

An adaptable and scalable least cost network for air-taxis in urban areas

Study area: Manhattan, New York

Moritz Hildemann
Universidade Nova de Lisboa
Information Management School
Campus de Campolide 1070-312
Lisbon, Portugal
m20180790@novaims.unl.pt

Carlos Delgado
Universidade Nova de Lisboa
Information Management School
Campus de Campolide 1070-312
Lisbon, Portugal
m20181032@novaims.unl.pt

Abstract

The first part of this work explains the legal flight restrictions and concepts for possible future flight areas. The goal is to derive the necessary information for the selecting restricted areas for possible flight routes with the least effect to the citizens. These restrictions are implemented with a Geographical Information System. Secondly, the optimization potential of the non-restricted flight areas is examined. The optimization consists of the development of an adaptable and scalable least-cost network in the aerial space of Manhattan. The cost is the distance between 3D-points with avoiding the restricted airspace and considering the minimal negative impact on the citizens. The scalability of the network's capacity is considered for times of high demand. Also, on-demand transportation and temporal impedances are considered by using dynamic geofences. The idea of the implemented geoprocessing model builds on designed paths for helicopters. Combined with proposed concepts of space agencies for optimal management of urban aerial space, a parameter-driven and semi-automatic model is developed. The limiting factors of the airspace are adaptable to the laws and restrictions of the city management of other study areas. The maps shall support the decision makers of the city management and of the space agencies to manage the urban airspace in the future.

Keywords: Urban Air Taxis, 3D geofences, Least Cost Network; Aerial Space Management

1 Introduction

The testing phase of small flying aircraft in urban areas recently began. The German start-up Volocopter demonstrated, that the technical requirements for an electric aircraft transportation system are already fulfilled for electrical weight-shift-aircrafts (Volocopter 2018). The competition in electric aircraft transportation, manned or unmanned, is increasing.

But flight laws regulate urban areas now as well as in the future. The futuristic idea therefore faces restrictions (Federal Aviation Administration 2013; Civil Aviation Authority 2018). Concepts are being developed by national and international aerial space regulating institutions like the DLR (Geister 2018), CAA (2018) or the NASA (2018), in which designs for the future urban aerial space management are presented (Geister 2017). The concepts propose how the airspace might be divided and limited by geofences, to restrict flying objects in certain areas.

This work develops a Geographical Information based model, that calculates the least cost paths of operating aircrafts in an urban area. Points and areas of interests are used for the calculation of static and dynamic 3D-geofences.

The output of the model is the least path cost network for the selected study area of Manhattan in New York.

The software used is ArcGIS Pro (Esri 2018) and the used data is Open Source:

- Open Street Map Data (2018),
- Flight obstacle Maps (Federal Aviation Administration 2017)
- Rooftop heights from Open Data NY (2018)

2 Restrictions for air-taxis in urban areas

Flying vehicles are ready to operate and can land and start vertically. Most are battery driven weight-shift-control aircrafts and helicopters. Lilium Aviation (2018) and Volocopter (2018) aim to compete with local taxis in urban areas like New York City. They advertise with a comparison between taxis and air taxis in New York without considering aerial restrictions.

The goal of this chapter is to underline, that aerial space is a scarce resource and that not only Lilium Aviation (2018) and Volocopter (2018) face another challenge: being allowed to operate in the aerial space of a region, where not only flight regulations of commercial and regular planes operate. Moreover, the high population density with tall buildings and several protected areas do limit the space.

2.1 Legal restrictions for the flight paths

The flight restrictions derive from aerial space agencies like the European Space Agency (ESA) or the Federal Aviation Administration (FAA) from the United States of America. The laws are strongly dependent on national legislation. For this work the law of the FAA is shortly outlined, corresponding to the example of Lilium Aviation in Manhattan. The restrictions differ for different aircrafts: Unmanned Aircraft Systems, Ultra-Light-Vehicles, Aircrafts with and without communication possibilities, fixed-wing aircrafts and helicopters, including weighted shift-control vehicles (Federal Aviation Administration 2017). The regulations for the sample area and the example vehicle are the following (Sec. 91. 119 FAA, paragraph c and d):

(c) Over other than congested areas: An altitude of 500 feet above the surface, except over open water or sparsely populated

areas. Therefore, the aircraft may not be operated closer than 500 feet to any person, vessel, vehicle, or structure.

(d) Helicopters, powered parachutes, and weight-shift-control aircraft. If the operation is conducted without hazard to persons or property on the surface:

[...]

(2) A powered parachute or weight-shift-control aircraft may be operated at less than the minimums prescribed in paragraph (c) of this section.”

These legal restrictions are implemented in the Model Builder as static geofences.

In the study area, also helicopter routes exist like described in Sec. 91. 119 FAA a(1)A. Most of the helicopter routes are planned above open water regions (Federal Aviation Administration 2017).

As the electrical aircrafts are not as noisy and large as a traditional helicopter, special routes are proposed for this kind of aircrafts. This optimization is the main goal of the output of the model.

2.2 Concepts for the future aerial space management

For the future urban airspace, Geister (2017) from the German Aerial Space Agency (DLR) proposes a concept of an integrated Urban Airspace, that is used by different aircrafts including unmanned and manned aviation.

Geister (2017) states the importance of static and temporal no-fly-zones. Also, all aircrafts get assigned an “Aircraft Safety Bound”, which is dependent on the speed and other safety parameters.

Taking that concept into account, the following chapter contains the implementation of the discussed restrictions and possible solution for the future urban aerial space.

3 Geoprocessing model for least cost flight paths and least cost network

The methodological process implemented for least cost connections between ports and hubs for air taxis is based on a geoprocessing model and developed with the Model Builder from the software ArcGIS Pro from Esri (2018). It is not possible to describe all granular steps for integrity and replicability of the solution due to the complexity of the model. The emphasis lies in describing the most important steps of the model.

However, it is important to note that the process of acquiring information is essential to carry out the development of the project. It is necessary to collect open and freely accessible data for the identification of the rooftops of buildings in a city, the geometry of the buildings with their elevation attributes (Open Data NYC 2018) and the economic/social use of the urban area (Open Street Map 2018).

Also, it is necessary to digitize flight obstruction maps that are freely available in PDF and TIF format (Federal Aviation Administration 2017).

Having elaborated the tasks of pre-processing, the Model Builder from ArcMap (Esri, 2018) is the selected tool for the design of the geoprocessing model.

3.1 Generating 3D Geofences

The first geoprocessing model considers capturing the altitude values from the geographic layers coming from the rooftop heights. These in combination with restricted geographic areas such as educational centres, hospitals, embassies and cemeteries are subsequently used to calculate 3D buffers. The 3D buffers are extruded 2D buffers with the derived z-information from the buildings and areas.

The height restrictions differ to the restrictions of buildings, because parks, graveyards and recreational areas are usually large polygons.

The highest restriction is the 25.000 feet distance line to the airports. These have special characteristics in the construction of the 3D buffers and they are assigned a vertical border of 600 meters. A 3D path is cut into this geofence to simulate a special way to and from the airports to enable a connection that is nearby the airport.

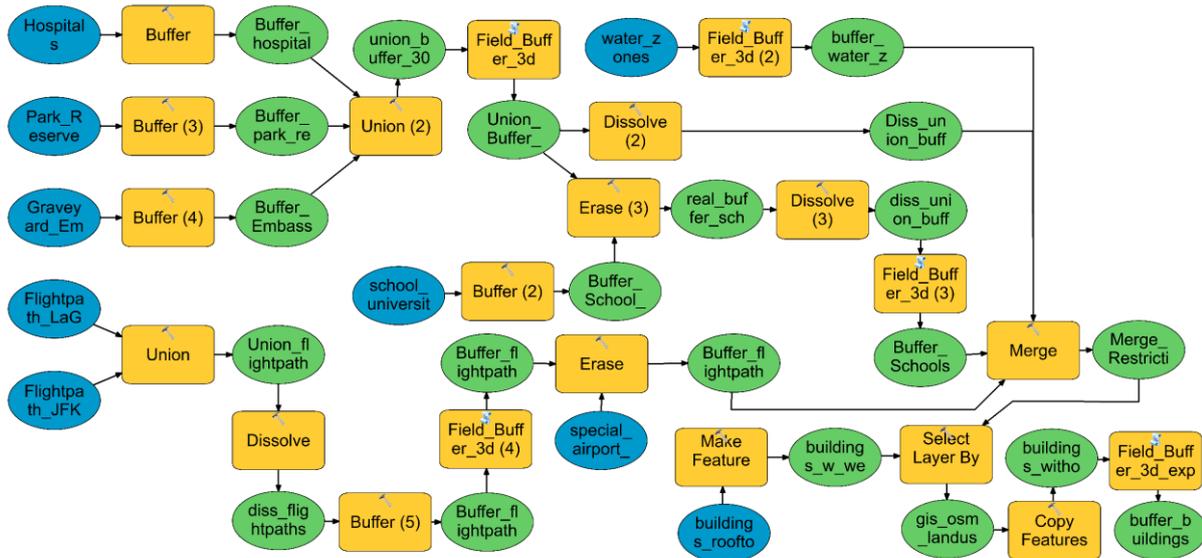
Table 1: Vertical and horizontal restrictions in meters

Landuse	Vertical	Horizontal
Airport	600	Dynamic
Hospitals	300	300
Universities	200	300
Embassies	300	300
Parks	300	100
Graveyards	300	100
Recreational areas	300	100
Rooftops	152,4	-

The process begins by calculating the spatial impedances and building three-dimensional geofences that are conform with the flight regulations (Figure 1). That impedances influence the cost for the transportation of electric aerial taxis, therefore the goal is finding the route with the minimal accumulated cost.

The geofences are represented as 3D-buffers, which can overlap. To obtain a unique geographical restriction layer that serves as an input for the second stage of the geoprocessing model, it is necessary to apply a dissolving geoprocess between all the buffers. This process must be executed sequentially from those buffers that have greater heights towards those with lower heights. This ensures that the largest buffers cover the smallest and therefore achieving the spatial integrity of the area of influence. The model also includes the generation of new attributes with reference to the layer of buildings that are outside the area of influence of the buffers. This is done to determine the minimum height that air taxis can fly over buildings in unrestricted areas. In this way, the addition of 152,4m (500ft) is added to each of the roof heights of these buildings, which are the regulations of the FAA. The model includes a possibility to dynamically add and remove geofences.

Figure 1: First generalized geoprocessing model for 3D restrictions.



3.2 Generating the minimal height planes

For generating the surface of the minimum flight altitude, the model takes as input layers to finally convert it into an Inverse Distance Weighting interpolation algorithm (IDW), as the cost surface. Therefore, the first step is to take all the polygon-type geometries belonging to the building layer outside the restriction areas as point type, considering the sum of the height of the roofs and the additional height of 152,4 meters which is the 500 feet restrictions by the Federal Aviation Administration (2017). As the area of restriction of the existing Geofences is quite extensive and needs also be converted to points for

interpolation, the mesh of points is chosen to be no smaller than 30 meters of distance between the points.

Each of the points within the geofences inherits the height of the vertical restriction. Subsequently, the different point layers from the rooftops and the geofences are combined and are the input for an IDW interpolation algorithm. The result is a raster surface with a spatial resolution of 30 meters that serves as the least cost surface.

The first step of the routing for urban air-taxi therefore includes converting the 3D-Geofences to a least-cost surface (Figure 2).

Figure 2: Second generalized geoprocessing model for the least cost surface

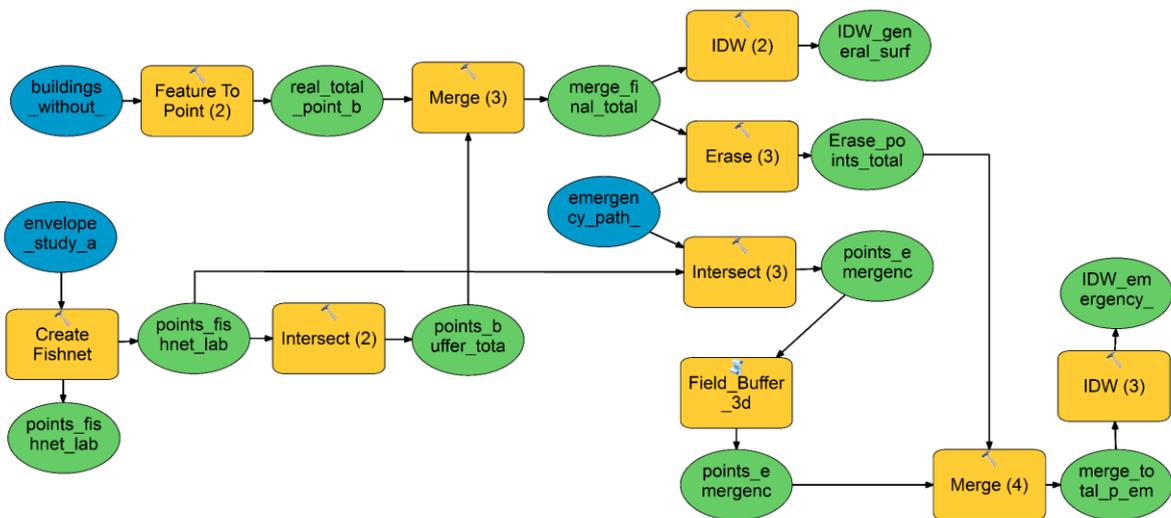
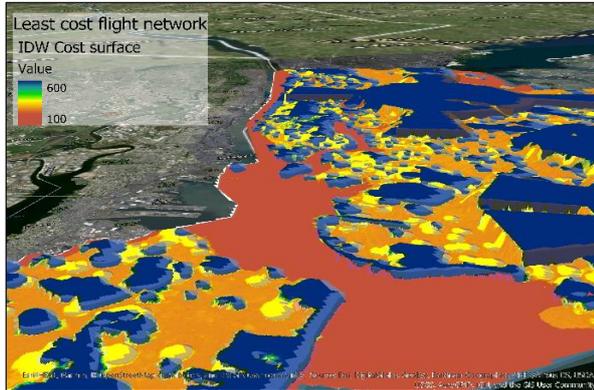


Figure 3: Least cost surface (IDW)

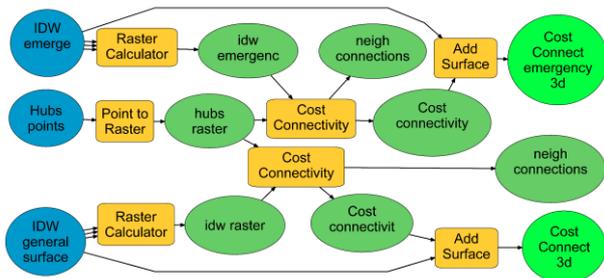


The IDW (Figure 3) visualizes the different minimal flight heights. The open water regions are visualized in red, followed by the basic heights of 152,4 meters, which are orange. The yellow parts represent the 3D buffers with a lower vertical restriction than the blue parts of the map.

3.3 Generating the least cost flight routes

The next step consists of the calculation of the least cost networks on the least cost surface in order to generate the optimal route for air taxis. The best route is the smallest accumulated sum of the costs between the starting and landing points, where the cost is the distance of each raster cell to their neighbor cells in the IDW. That is calculated using the Cost Connectivity Tool from ArcGIS Pro (Figure 4).

Figure 4: Third generalized geoprocessing model for the least cost network

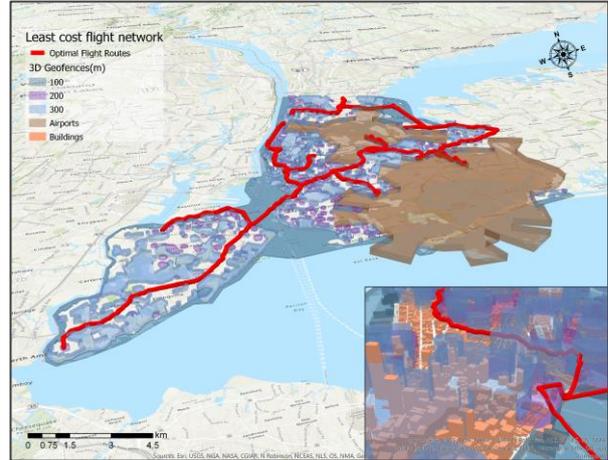


The model includes a parameter of the cost factor that multiplies the vertical distance of the generated artificial surface (IDW) with the raster calculator. This allows to manipulate the cost surface and demonstrates the trade-off between the cost of surrounding or overflying geofences. That parameter can be set to get minimize flight times and energy consumption with a higher effect on the citizens or a lower effect on the citizens with longer flight routes. The parameter allows the optimal and highly accurate route calculation for different types of urban areas. The model used different factors and considered the factor of 30 as the optimal parameter for the city of New York (Figure 4). This factor enforces a very high probability of flying around geofences rather than flying above.

The chosen hubs are distributed in the city and potential stations (hubs) for air taxis are manually chosen. The hubs are defined as point-type geographic layers and are converted to

raster for the Cost Connectivity algorithm. The result is a vector layer with the optimal route for aerial vehicles (Figure 5).

Figure 5: Least cost network and 3D geofences in NYC



3.4 Dynamic impedances and scalable network

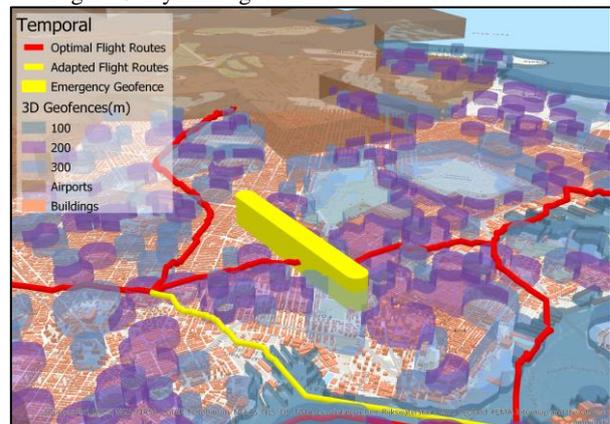
Finally, the model contemplates the execution of some spatial tools for the adaptation of the least cost network. The requirements for the future urban network are scalability and dynamic adaptability (Alexandrov 2004; Geister 2017). The new routes in the network are recalculated with the geoprocessing models in chapter 3.1 – 3.3 but include dynamic geofences, on-demand routes and a second network layer in time of high demand.

3.4.1 Dynamic impedances

The presence of dynamic impedances (dynamic geofences) might occur when high priority helicopter routes for emergencies or special events like demonstrations take place (Figure 6).

To avoid the crossing of flying vehicles, the network can be recalculated with the dynamic impedance of the 3D buffer. The dynamic impedance leads to a recalculation of the old network, at least of parts of the old network.

Figure 6: Dynamic geofences and network recalculation

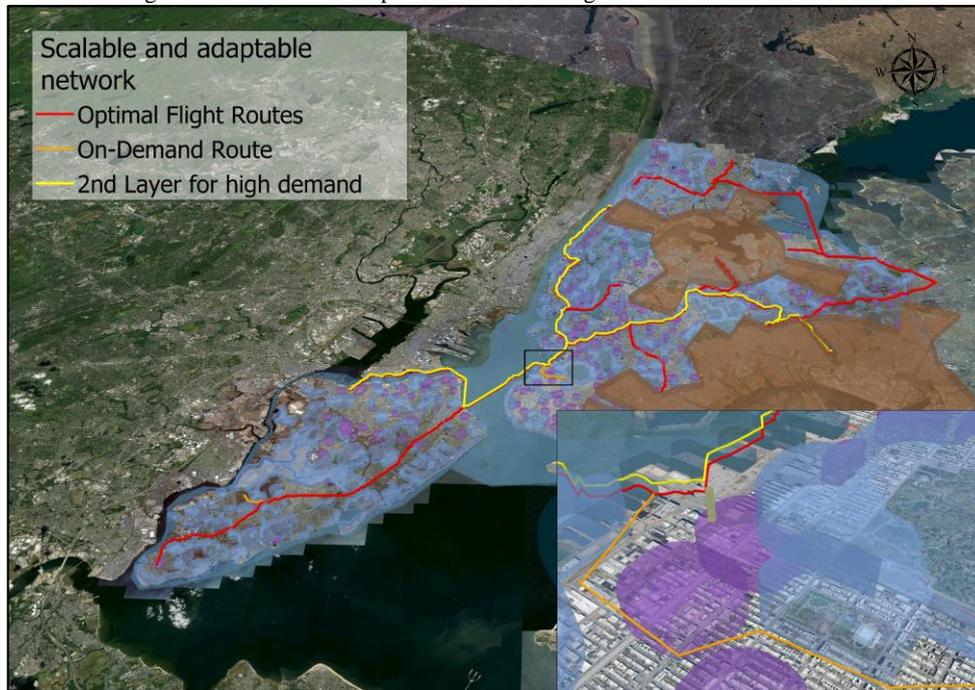


3.4.2 Scalable and adaptable network

The scalability of the network is implemented with a vertical extension of the parts of the network, that face the highest demand. It is visualized in yellow (Figure 7). The on-demand extension of the network is visualized in orange.

The idea of it is to enable on-demand flights without affecting the citizens with additional routes. The cost surface which is covered by the least cost network is reduced with the raster calculator. This forces the route to use the existing network.

Figure 4: Scalable and adaptable network for high- and on-demand situations



4 Conclusion

The network calculation for urban air taxis with a semi-automatic model is a tool to support the responsible regulative authorities as well as city and regional planners to manage the urban air space. GIS is used to ensure an information gain for this futuristic concept and a valuable tool for the decision makers. The visualization is another key factor for consulting the authorities and informing the public about possible routes.

The network is dynamic and adaptable to fit different purposes with different demands. It considers on-demand transportation as well as a network extension. Possible next steps in the process to make this concept reality and to improve the designed network are also concerning location and therefore GIS play a key role:

- Improving the network topology in several layers in times of high demand (Alexandrov 2004).
- The site planning for hubs in central places and on the rooftops of high frequented buildings.
- Planning of possible emergency stops in congested areas (Geister 2017).
- Monitoring of all flying vehicles in real time (Geister 2017).
- Planning and forecasting high demand areas.

Furthermore, several things need to be emphasized. Firstly, this work tries to consider the flight restrictions and the public. The vertical extent complies with the flight regulations, which forbids to fly higher than 700 feet above ground height.

Secondly, the reliability of the data needs to be inspected. The data is open source and might be unprecise and inaccurate. Instances to approve the underlying data might be space agencies, the airport management or city authorities. Thirdly, the assumptions of the boundaries of the geofences in all directions rely on existing concepts, but without specific restrictions how much distance needs to be withheld from hospitals, embassies and the other buildings, areas and points of interest. Anyway, these values are parametrized and can be easily changed.

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