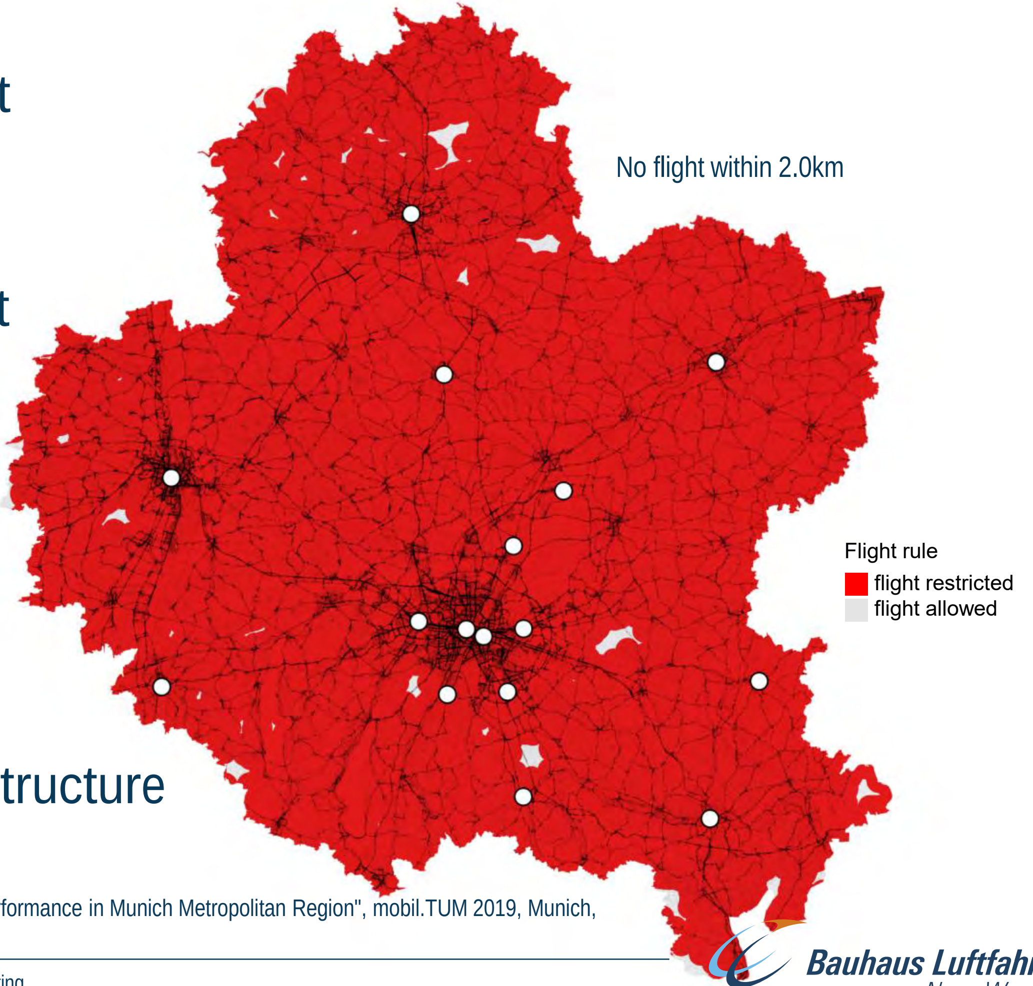
Routing strategies

Restricting Residential Overflight

- Remaining fly-able area when restricting residential overflight
  - No restrictions 100%
  - No overflight 89%
  - No flight within 0.5km 37%
  - No flight within 1.0km 11%
  - No flight within 2.0km 1%
- Use of existing transport infrastructure for noise overlay and safety

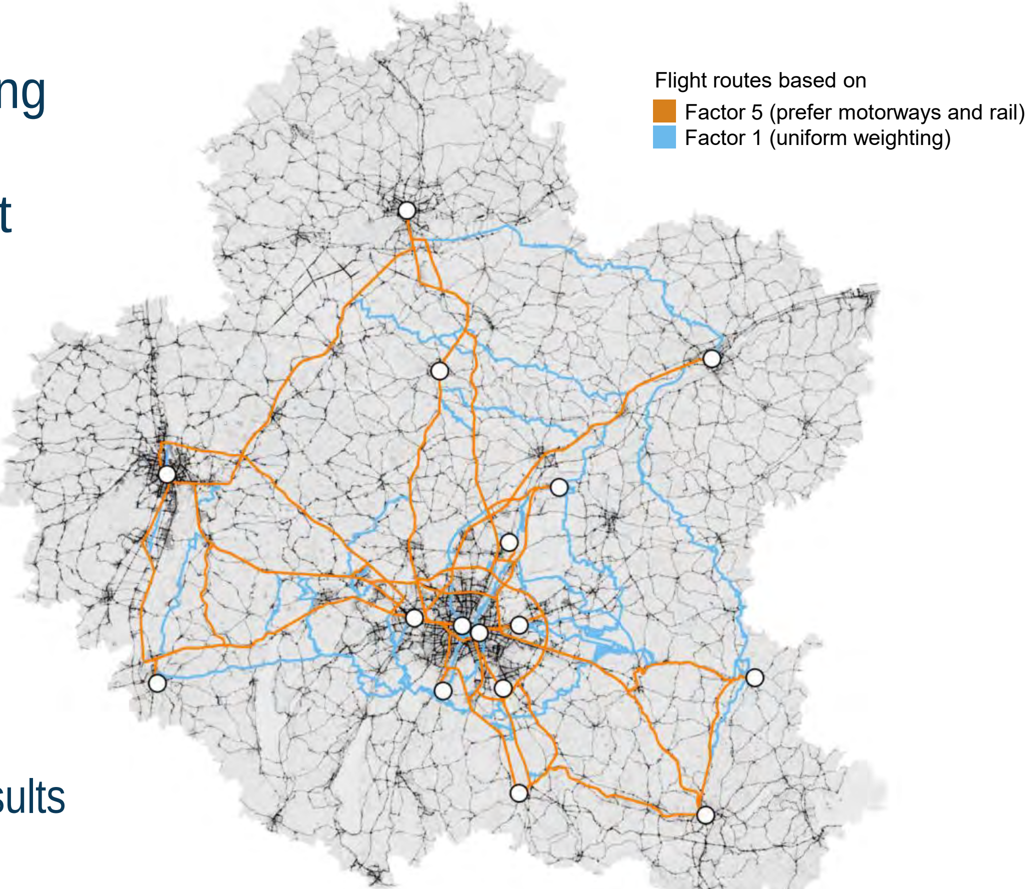


From R. Rothfeld, M. Fu, C. Antoniou, "Analysis of Urban Air Mobility's Transport Performance in Munich Metropolitan Region", mobil.TUM 2019, Munich, 2019.; methodology exemplified on a 16 vertiport network structure

Routing strategies

Infrastructure-based Flight Routing

- Using OpenStreetMap transport infrastructure for routing
  - Prioritisation based on categories:
    1. Regional and high speed rail, as well as motorways and primary roads
    2. Secondary and tertiary roads
    3. All other roads or e.g. tram
  - Variation in prioritisation factors results in higher/lower detour factors



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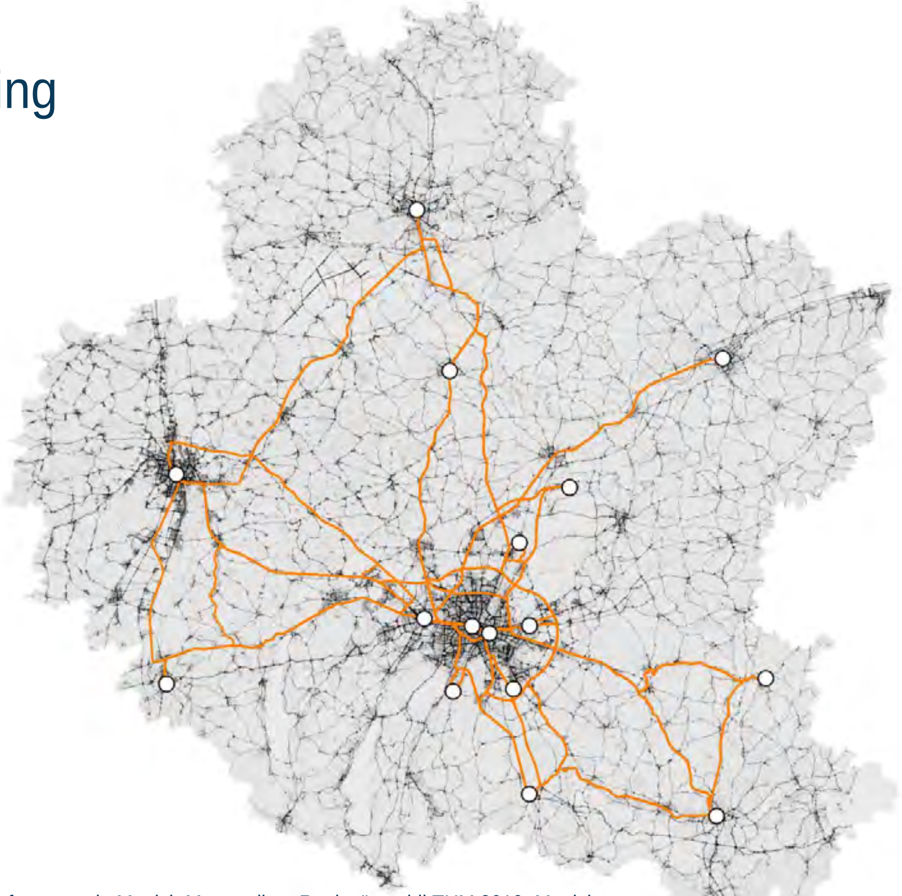
Routing strategies
Infrastructure-based Flight Routing

- Final applied factor
  - Factor 3 has been selected as the prioritisation factor based on the sensitivity analysis → usage of both main roads and smaller roads



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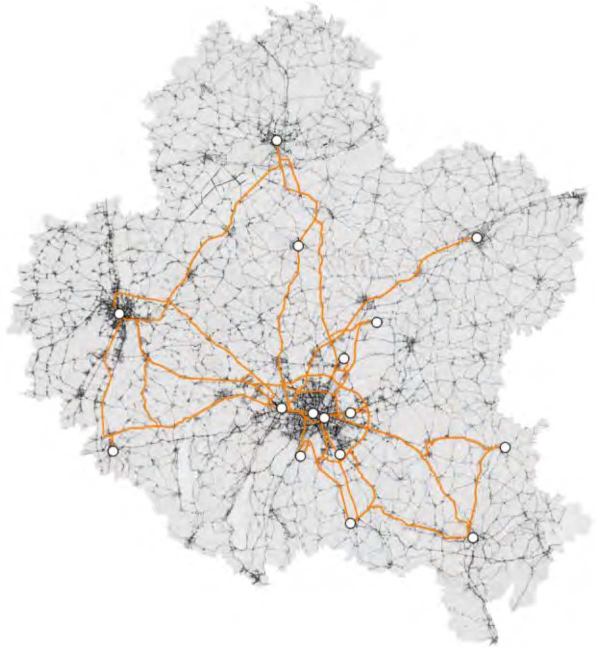
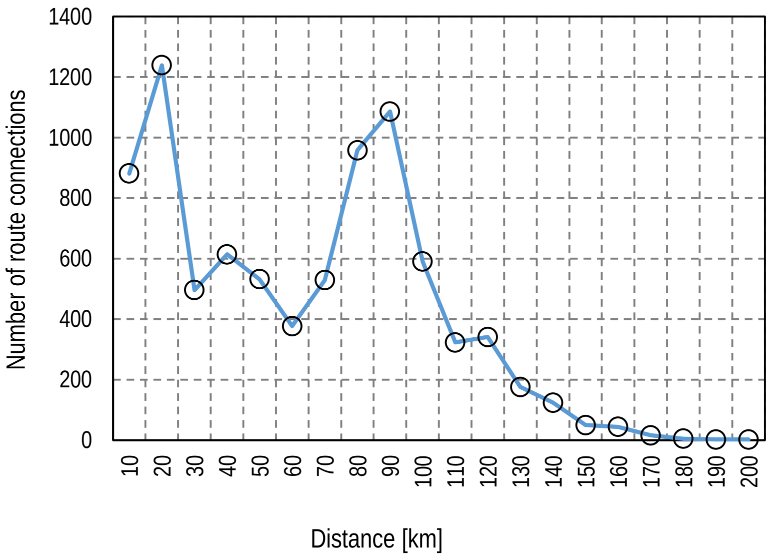
Routing strategies

Distribution of route distances based on the high density network





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Technische Hochschule Ingolstadt

OBUAM:

BUSINESS MODEL , INFRASTRUCTURE AND LEGAL FRAMEWORK

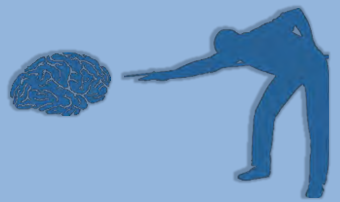
Sponsored by

Bavarian Ministry of Economic Affairs,
Regional Development and Energy

Basic information – what is it about?

Objective

To show how future **UAM-based passenger transport** can **complement public transport** in upper bavaria as part of an UAM provider business model to generate **thought-provoking ideas for today**



Sub-objective

To **identify sensitive variables** in order to attain **taxi comparable prices** for the customers

≈2 €/Km

Time outlook

due to **not yet existing** infrastructural conditions, legal framework, mature devel-oped eVTOLs and a positive population attitude

2030

Methods

Derivations
&
Assumptions

f(x)

↓

f‘(x)

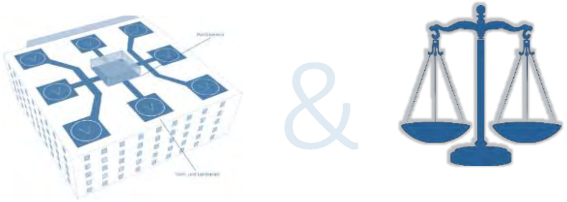
Content

1\.

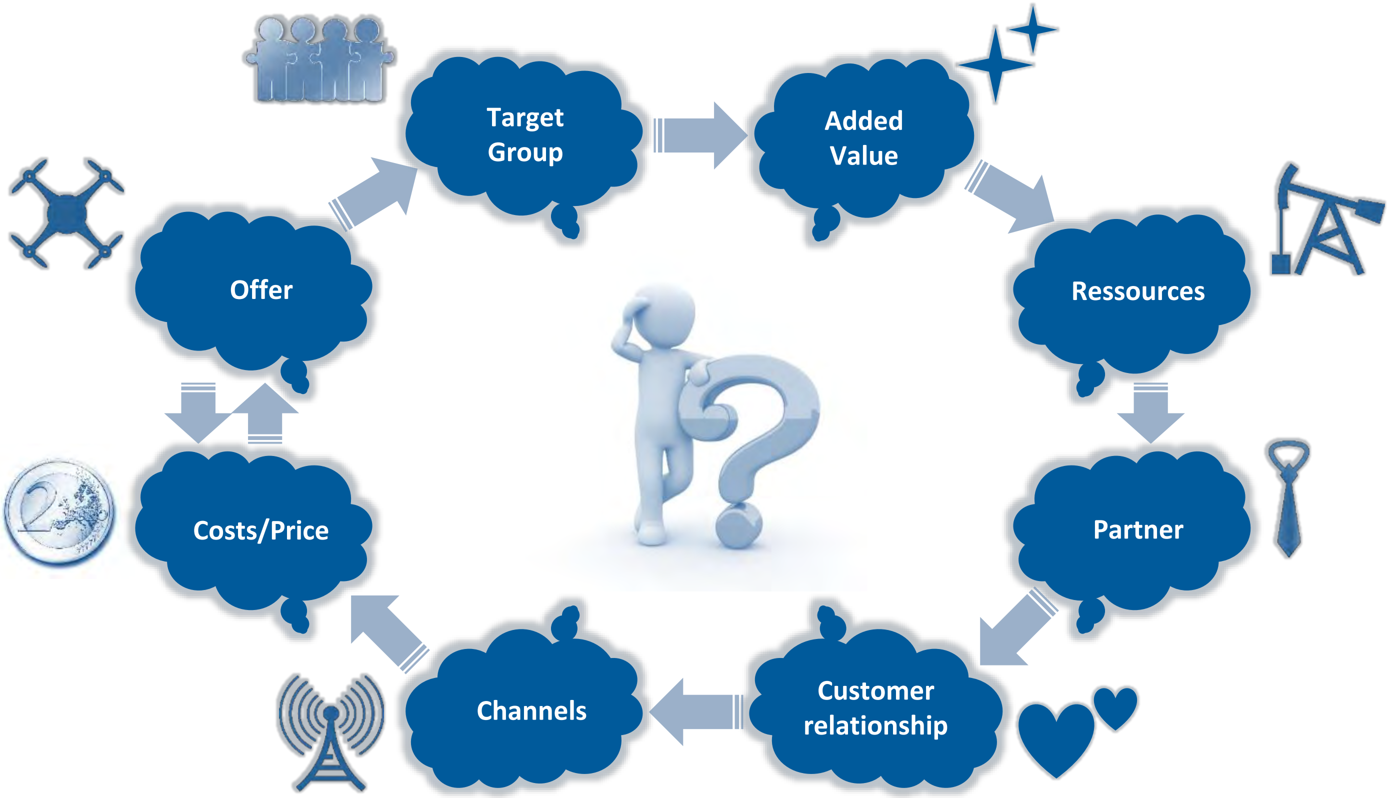
UAM provider business model

2\.

Infrastructural conditions and **legal framework**



UAM provider business model



UAM provider business model

Offer?

Passenger transportation as a complement for public transport

Maybe the passenger can **choose a prefered profile** of the passenger he or she has to travel with

UAM provider business model

Target Group?

Commuter	Accesibility
Business	Tourism

UAM provider business model

Added Value?

Time saving

Stress reduction

Experience/ adventure

UAM provider business model

Ressources?

Ground infrastructure	Legal framework	Maintenance/ repair	Platforms (APP etc.)
eVTOLs	Ground staff	Marketing concept	Security concept

UAM provider business model

Partner?

- Infrastructure operator
- Deutsche Flugsicherung
- Government agencies
- Component supplier
- Investors/ sponsors
- Meteorological services
- Transportation companies
- Academical institutions
- Battery developer

UAM provider business model

Customer relationship?

Marketing activities	Feedback system	Secure system	Comfort
On-board communication	Service hotline	Reliability	Transparency

UAM provider business model

Channels?

Homepage/ APP	Social media	Classic media
Infotainment	Exhibitions/ events	Customers

UAM provider business model – basis of calculation

- Autonomous steering
- 40 Km flight route/average
- 600 m/min take-off/landing
- 12 hours/day in average
- 110 kWh battery capacity
- 15 minutes ground handling
- 600 meter flight level
- 100 % occupancy
- 300 days usage/year

Costs/price ?

Scenario	Stations	Vehicle/station	Passenger capacity/vehicle	Vehicle cruise speed
A	24	10	2 (900 Kg)	50 Km/h
B	24	50	2 (900 Kg)	80 Km/h
C	74	50	2 (900 Kg)	100 Km/h
D	74	50	4 (2,200 Kg)	150 Km/h
E	130	100	4 (2,200 Kg)	300 Km/h

UAM provider business model – calculation

Scenario A

UAM provider business model – Scenario A

		Costs/flight
Staff		15.02 €
Vehicle	Maintenance	12.30 €
	Repair	11.36 €
	Battery	1.65 €
	Depreciation	33.86 €
Vertiport	Landing costs	95.00 €
	Fixed rate	20.00 €
ATM	Base rate	7.46 €
	Route tariff	3.42 €
Energy		6.48 €
Taxes/duties	Air traffic taxe	16.00 €
	Safety/environmental taxe	10.00 €
	Fixed rates	30.00 €
	Insurance	1.19 €
Costs		263.74 €

5,400 passengers/day

24 stations

10 vehicles/station

2 passengers

50 Km/h cruise speed

	Costs/flight
Costs	263.74 €
Marketing (20 %)	52.75 €
Costs 2	316.49 €
Profit (5 %)	15.82 €
Price net	332.31 €
VAT (19 %)	63.14 €
Gross list price	395.45 €
Price Km/passenger	4.94 €

UAM provider business model – Scenario A

		Costs/flight	-70 % LC
Staff		15.02 €	
Vehicle	Maintenance	12.30 €	
	Repair	11.36 €	
	Battery	1.65 €	
	Depreciation	33.86 €	
Vertiport	Landing costs	95.00 €	28.50 €
	Fixed rate	20.00 €	
ATM	Base rate	7.46 €	
	Route tariff	3.42 €	
Energy		6.48 €	
Taxes/duties	Air traffic taxe	16.00 €	
	Safety/environmental taxe	10.00 €	
	Fixed rates	30.00 €	
	Insurance	1.19 €	
Costs		263.74 €	197.24 €

5,400 passengers/day

24 stations

10 vehicles/station

2 passengers

50 Km/h cruise speed

	Costs/flight	-70 % LC
Costs	263.74 €	197.24 €
Marketing (20 %)	52.75 €	39.45 €
Costs 2	316.49 €	236.69 €
Profit (5 %)	15.82 €	11.83 €
Price net	332.31 €	248.52 €
VAT (19 %)	63.14 €	47.22 €
Gross list price	395.45 €	295.74 €
Price Km/passenger	4.94 €	3.70 €

UAM provider business model – Scenario A

		Costs/flight	-70 % LC	-70 % LC / 4-seats
Staff		15.02 €		
Vehicle	Maintenance	12.30 €		
	Repair	11.36 €		
	Battery	1.65 €		
	Depreciation	33.86 €		
Vertiport	Landing costs	95.00 €	28.50 €	28.50 €
	Fixed rate	20.00 €		
ATM	Base rate	7.46 €		9.95 €
	Route tariff	3.42 €		4.27 €
Energy		6.48 €		6.00 €
Taxes/duties	Air traffic taxe	16.00 €		32.00 €
	Safety/environmental taxe	10.00 €		20.00 €
	Fixed rates	30.00 €		
	Insurance	1.19 €		
Costs		263.74 €	197.24 €	226.09 €

5,400 passengers/day

24 stations

10 vehicles/station

2 passengers

50 Km/h cruise speed

	Costs/flight	-70 % LC	-70 % LC / 4-seats
Costs	263.74 €	197.24 €	226.09 €
Marketing (20 %)	52.75 €	39.45 €	45.22 €
Costs 2	316.49 €	236.69 €	271.31 €
Profit (5 %)	15.82 €	11.83 €	13.56 €
Price net	332.31 €	248.52 €	284.87 €
VAT (19 %)	63.14 €	47.22 €	54.12 €
Gross list price	395.45 €	295.74 €	338.00 €
Price Km/passenger	4.94 €	3.70 €	2.11 €

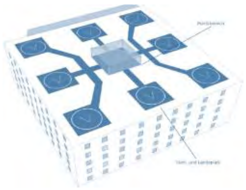
UAM provider business model – all scenarios

Scenario	Stations	Vehicle/ station	Passenger capacity/vehicle	Vehicle cruise speed	Passengers/ day	Price Km/passenger	Price -70 % landing costs	Price -70 % LC/4-seats
A	24	10	2 (900 Kg)	50 Km/h	5,400	4.94	3.70	2.11
B	24	50 ↑	2 (900 Kg)	80 Km/h ↑	37,560	4.63	3.38	1.96
C	74 ↑	50	2 (900 Kg)	100 Km/h ↑	133,200	4.53	3.28	1.91
D	74	50	4 (2,200 Kg) ↑	150 Km/h ↑	333,000	2.47	1.75	
E	130 ↑	100 ↑	4 (2,200 Kg)	300 Km/h ↑	1,560,000	2.40	1.77	

Content

2.

Infrastructural conditions and **legal framework**



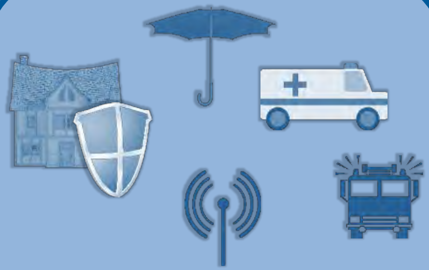
&

Infrastructural conditions and legal framework

A legal framework for building a vertiport does not exist

LuftVG (§6 Abs. 1 Satz 1)

General administrative rules



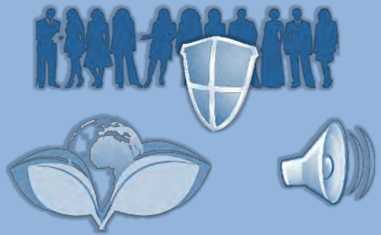
Approval & structural design to construct new aerodromes

ICAO Annex 14, Volume 2

Regulatories for infrastructure and operation of heliports

Less allowed flights per year

Plan approval procedure



Formal administrative procedure in the view of public interests

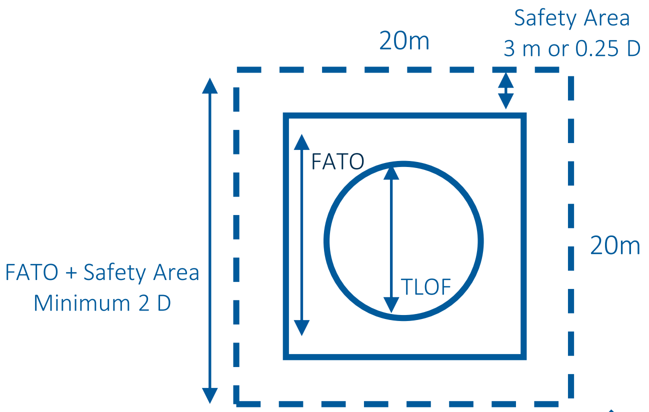
Up to 2 years

Infrastructural conditions and legal framework

ICAO Annex 14, Volume 2

Required modules for Helipads

- → FATO = Final Approach and Take-off Area
- → TLOF = Touchdown and Lift off
- → Safety Area
- → Visual aids

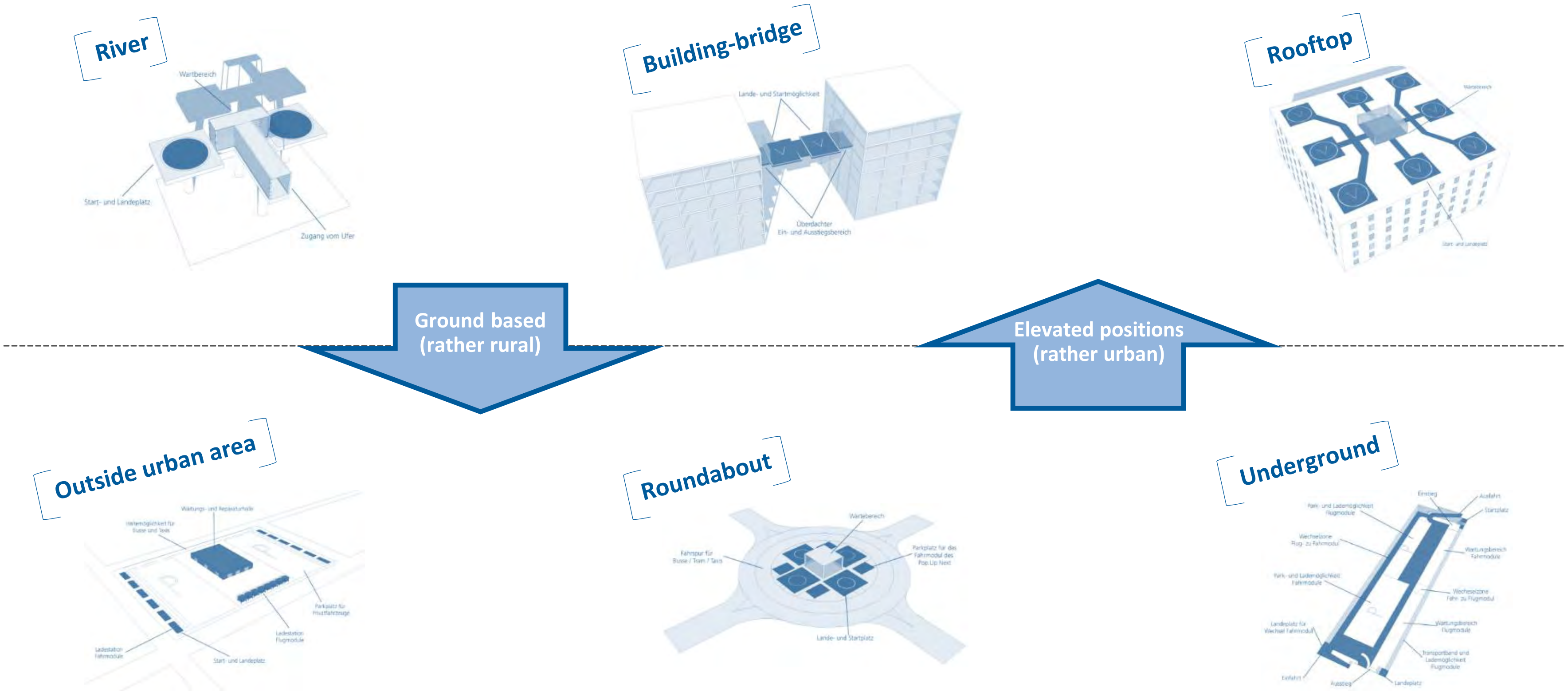


Legend:
D = maximum overall dimension on the Helicopter

A possible higher **accuracy** and **smaller** required **total area** due to **autonomous steering**

Parking pads = 16x16 meters

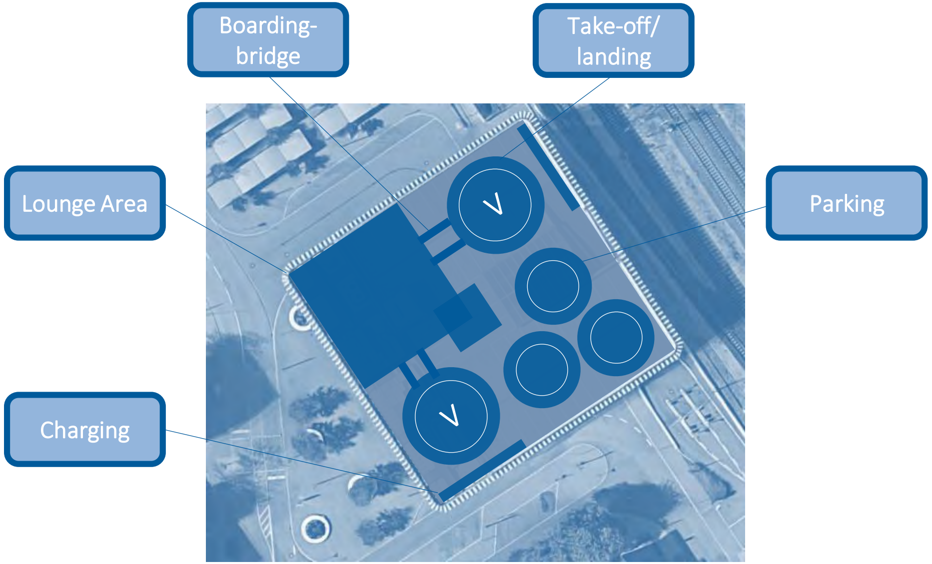
Infrastructural conditions and legal framework – design opportunities



Infrastructural conditions and legal framework

What does the vertiport need?

- Take-off and landing pads
- Parking areas (eVTOLs, Cars etc.)
- Charging infrastructure
- Digital infrastructure
- Passenger boarding bridges
- Lounge areas
- Autonomous check-In
- Storage areas
- Fire fighting system
- Escape and emergency routes
- Security
- system with a high degree of automation
- Acoustic insulation
- Feeder ways
- Appropriate buildings (static)



Infrastructural conditions and legal framework

Scenarios of Uber

Scenario	Stations	Vehicle/ station	Passenger capacity/vehicle	Vehicle cruise speed	Passengers/ day	qm/vertiport
A	24	10	2 (900 Kg)	50 Km/h	5,400	4,160
B	24	50 ⬆	2 (900 Kg)	80 Km/h ⬆	37,560	20,400
C	74 ⬆	50	2 (900 Kg)	100 Km/h ⬆	133,200	21,200
D	74	50	4 (2,200 Kg) ⬆	150 Km/h ⬆	333,000	23,200
E	130 ⬆	100 ⬆	4 (2,200 Kg)	300 Km/h ⬆	1,560,000	53,000

Quintessence
A high degree of automation of all processes (e.g. security, surveillance) is needed to generate a high throughput similar to train stations

But
due to the vertiport size it is a difficult scenario for urban regions like munich!

Task for the future
Develop appropriate vertiport solutions for urban regions with a high throughput

Conclusion

What do specific vertiports in munich and ist surrounding area look ike to realise UAM as a complement to public transport?

Appropriate infrastructure

What is a necessary specific legal framework for using autonomous eVTOLs for passenger transport in German urban and rural areas?

Legal framework

To Be Done

What are the criteria for eVTOLs to realise a high passenger throughput in a public transport complementary UAM network?

eVTOL development

Which are the methods to create a positive population attitude regarding the passenger transport per autonomous eVTOLs in Germany?

Population attitude

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Neue Wege.

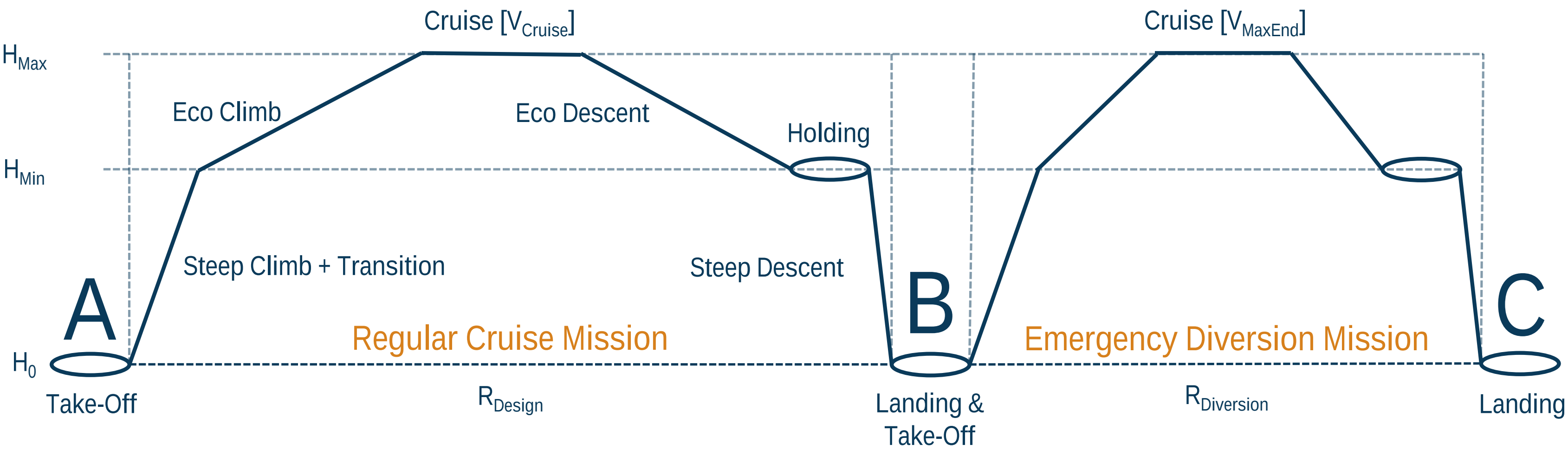
Vehicle Design & Mission Requirements

Michael Shamiyeh

OBUAM Final Conference,
München, 30.01.2020

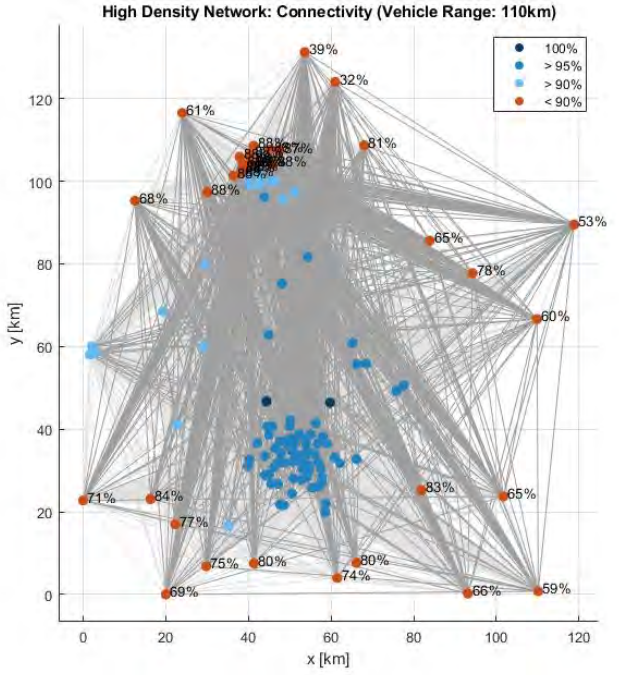
Gefördert durch
Bayerisches Staatsministerium für
Wirtschaft, Landesentwicklung und Energie

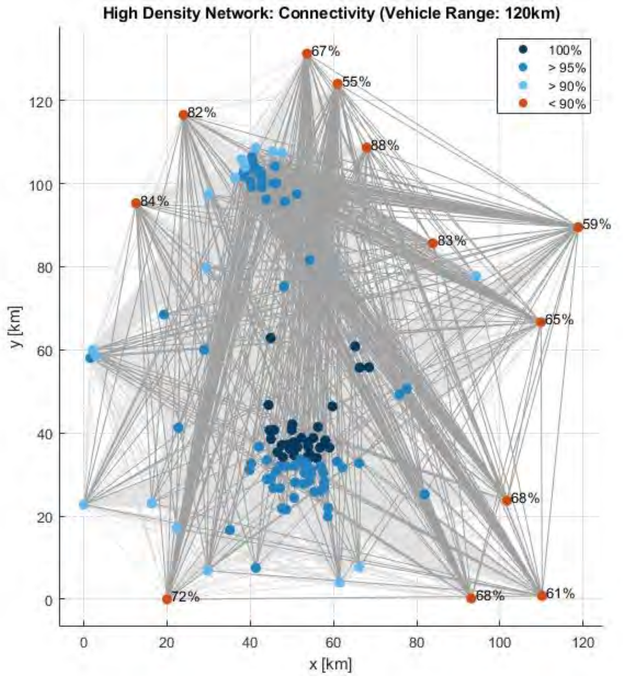
Aircraft Design Mission for Oberbayern UAM



- Single Leg + Diversion:
  - Recharging infrastructure required at most vertiports
- Steep/Vertical Climb:
  - H_{Min} = 100m AGL
  - Obstacle Clearance/Noise Abatement
- Holding: 1min
  - for operational uncertainties

Aircraft Design Range (1)





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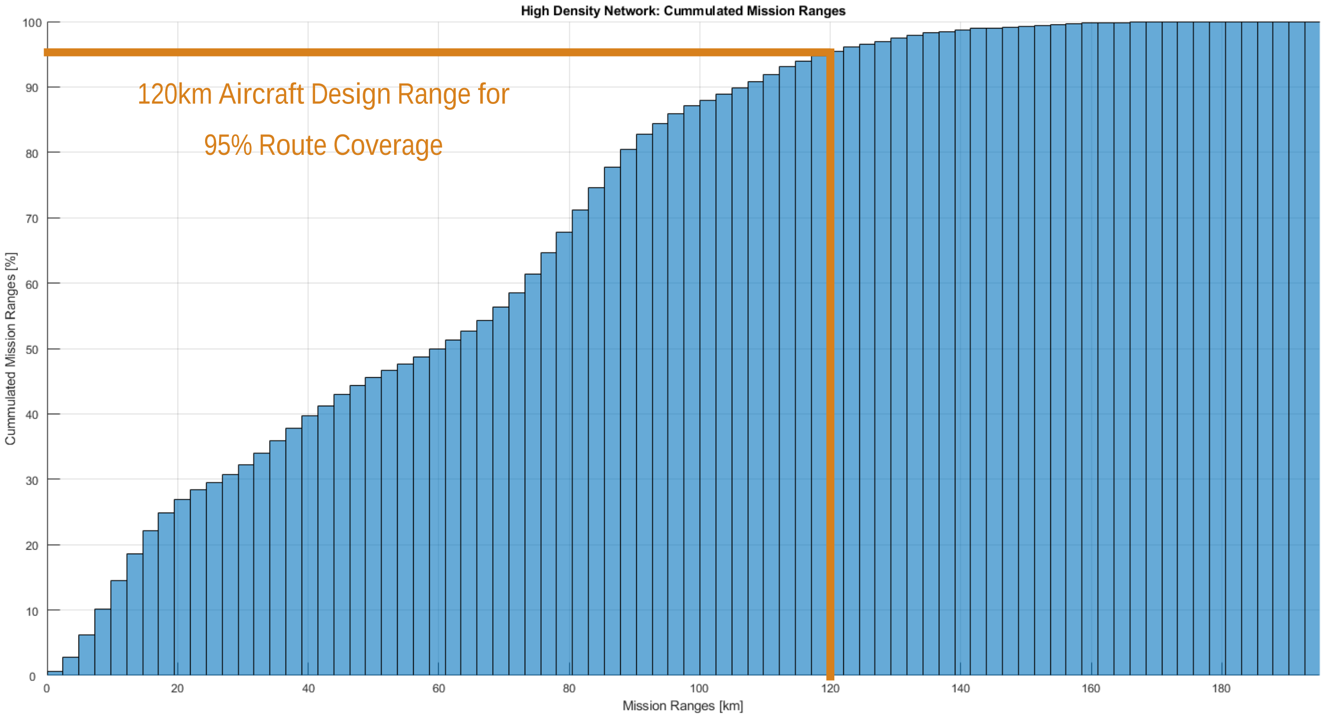
Aircraft Design Range (2)



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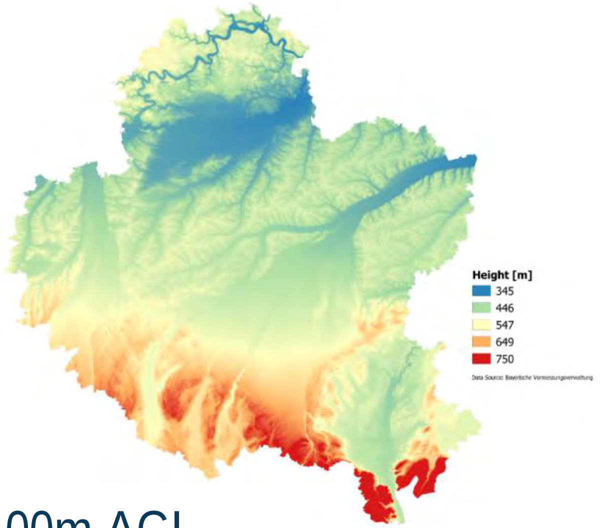
Altitudes



- Assumptions:
  - Detailed and up-to-date data on obstacles and geographical characteristics available
  - High-performance sense-and-avoid system available for aircraft, real-time coordinated flight
- Specified cruise altitudes: H_{Min} = 100m AGL, H_{Max} = 400m AGL
  - Four flight levels with an assumed vertical separation of 100m.
- Considering vertiport elevation: $H_{Max} = H_{Max}$ **+ ΔH = 800m** AGL
- Minimum cruise altitude may have to be increased due to noise.

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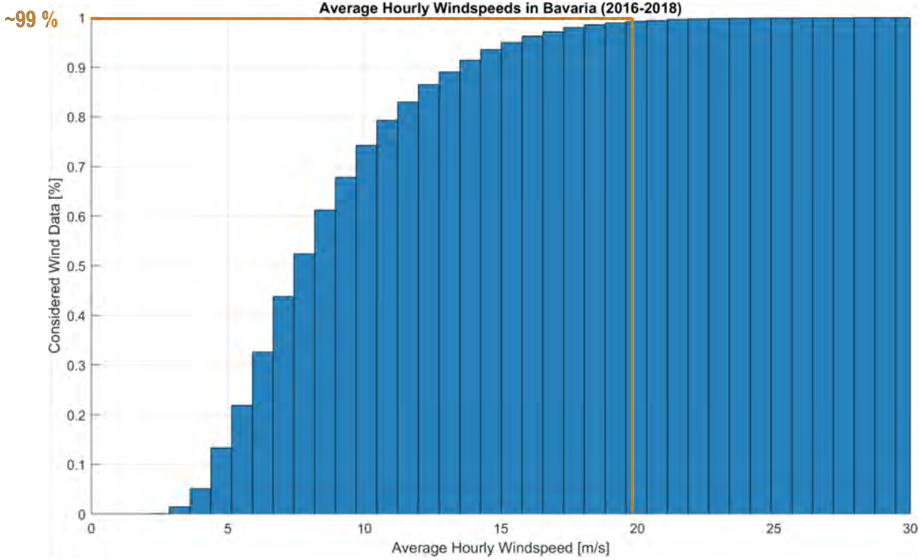
Weather & Climate

- Aircraft design for VTOL at ISA+30°

- Design mission with headwind:
  - Evaluation of hourly average windspeeds for the years 2016-2018
  - 66 weather stations, wind speeds 10m above ground
  - Source: Climate Data Center of the Deutscher Wetterdienst



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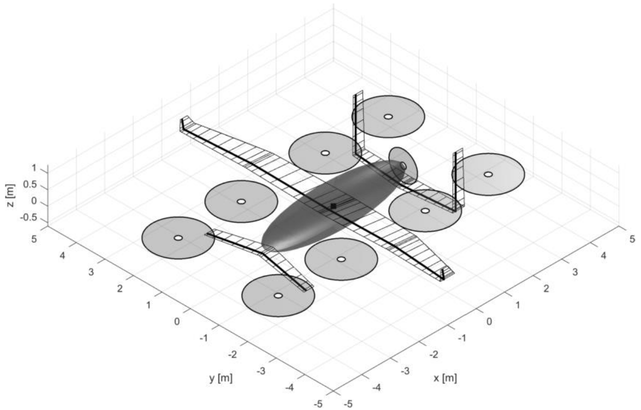
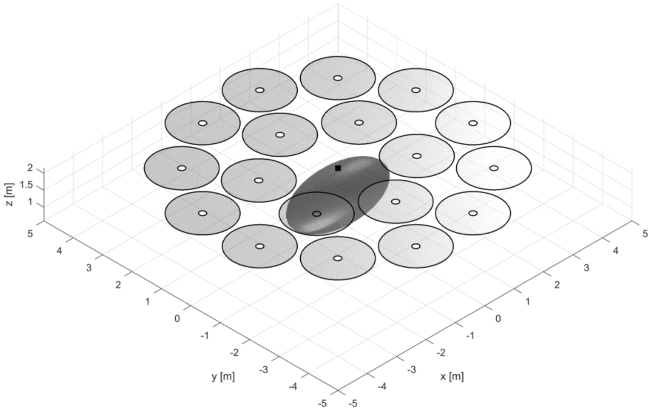
VTOL Aircraft Configurations

- Long-Range Aircraft:
  - Lift+Cruise Configuration
  - 120km Design Range
  - 180km/h Cruise Speed



- Short-Range Aircraft:
  - Multicopter
  - 40km Design Range
  - 70km/h Cruise Speed



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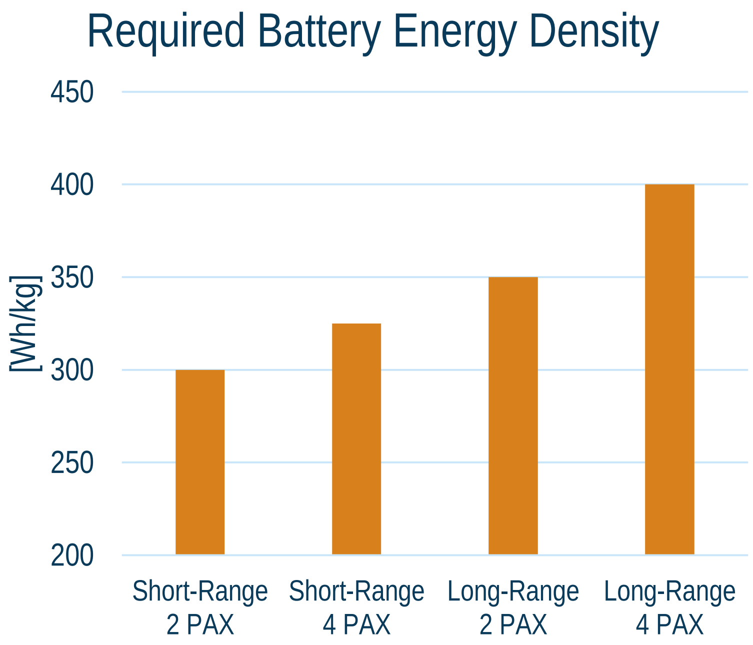
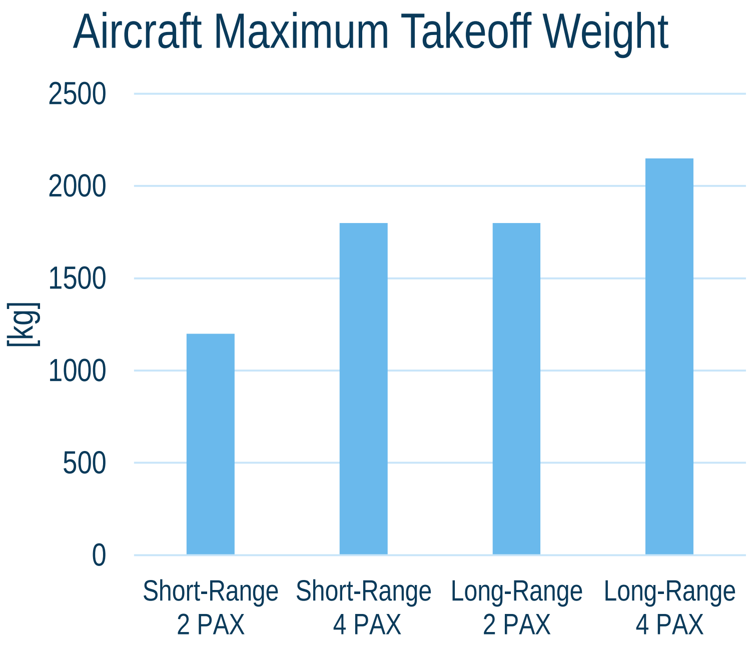
Technology Requirements: Battery Specific Energy





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Regulatory Aspects & Sensitivity Analysis

Sponsored by
Bavarian Ministry of Economic Affairs, Regional Development and Energy

Anna Straubinger

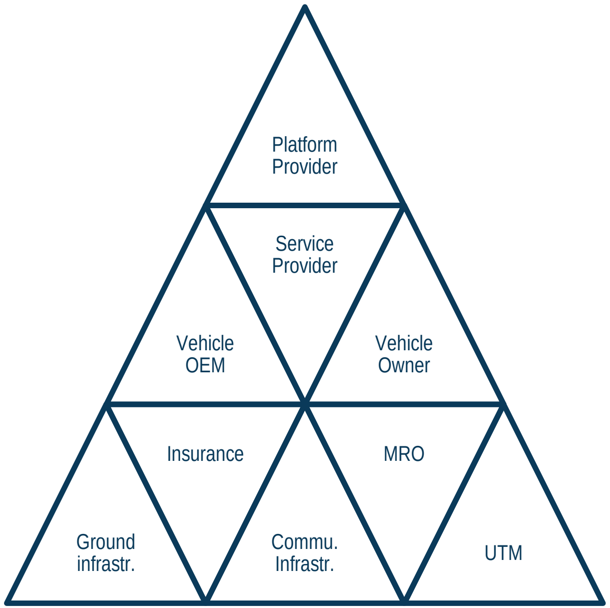
OBUAM Final Conference,
Ingolstadt, 19.11.2019

Market Regulation

Market Regulation and Policies

- Market structure on the different levels still unclear
  - Monopolies, oligopolies, perfect competition
  - Level of vertical integration relevant as well

- Are there reasons for regulatory interventions?
  → Yes! Market power, externalities, information asymmetry, public goods
  → otherwise: market failure

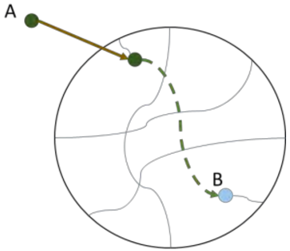
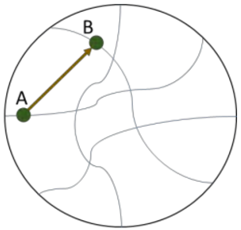
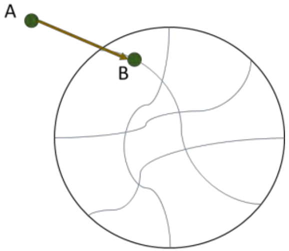


Options for Regulation

- Quantity regulation: concessions
- Quality regulation: Considering safety/environmental/schedule standards mandatory
- Price regulation: congestion tolls, peak-load pricing, taxes, subsidies,...
- Market entry/exit: tender for the market

Integration with Public Transport

(as presented at mobil.TUM 2019 (A. Straubinger, M. Fu, "Identification of Strategies How Urban Air Mobility Can Improve Existing Public Transport Networks", mobil.TUM 2019, Munich, 2019.))

<table>
<tr><th>Feeder concept
Connecting between rural area and city or two cities, enabling passengers to access the PT system of the destination city. Similar to P+R concept</th><th colspan="2">PT Improvement
Directly connecting between rural area and city or two cities, supplementing current PT system (e.g. reducing the efforts transferring between different PT lines) by adding on-demand UAM routes instead of setting up completely new PT routes (especially for OD pairs with low demand).</th></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Vertiport can be part of, e.g. multimodal mobility stations, providing a chance for the integration of UAM and the current existing PT lines.</td><td>UAM directly connects two vertiports within a city (as part of multimodal mobility stations).</td><td>UAM directly connects an origin outside the destination city with a location within the destination city.</td></tr>
<tr><td>PT network</td><td>UAM route
PT route</td><td>Destination point
Vertiport</td></tr>
</table>

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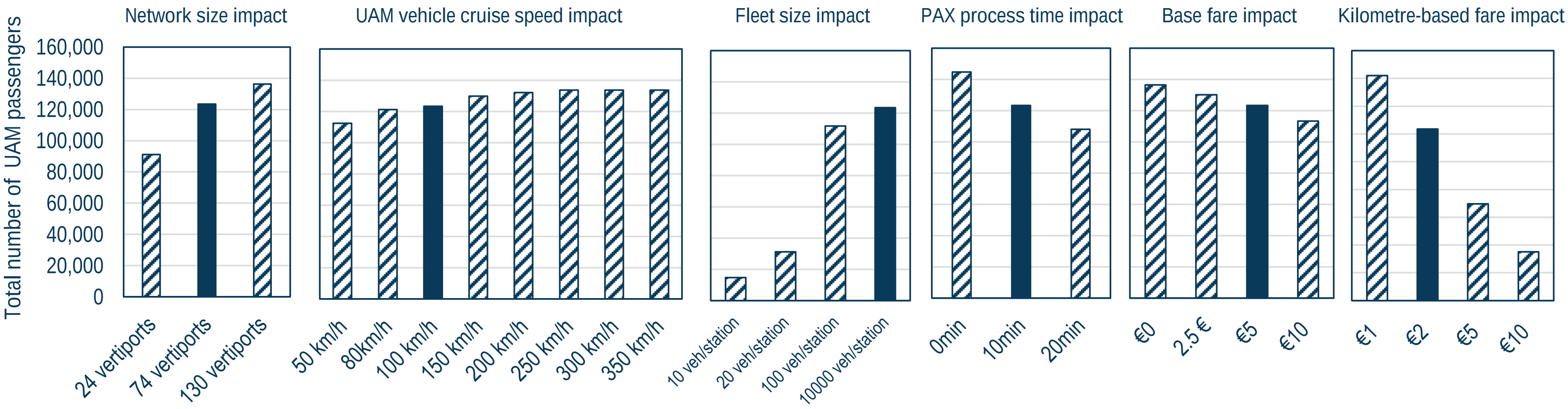
Possible Implications for UAM Operations

- UAM prices might be fixed
- Fleet size might be restricted
- Business models might be adapted
- Network design might change in order to incorporate no-fly zones, noise restrictions or curfew hours
- Network design might change in order to prohibit direct competition with public transport routes
- Infrastructure size and locations
- Possible flight distances might be restricted to prohibit very short trips

Sensitivity Analysis

- Network size
- Vehicle cruise speed
- Number of UAM vehicles per vertiport
- Passenger process time at vertiports
- Ticket fares

Factors Influencing Demand



- Fleet size and kilometre dependent prices have the strongest impact on demand
- Vehicle speed only has a minor impact (most trips are on rather short distances; travel time savings thus are minor)

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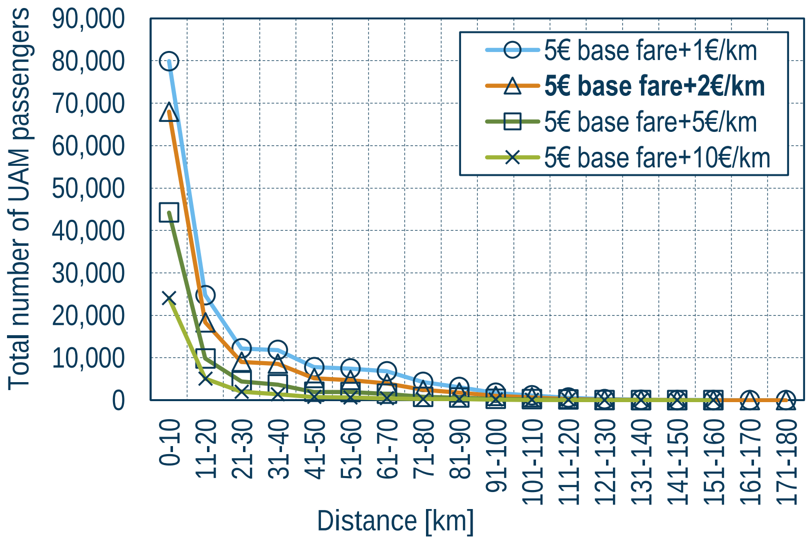
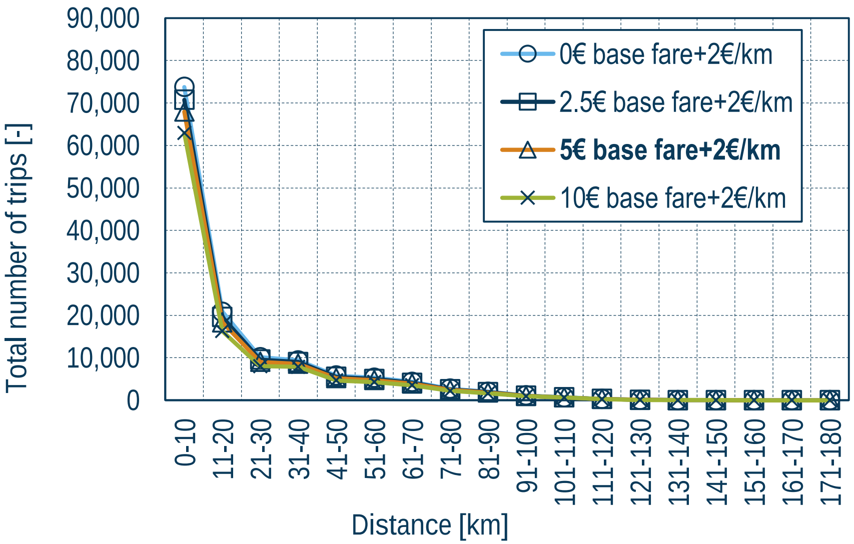
Price Variation – Absolute Changes





- Changes on the kilometer dependent fare have higher impact on overall demand for UAM than changes on the base fare

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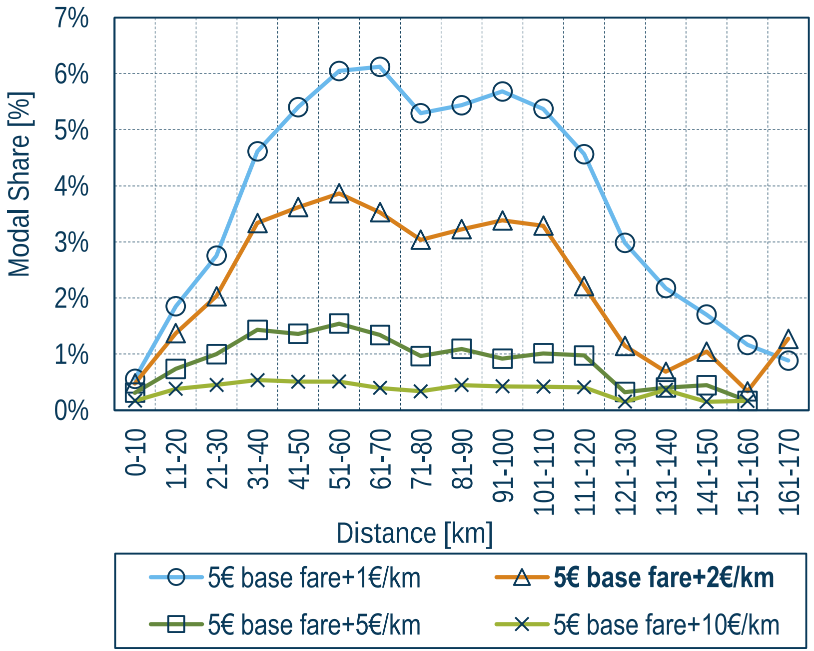
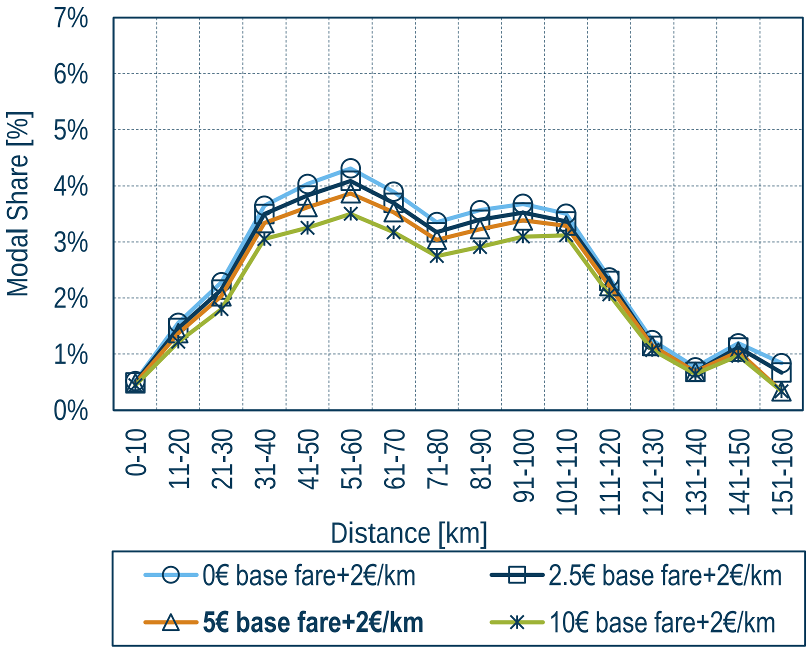
Price Variation – Changes of Mode Choice





- This is even more clear when looking at relative numbers

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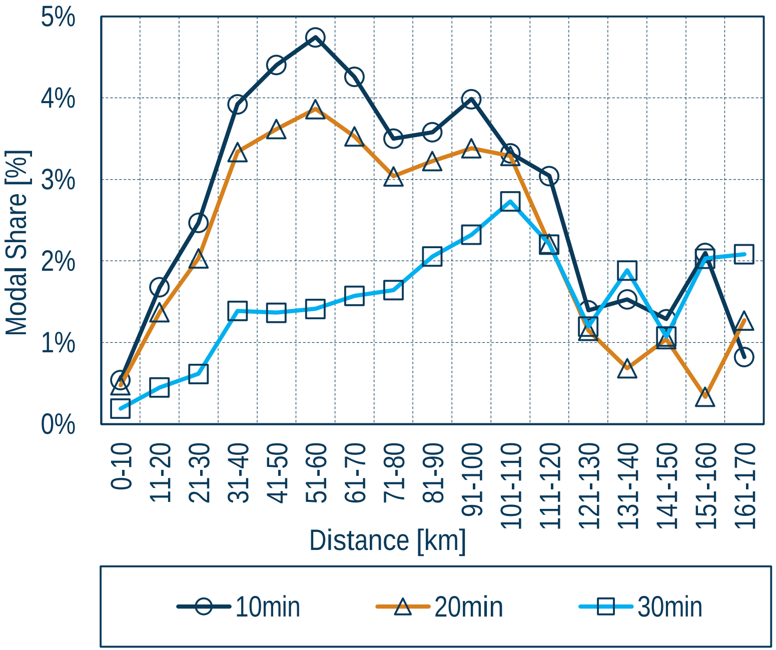
Demand Response to Changes in Process Time



- Process times before and after flights have a massive influence on demand on shorter routes

- The shorter the travelled route the larger the impact of increasing waiting times

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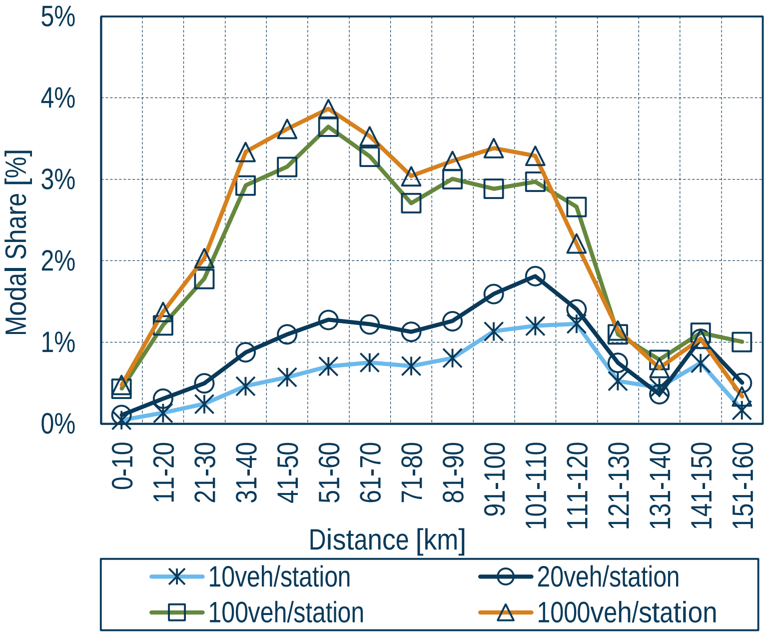
Demand Response to Vehicle Fleet Size



- The number of vehicles per station and thus the fleet size have a massive impact on UAM demand
- The number of available vehicles mainly influences the waiting time, therefore the impact is stronger on short routes

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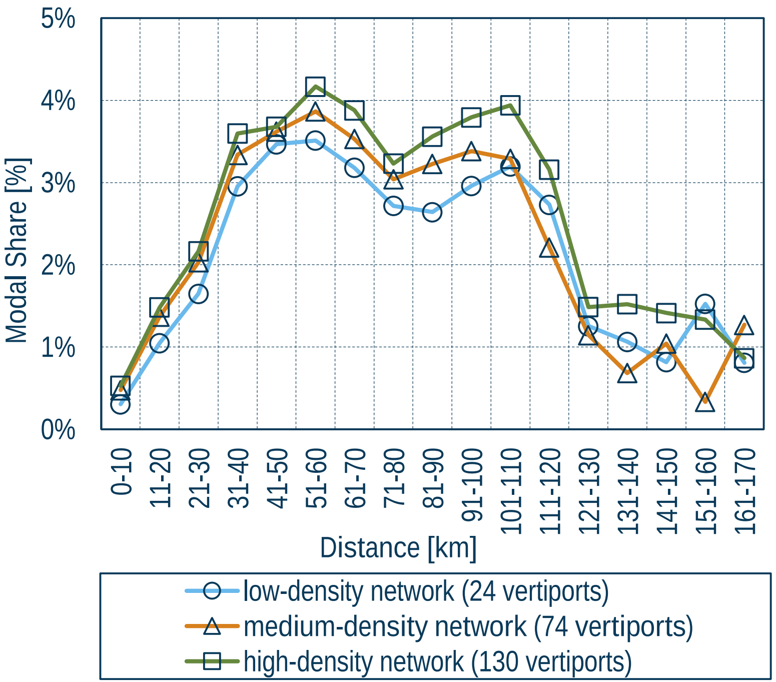
Demand Response to Changes in the Network



- Network density only has a minor influence on demand

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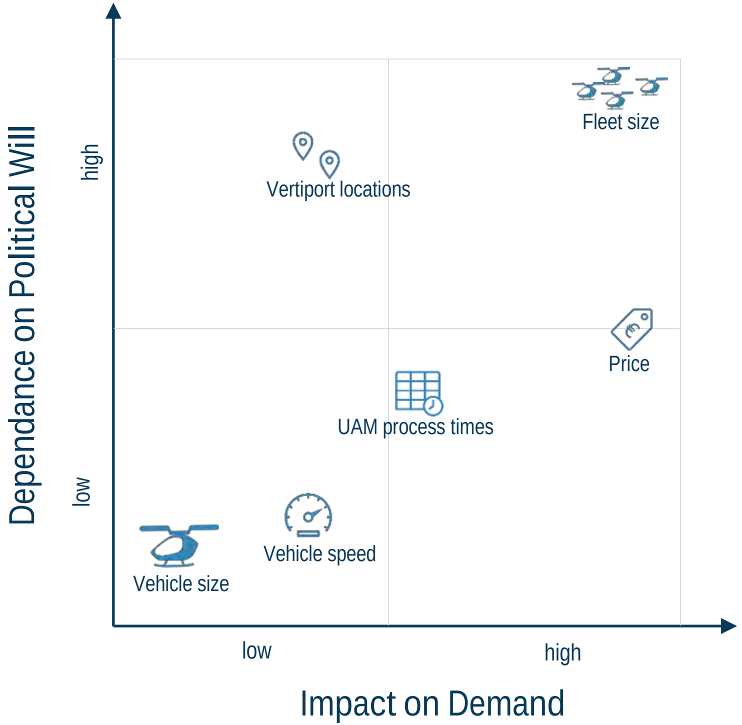
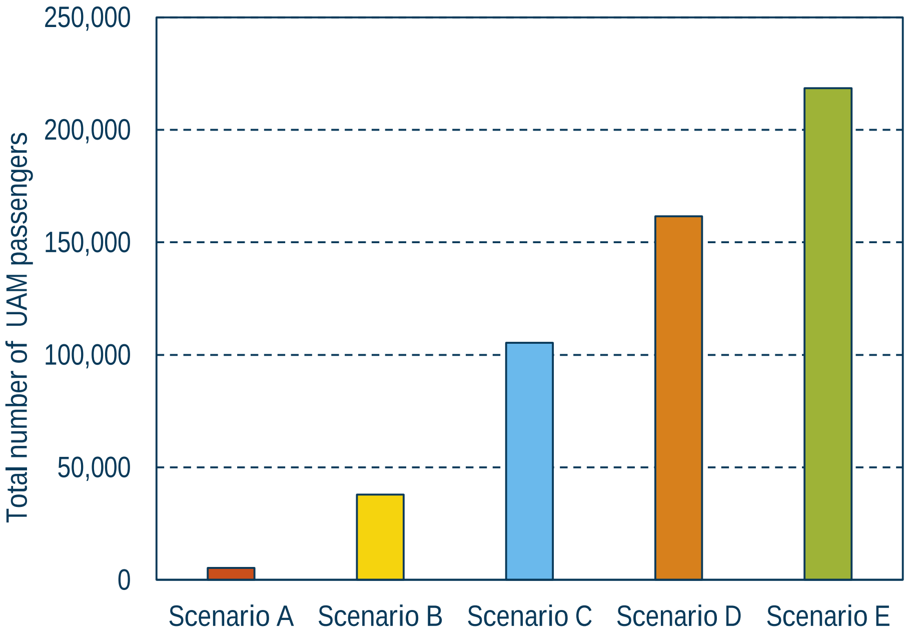
Key Sensitivities and Need for Political Will



Scenario Analysis

Scenario Description

Scenario	A	B	C	D	E
Network	Low density	Low density	Medium density	Medium density	High density
Speed [km/h]	50	80	100	150	300
Base price [€/trip]	10	10	5	5	0
Km price [€/km]	5	2	2	1	1
Fleet size [veh/station]	10	50	50	50	100
Process times (preflight+ postflight) [min]	30	20	20	10	10
Seat capacity [PAX/veh]	2	2	2	4	4
Mode share [% of trips]	0.03%	0.22%	0.62%	0.96%	1.29%
Mode share [% of km]	0.05%	0.36%	0.93%	1.13%	1.60%



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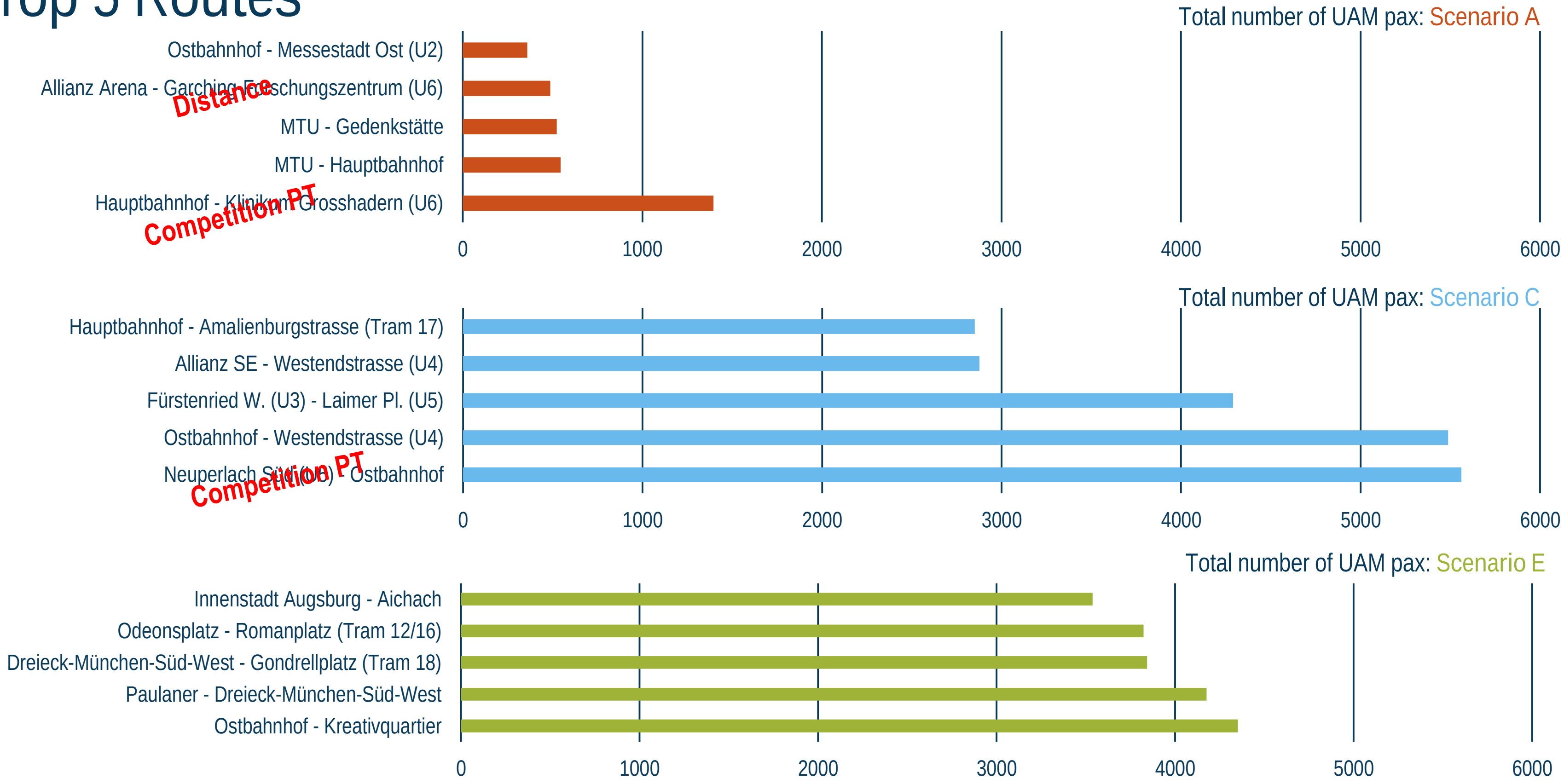
Top 5 Routes



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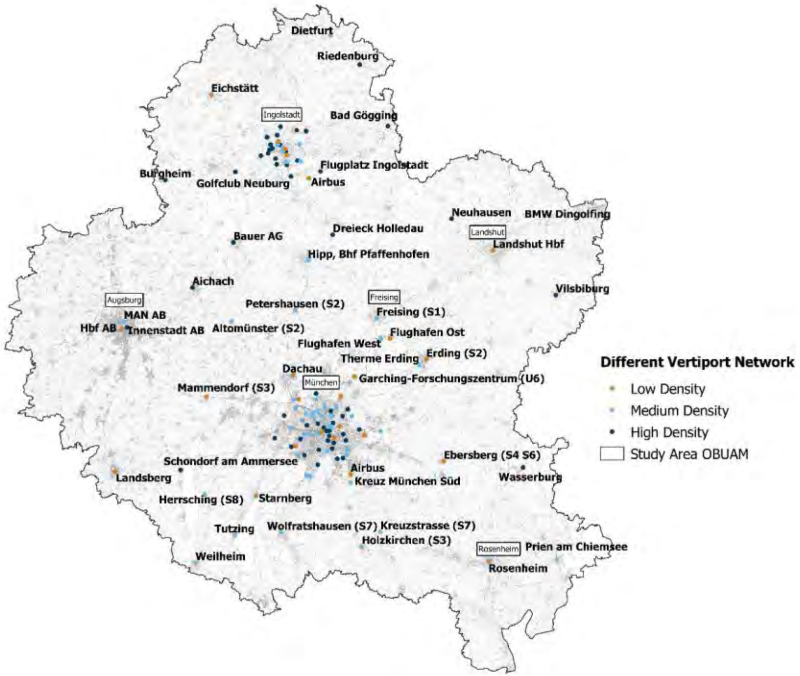
Top 5 Routes – Scenario E

- Demand more distributed
- Fifth most demanded route is outside of Munich



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Demand of routes within and outside of City of Munich

Scenario	A	B	C	D	E
Total UAM PAX* of routes connecting locations within the city of Munich (e.g. Hbf – Klinikum Grosshadern)	3,056 (57%)	22,471 (59%)	72,411 (69%)	98,340 (61%)	118,404 (54%)
Total UAM PAX of routes connecting locations within and outside of the city of Munich (e.g. MTU - Dachau)	1,867 (35%)	12,464 (33%)	17,903 (17%)	35,802 (22%)	52,340 (24%)
Total UAM PAX of routes connecting locations outside of the city of Munich (e.g. Augsburg Innenstadt - Aichach)	435 (8%)	2,927 (8%)	15,005 (14%)	27,454 (17%)	47,755 (22%)

Only 40% of vertiports inside Munich

Share of available routes in high density network: In/in: 16% | In/out: 48% | Out/out: 36%

*Sum of inflows and outflows

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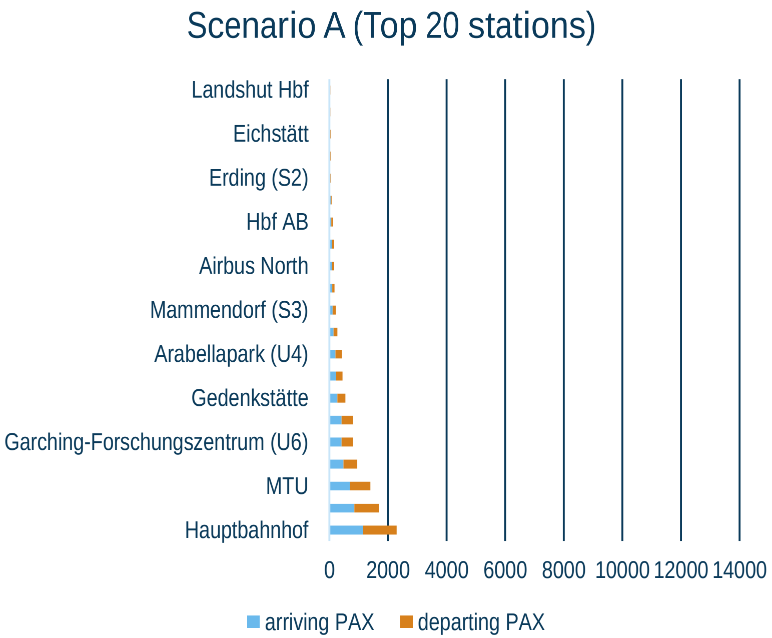
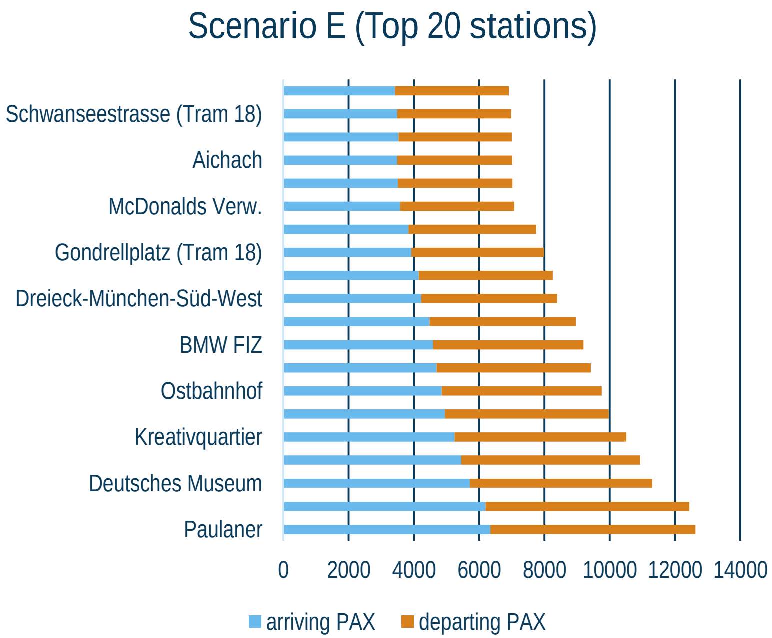
Top 20 Stations





- Increasing network density distributes demand more evenly over different vertiport locations

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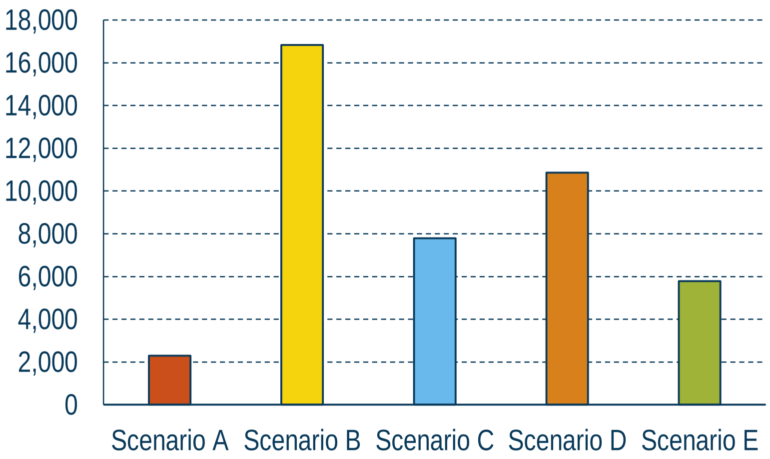
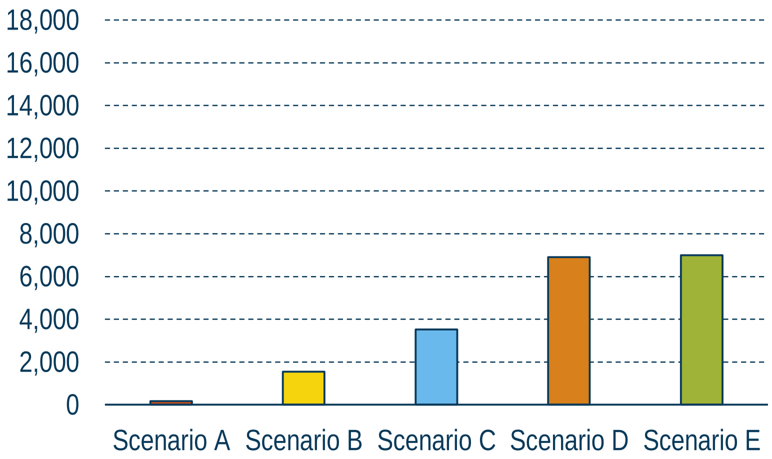
Passenger Demand Development per Station

Total daily UAM PAX of Hauptbahnhof



Total daily UAM PAX of Flughafen Ost



- Assuming increasing market shares over time might lead to a need for a modular set up of vertiports in order to be extended according to demand

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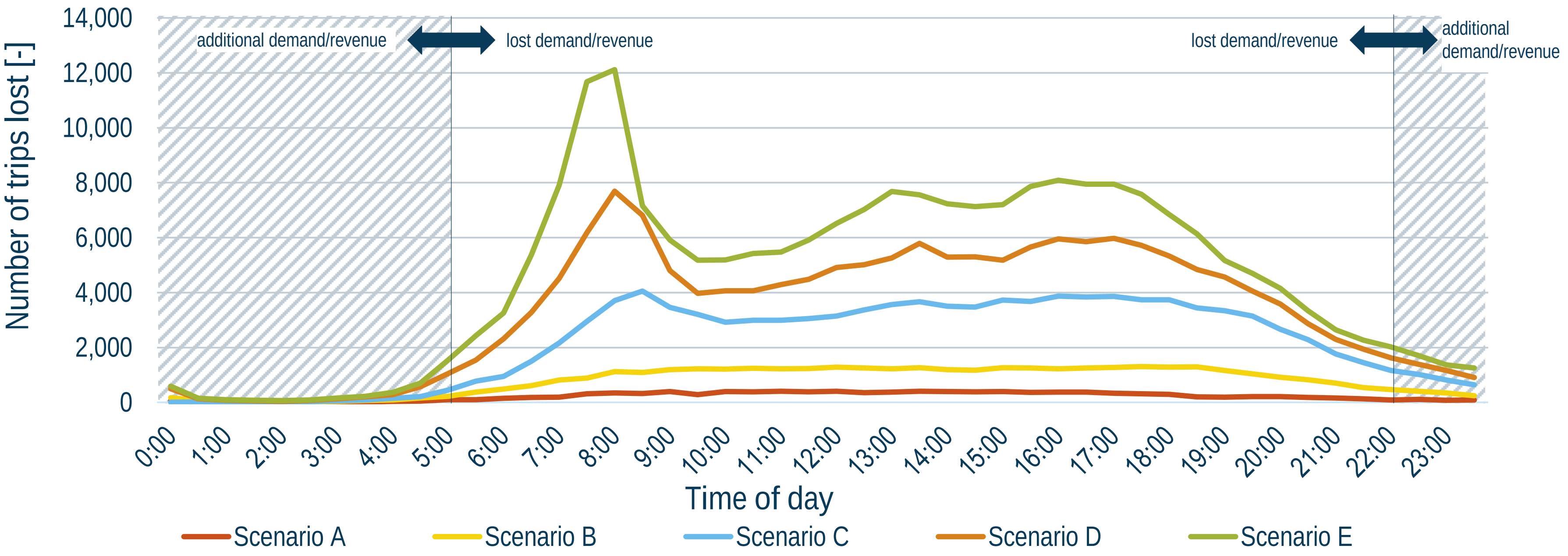
Time of Day Distribution



- Night curfews (22:00-5:00) would not lead to massive passenger losses

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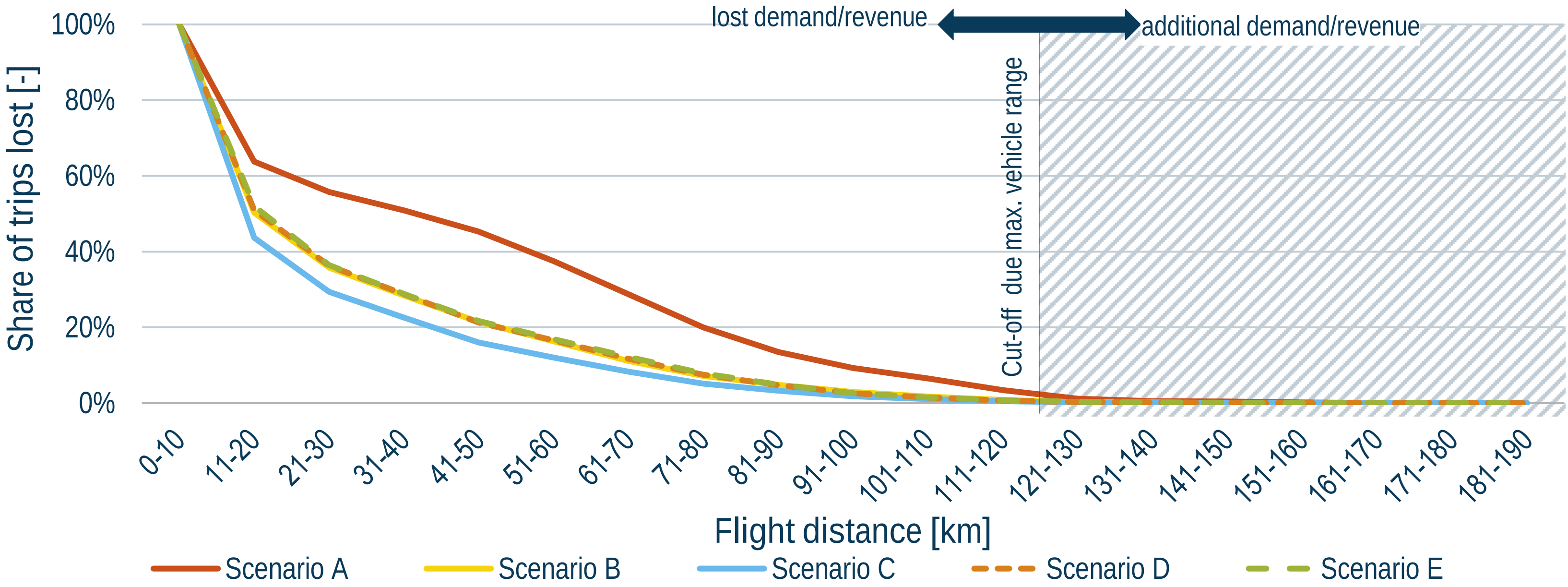
Trip Length and Vehicle Range



- Limits in vehicle range would not lead to massive losses in demand

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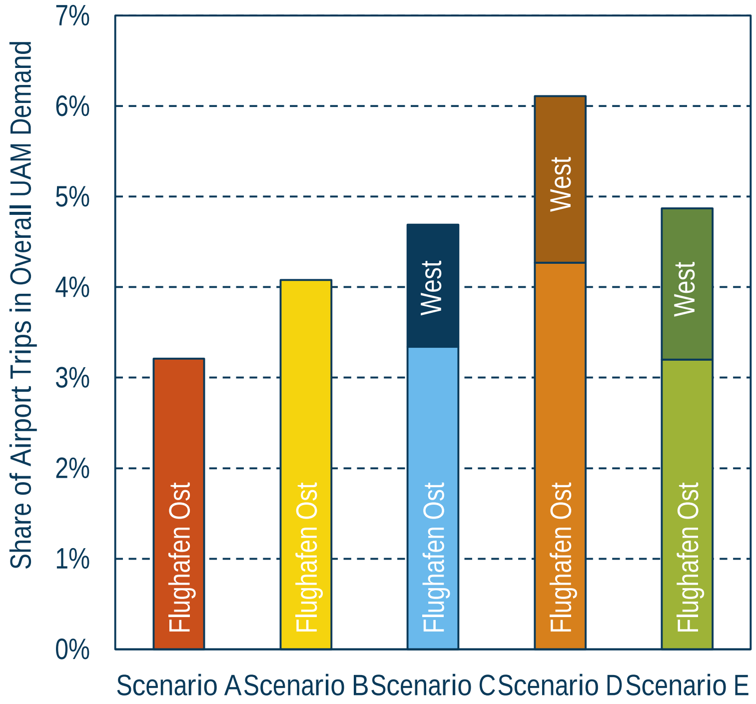
Airport Passengers



- Airport passengers account for 3-6% of overall UAM demand
- Flughafen Ost is the more attractive location for a vertiport
- Attractiveness of UAM as airport access increases with increasing accessibility of more people

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Key Take-Aways (1/3)

Demand sensitivities

- Fleet size and kilometre dependent prices have the largest impact on UAM demand
- Increasing vertiport density increases demand and distributes it more equally over different vertiports
- Vehicle speed only has a minor impact on demand

Scenarios

- Overall system setting massively influences the success of UAM
- Modal shares can reach from 0.05% to 1.60%
- Infrastructure design has to allow for vehicle fleet sizes that are able to supply UAM services according to demand
- Prices of at least taxi levels have to be reached in order to take UAM out of the niche

Key Take-Aways (2/3)

Overall implications

- UAM will likely not change the overall mobility system
- Yet, the current transport offer might be supplemented by a fast and flexible service
- For longer distances (40-100km) this might even increase to up to 3% and more
- On short distances (<10km) UAM shares only account for less than 0.5% of modal split
- Absolute demand is mainly focussed on distances less than 40km
- Some routes directly compete with public transport

Key Take-Aways (3/3)

Regulation

- Looking at the simulation results shows that policy makers need to understand how efficient UAM setting have to look like
- Considering inter alia environmental, equity, urban planning and overall transport system aspects common ground has to be found
- Vertiports are going to face capacity constraint, thus, the resource has to be made accessible to all actors in an efficient way

Policy recommendations

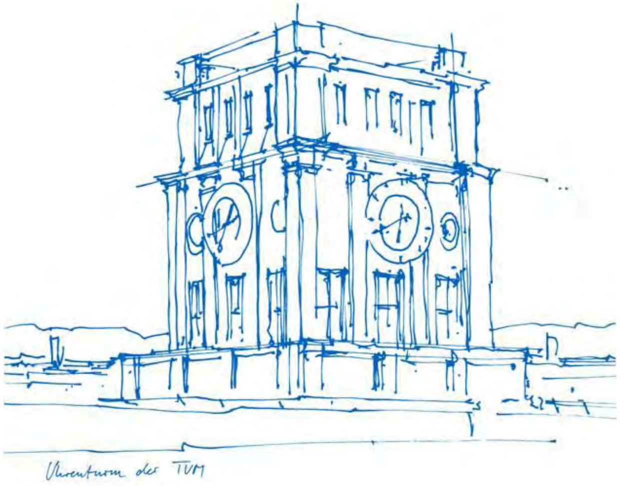
- Ensure no cannibalization of publicly funded public transport connections
- Ensure efficient flight routes to somewhat enable UAM operation that is in line with overall environmental goals
- Minimize negative impact on all parts of society
- Enable all parts of society to make use of this transport service
- Ensure equal access to infrastructure

Gefördert durch

Bayerisches Staatsministerium für
Wirtschaft, Landesentwicklung und Energie

MCA & Results

Christelle Al Haddad
Chair of Transportation Systems Engineering
Technische Universität München
Ingolstadt, 19.11.19



Outline

- Introduction to MCA
- Indicators selection
- KPI results
- MCA results
- Conclusion

Introduction to MCA

- **Multi-Criteria Analysis** used to assess different alternatives
- Takes into account indicators that are difficult to monetize
- Assessment of different scenarios:

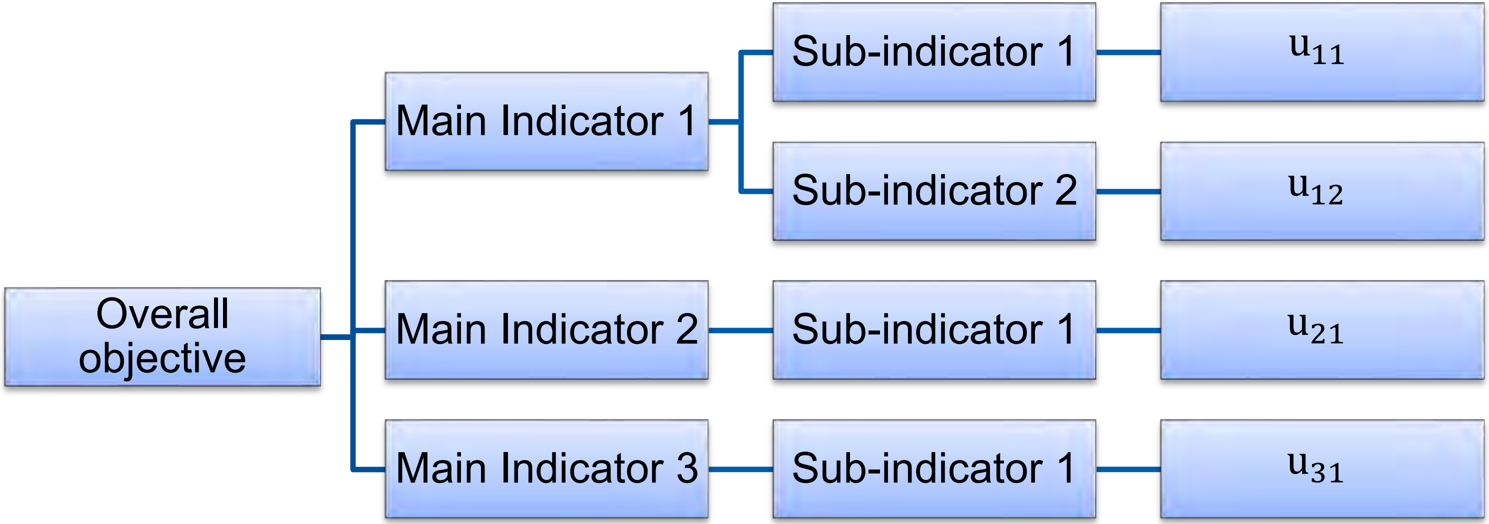
→ 2030 (no UAM); 2030 (A); 2030 (C); and 2030 (E)

- Uses the Multiple-Attribute Utility Theory (MAUT)

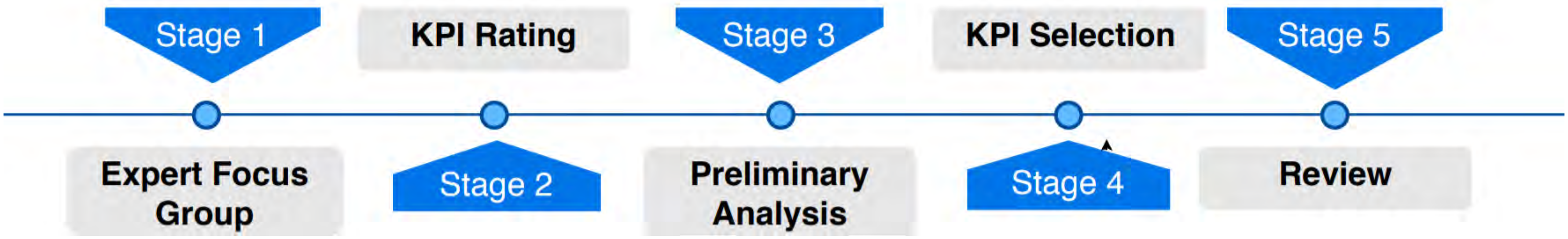
→ Linearize and convert the indicator values to utility points

→ Set target for each indicator: maximize or minimize

MCA methodology

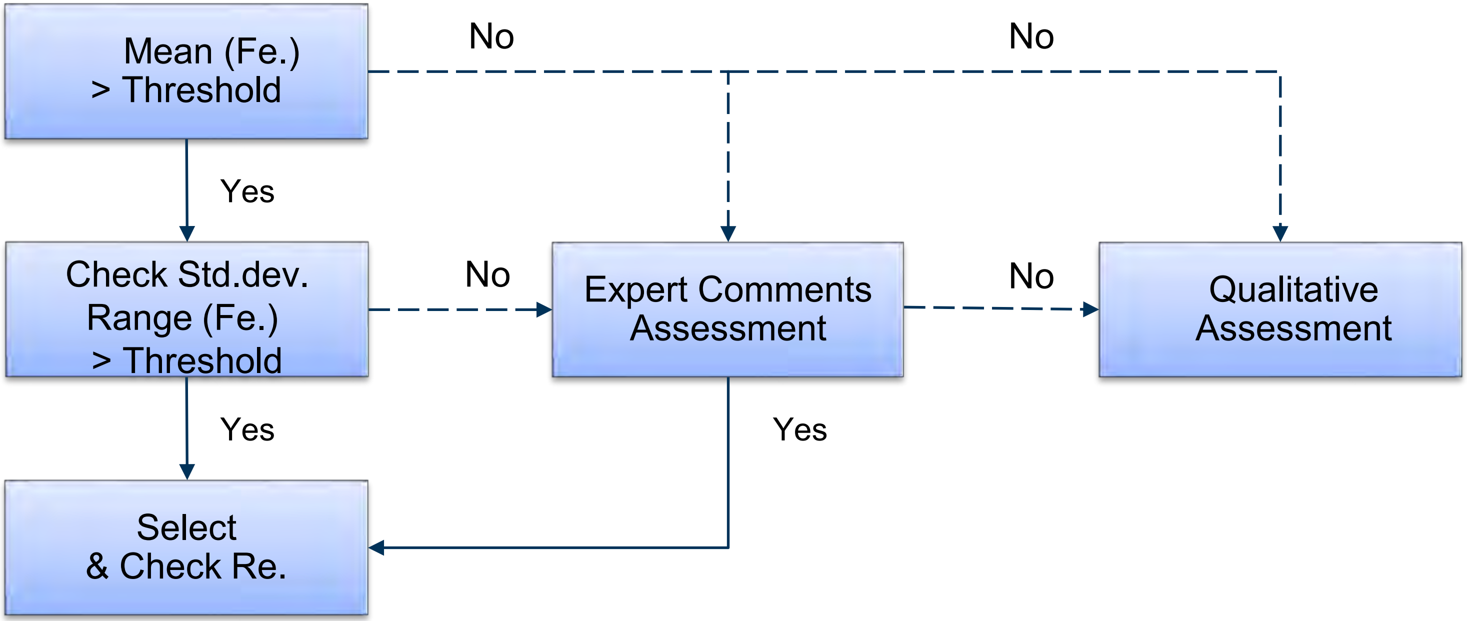


Indicators selection



Al Haddad et al., Multi-Criteria Analysis for the Assessment of Future Transport Systems. A Case Study of Urban Air Mobility in Upper Bavaria, Germany. In the 99th Annual Meeting of the Transportation Research Board, 12-16 January 2020, Washington, D.C.

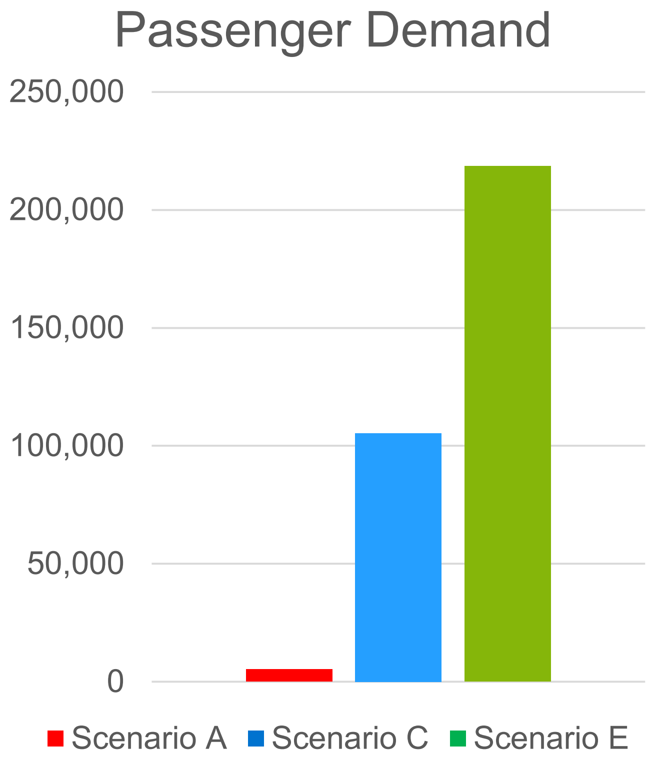
Thresholds for KPI selection



Al Haddad et al., Multi-Criteria Analysis for the Assessment of Future Transport Systems. A Case Study of Urban Air Mobility in Upper Bavaria, Germany. In the 99th Annual Meeting of the Transportation Research Board, 12-16 January 2020, Washington, D.C.

Assessment of scenarios A, C, and E

Scenario	A	C	E
Network	Low density	Medium density	High density
Speed [km/h]	50	100	300
Base price [€/trip]	10	5	0
Km price [€/km]	5	2	1
Fleet size [veh/station]	10	50	100
Process times (preflight+ postflight) [min]	30	20	10
Seat capacity [PAX/veh]	2	2	4
Mode share [% of trips]	0.03%	0.62%	1.29%
Mode share [% of km]	0.05%	0.93%	1.60%



Indicators selection

Group KPIs	Variable
Environmental	Energy consumption [kWh]
	Air emissions [Tons of CO2, NOx]
	Noise pollution
	Visual pollution
	Space requirements for vertiport infrastructure [m²]
Transport	Total travel time [hours]
	Congestion on the ground
	Volume travelled [PAX-km]
	Access + egress time [average in minutes]
	Waiting time [average in minutes]
	Induced demand
	Sustainable modal share [%]
	Total number of passenger trips
	Costs (investment + operation) [EUR/km]
	Safety
Socio-economic	Privacy [number of dwellings affected]
	Equity
	Travel expenditure (affordability)
	Potential accessibility

Legend:

With and without UAM scenarios
Between UAM scenarios only
Removed

KPI results

Main indicator	Variable	Target	no UAM	Scenario A	Scenario C	Scenario E
Environmental	Energy consumption (kWh)	Minimize	65,046,479	65,042,102.05	65,246,434.12	65,388,452.3
	Air emissions (Tons of CO2, NOx)	Minimize	17,731.11	17,728.24	17,757.79	17,779.05
	Noise pollution	Minimize	0	42.34	705.59	933.08
	Visual pollution	Minimize	0	42.34	705.59	933.08
	Space requirements for vertiport infrastructure (m2)	Minimize	0	4,160	21,200	53,000
Transport	Total travel time (hours)	Minimize	1,428,879	1,429,008.25	1,411,336.47	1,377,211.20
	Volume travelled (PAX-km)	Minimize	122,642,092.7	122,665,644.4	122,975,193.3	122,461,700.7
	Access + egress time (average in minutes)	Minimize	0	35.9	31.7	32.5
	Waiting time (average in minutes)	Minimize	0	54.5	10.3	4.0
	Sustainable modal shares	Maximize	0.43	0.43	0.42	0.42
	Costs (investment + operation): EUR/km	Minimize	0	4.66	4.25	2.30
Socio-economic	Privacy (number of dwellings affected)	Minimize	0	4,845,200	107,512,816	198,715,036
	Equity	Minimize	0	3.67	5.81	10.14
	Travel expenditure (affordability)	Maximize	4.85	4.93	6.35	8.84
	Potential accessibility	Maximize	81.31	81.07	81.50	82.14

Assessment by looking only at indicators relevant for both non-UAM and UAM scenarios

Group KPIs	Variable
Environmental	Energy consumption [kWh]
	Air emissions [Tons of CO_2, NO_x]
Transport	Total travel time [hours]
	Volume travelled [PAX-km]
	Sustainable modal share [%]
Socio-economic	Travel expenditure (affordability)
	Potential accessibility

MCA results assessing only indicators relevant for both non-UAM and UAM scenarios

Main indicator	Main weight	no UAM	Scenario A	Scenario C	Scenario E
Environmental	1/3	96.57	99.99	41.41	0
Transport	1/3	54.00	52.49	31.42	66.65
Socio-economic	1/3	12.34	0.88	38.82	100
Total	1	**54.30**	**51.12**	**37.22**	**55.55**

Best scenario is E, followed by no UAM, then A, then C

MCA under different weights

- All weights are equal (environmental = transport = socio-economic = 1/3)
  Scenario E (highest PAX demand) is the best, followed by no UAM, then A, then C

- Environmental perspective (environmental weight = 1; rest = 0)
  Scenario A (lowest PAX demand) is the best, followed by no UAM, then C, then E

- Transport perspective (transport weight = 1; rest = 0)
  Scenario E is the best, followed by no UAM, then A, then C

- Socio-economic perspective (socio-economic weight = 1; rest = 0)
  Scenario E is the best, followed by C, then no UAM, then A

Assessing using all indicators only between UAM scenarios

Group KPIs	Variable
Environmental	Energy consumption [kWh]
	Air emissions [Tons of CO2, NOx]
	Noise pollution
	Visual pollution
	Space requirements for vertiport infrastructure [m²]
Transport	Total travel time [hours]
	Volume travelled [PAX-km]
	Access + egress time [average in minutes]
	Waiting time [average in minutes]
	Sustainable modal share [%]
	Costs (investment + operation) [EUR/km]
Socio-economic	Privacy [number of dwellings affected]
	Equity
	Travel expenditure (affordability)
	Potential accessibility

Legend:

With and without UAM scenarios
Between UAM scenarios only

MCA results between UAM scenarios

Main indicator	Main weight	Scenario A	Scenario C	Scenario E
Environmental	1/3	99.99	37.95	0
Transport	1/3	23.36	45.59	82.44
Socio-economic	1/3	51.52	48.58	48.48
Total	1	**58.29**	**44.04**	**43.64**

Best scenario is A, followed by C, then E

Conclusion (1/2)

- Assessment results differ according to the indicators weighting and assessed indicators
- When assessing UAM and Non-UAM with relevant indicators only:
  - **Scenario E** (Highest PAX demand) performs best at equal weighting
  - **Scenario A** (lowest PAX demand) performs best (even compared to no-UAM) with regard to environmental weighting
- When assessing UAM only:
  - **Scenario A** (lowest PAX demand, equal weighting) performs best due to lower environmental impacts

Conclusion (2/2)

- **Future work:**

→ All indicators should be used to assess scenarios with and without UAM

→ Compute values (less assumptions) for indicators like pollution, noise, etc., and costs no UAM scenarios

→ Can be a tool for policy-makers to choose a design scenario according to **what is valued most** or depending on the desired objective

Wrap Up (1/2)

- To be able to simulate and to assess UAM as an intermodal transport mode, future ground mobility scenarios & UAM specific mode choice models are required
- Overall UAM system settings massively influences the success of UAM
  - UAM will likely not change the overall mobility system but the current transport offer might be supplemented by a fast and flexible service
  - Prices of at least taxi levels have to be reached in order to take UAM out of the niche
  - Supply of sufficient vertiport infrastructure capacity seen as one, main bottleneck
  - Different UAM vehicle designs required to meet efficient payload-range flexibility

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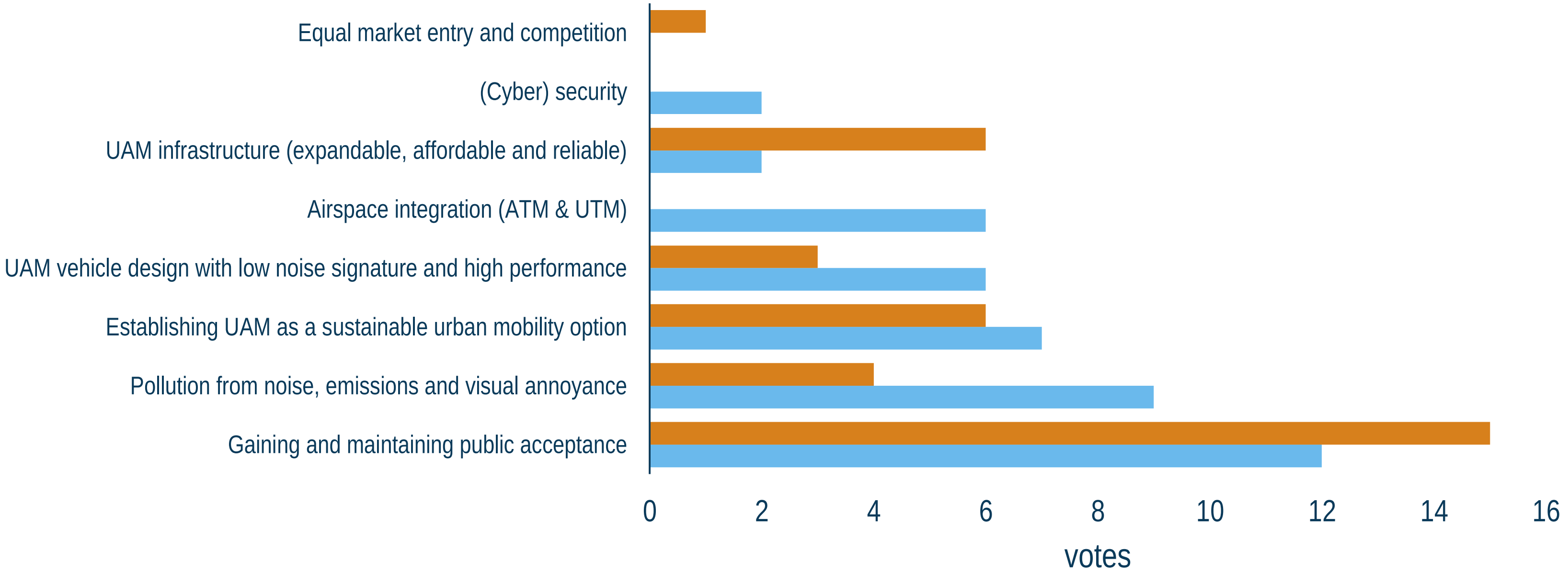
Wrap Up (2/2)

- Policy and regulatory support is required to ensure:
  - a compromise between environment, equity, urban planning and overall transport system aspects are met
  - no cannibalization of publicly funded public transport connections
  - minimize negative impact on all parts of society and to enable all parts of society to make use of this transport service

OBUAM Final Conference Feedback

Before & after the presentation: What are main hurdles for UAM (PAX transportation only) introduction?



OBUAM Final Conference Feedback

- Gaining and maintaining public acceptance: What are the required next steps?
  - Affordability (low ticket price) and granting all parts of society access to the service
  - Showing high level of safety
  - Multiply demonstration excercises
  - Showing sustainability and low noise impact
  - Co-Creation, citizen involvement, transparent communication and public relations w.r.t. challenges & security
  - Ensuring privacy
  - Ensuring relevant market entries (access for rural areas)

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OBUAM Final Conference Feedback

- Pollution from noise, emissions and visual annoyance: What are the required next steps?
  - R&D invest in noise reduction e.g. noise reduction by technical innovation or demonstrators, enabling noise assessment during conceptual vehicle design phase
  - Flight route analysis and optimisation (or restricted areas)
  - Local vs. global emission of battery concepts

OBUAM Final Conference Feedback

- UAM infrastructure (expandable, affordable and reliable): What are the required next steps?
  - Developing certification rules and processes
  - Gaining and maintaining political support
  - Ensuring open markets and development of standardisation strategy
  - Consideration for new buildings
  - Identification of available spaces and ensuring CAPEX investments
  - Long-term financing and operating model strategy
  - Quantification of demand

OBUAM Final Conference Feedback

- Establishing UAM as a sustainable urban mobility option: What are the required next steps?
  - Usage of only renewable energy sources
  - Significant improvement of energy efficiency
  - Research on battery energy density improvements or hybrid-energy systems
  - Ensuring low additional noise
  - Showing societal benefit, not focussing on high-income customers
  - Identification of relevant, specific use cases

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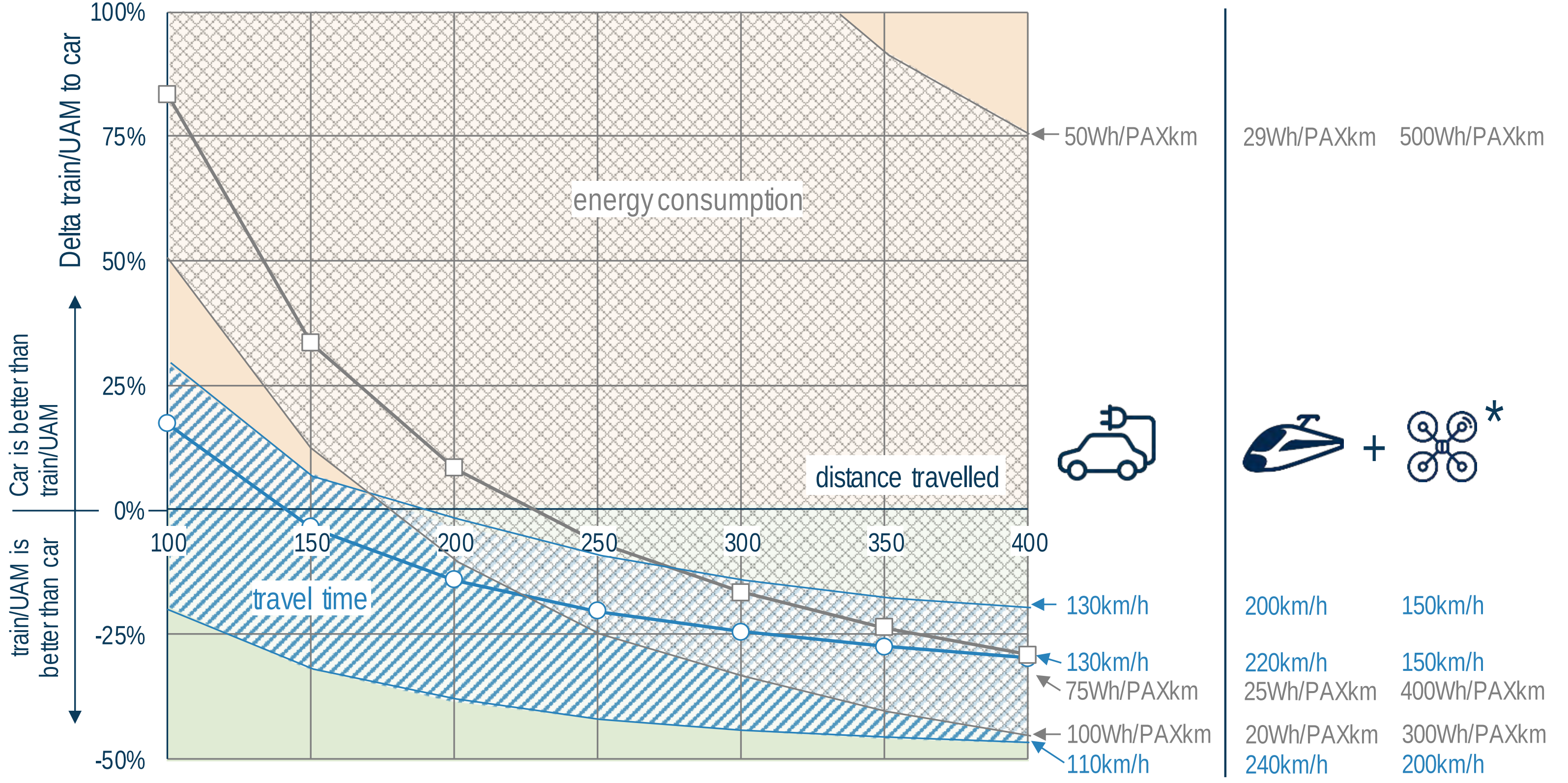
Zukünftiger Forschungsbedarf

- Intermodale Reiseketten->Synchronisation von Boden- und Luftverkehr
  - Anbindung ländlicher Raum
  - Schnittstellendefinition (Umsteigen Passagier, Daten, Haftung, dynamische Planung)

- Untersuchung weiterer Anwendungsszenarien
  - Verbesserung des Mobilitätsangebotes (ländlicher Raum, Inseln, Alpen)
  - Anbindung an Hochgeschwindigkeitstransport (ICE, Flughäfen)
  - Untersuchung Potential für den Tourismus

Anbindung an Hochgeschwindigkeitstransport (ICE, Flughäfen)



* including 10min buffer time before take-off and additional 15min transfer time from UAM to train, values for 50km UAM flight

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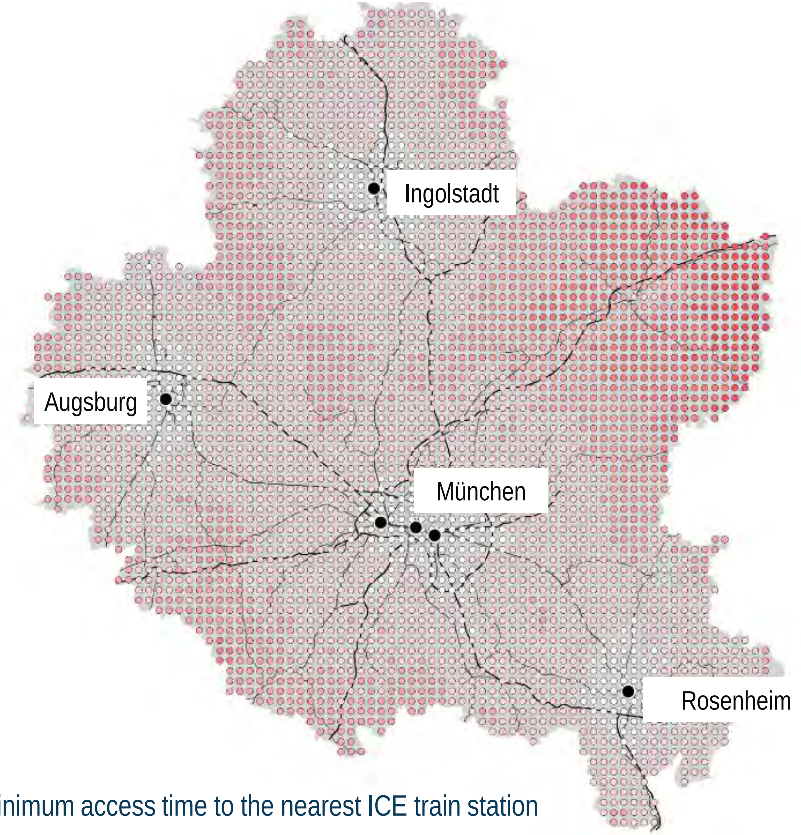
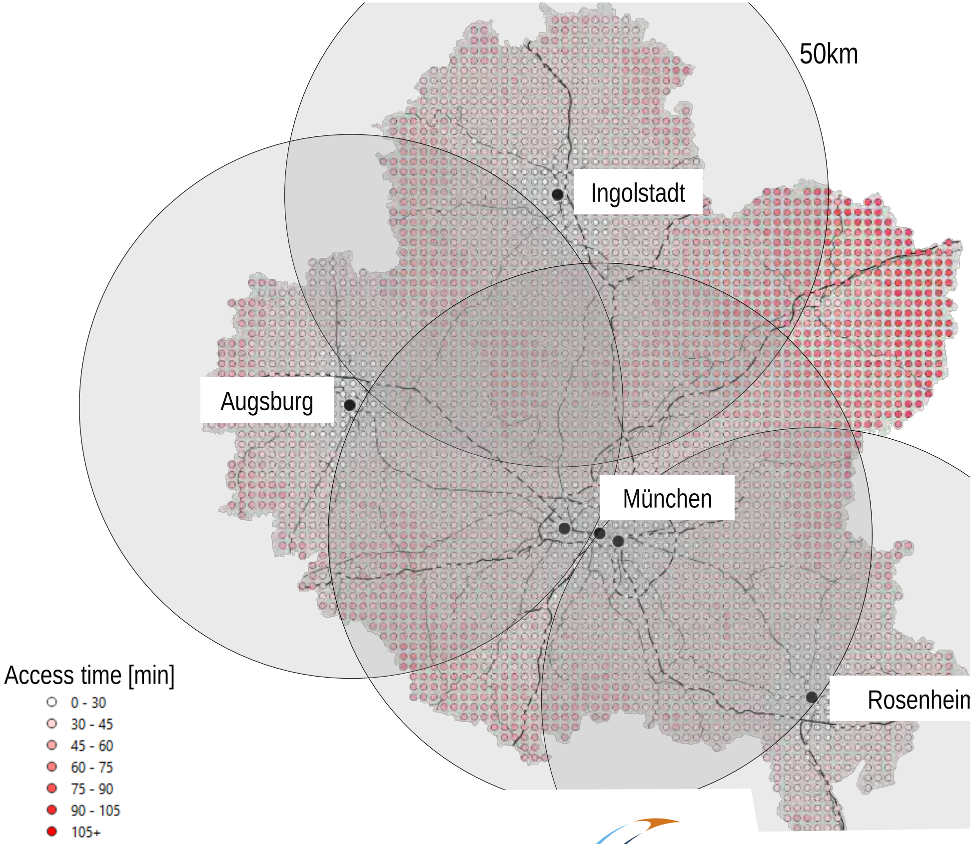
Anbindung an Hochgeschwindigkeitstransport (ICE, Flughäfen)



Minimum access time to the nearest ICE train station



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Nächsten Schritte

- Detailuntersuchungen
  - Vertiports (genaue Lage, Größe, operationelle Abläufe)
  - Flugrouten und dynamische Wegführung
  - Flotteneinsatzplanung und Optimierung des Betriebes
  - Identifikation erster UAM Strecken und Markteinführungsszenarien
- Grundlegende Untersuchungen
  - Einfluss auf Lärm und Sichtbarkeit
  - Veränderte Siedlungsstrukturen aufgrund neuer Mobilitätsangebote am Beispiel UAM
  - Anbindung von Arbeitsmarktregionen zur Stärkung benachteiligter Regionen
  - Untersuchung der Nutzerakzeptanz (Kunde) und gesellschaftlicher Akzeptanz

Publikationen und weitere Kommunikation

- Weitere Informationen zu der OBUAM Studie und den Simulationsergebnissen kann auf Anfrage an UAM@Bauhaus-luftfahrt.net zur Verfügung gestellt werden