MULTI-STOP ROUTE PLANNING

Application of Dijkstra's Algorithm on the night criminal activity of Lincoln Park (Chicago, IL)

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Abstract

This project focuses on a multi stop route planning method (Dijkstra algorithm) and implements it within an empirical use case framework. While going through the main principles of this network analysis subfield such as the Graph Theory, this research follows the entire multi stop route planning analysis workflow. This includes data collection and storing, data management and preparation, analysis, exposure and discussion of the outcome: a night police patrol network based on crime data of Lincoln Park (Chicago, Illinois).

Key words: Dijkstra, planning, algorithm, stop, multi, routing, patrol, Lincoln Park

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1. Introduction

1.1. Topic presentation and motivations

Network analysis as a very broad spatial analysis area, can be applied and give optimal solutions in multiple situations; basically, all the scenes that involve a network such as logistics, telecommunications, traffic, etc., can be study objects or inputs for this tool. Just by having some nodes or points, a route or even an entire network can be built from scratch in order to solve basic daily needs in a population. According to that and together with a strong interest in mobility planning, this seminar project is going to be based on multi stop route planning. However, it is still a very broad method and therefore, there is the need to further specify the interest of having chosen such a multifaceted topic.

Following this line, this project deals with crime data as an input to create a night police patrolling network for a specific geographical area: the Lincoln Park neighborhood (Chicago, Illinois). A city which has been categorized as one of the areas with the most criminal activity in the United States and which is currently presenting a dynamics change in the spatial distribution of its crime. Residential areas from the north side of the city, like Lincoln Park or Lake View, have been experiencing a very strong increase in their felonies during these past years. In numbers, during 2019, crime rate in Lincoln Park increased by 40% in comparison to 2018 and a considerable part of these phenomena take place at night (Cseke , 2020). Taking this into consideration, a need has been identified: the security improvement of these areas and consequently, the contribution to the fight of Chicago against the crime.

This exposed situation, as many of the current daily problems, can be minimized and optimized by using geospatial solutions. In this case, the personal passion for the smart (mobility) planning brought the author to look forward to use network analysis tools in order to solve a current social need. In other words, a potential smart solution is going to be created –a police patrol network- based on crime cores of the specific study area, with the aim of giving a tool which will minimize the night criminal activity in the neighborhood of Lincoln Park.

1.2. Study area and data

As mentioned in the previous subsection, this project will be based on a specific neighborhood of the city of Chicago (Illinois, US): Lincoln Park. To avoid confusions, it is important to consider that there is also a district named like that. However, as mentioned previously, this research will be carried out throughout the neighborhood of Lincoln Park and therefore, from now on, all the mentions to "Lincoln Park" will be referred to the neighborhood.

Having cleared possible semantic confusions, the defined study area has a total surface of 8,26km^2, a population of 67.260 and a population density of 8.142 inhabitants/km^2 (CMAP, 2016). According to these basic demographic figures it is a quite dense populated area in comparison to the general city dynamics (4.576 inhabitants/km^2) .This fact makes sense because it is a residential area and it is very centrally located since it is right next to the city downtown. The high accessibility together with the elevated income per household of the neighborhood -around $95.416 (CMAP, 2016) - make Lincoln Park an optimal target for the criminal activity. The following *Figure 1* locates the study area within the entire city of Chicago.

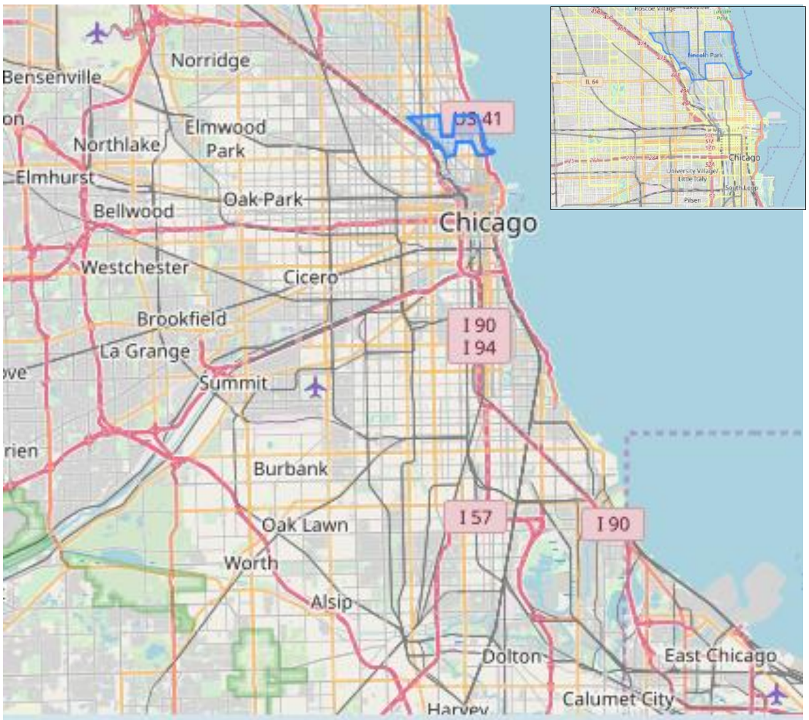

Figure1. Location of Lincoln Park neighborhood with zoomed area attached (Source: own elaboration in PostGIS).

Along with the study area definition, the data which will be used is the key part and main input of this entire project. According to what has been previously mentioned, the specific datasets used will be:

- Vector data of the Chicago neighborhoods
- Point data of the crimes in Chicago during the whole 2019 (256.879 records)

Both datasets have been extracted from the Chicago Data Portal (https://data.cityofchicago.org/). On one hand, the vector data has been queried for the specific study area (Lincoln Park). On the other hand, the crime data has been clipped according to the study area as well. Additionally, this crime data has also been queried with the time span (21h-6h), so the night felony areas can be perfectly identified. Taking this into account, the upcoming *Figure 2* shows the set up environment:

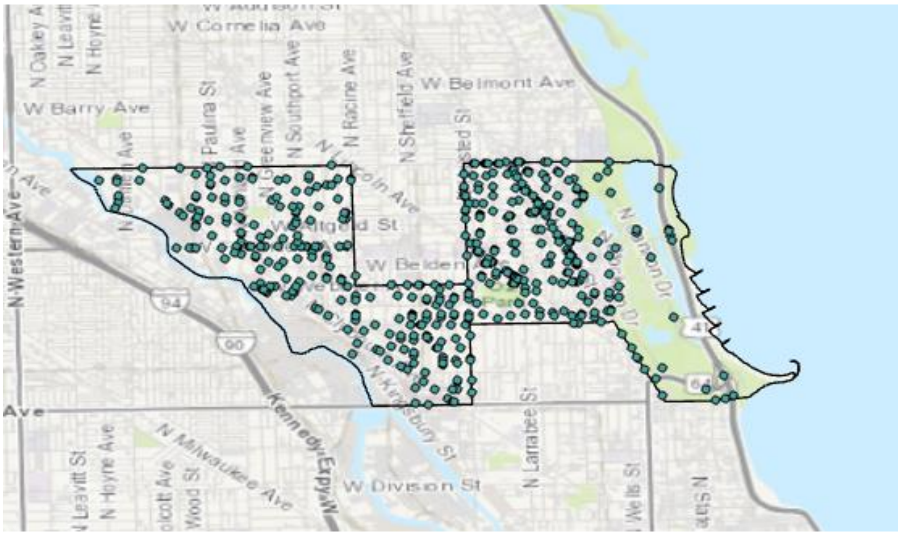

Figure2. Vector data as Lincoln Park boundaries and point data as crimes. After this data pre-processing, the records went down to 859 crimes (Source: own elaboration).

In terms of software tools, the data conversion (from JSON/CSV to SHP or any type of spatial file format) is done with QGIS and imported right away to a local database (PostgreSQL) which stores all the data in order to smoothen the data cleaning and management process throughout SQL. Once this is set, a connection with the database will be done in ArcGIS Pro and the pre-analysis phase will be able to start (data preparation for the analysis – e.g. nodes allocation). After this, the analysis itself will be carried out within the ArcGIS Online (cloud based GIS environment).

1.3. Objectives

Continuing with the introductory section and as the last part of it, the research objectives must be clearly defined. In this case, they will be divided between main and secondary objectives. According to that, the primary guidelines or targets to be achieved during and at the end of the projects are listed below:

1- Create from scratch an optimal network of night police patrol routes for the Lincoln Park neighborhood in order to increase its (night) safety.
2- Implement correctly and efficiently the Dijkstra Algorithm (through ArcGIS tools) for the defined study area and data, as the main multi-stop route planning method for this research.
3- Understand, in a complete way, the fundamentals which compose the Dijkstra Algorithm and therefore, the principles of route planning by applying it to a real case of study.

These three objectives are going to be the main guidelines. However, this is also going to be followed by some specific or secondary objectives which will provide concretion in the project:

- Get a full understanding of the data and study area defined, in order to provide an accurate and realistic output which will become a potential solution for a specific need.
- Choose the optimal parameters while applying Dijkstra's, in a way that the corresponding output becomes optimal.

2. Methodology: Route Planning using Dijkstra's Algorithm

2.1. Overview

Route planning can be carried out on multiple scales. Going from a location A to a location B, extending this with locations C and D, or even creating a full network to cover a specific need. It is all based in the Graph Theory principles: converting the real world into a network composed by nodes -as points or cores- and edges –as node connectors- with topological relationships (Pressl, 2012). According to that, this network-based approach as the representation of a specific environment or world phenomenon, is the base in which methods and algorithms in the route planning field are built upon.

2.2. Graph Theory

The Graph Theory was introduced by the Swiss mathematician and physicist Leonhard Euler in the 18^{th} Century. It all started in the old Prussian city of Königsberg (today Kaliningrad, Russia), which is divided by the Pregolya river and consequently, connected through seven bridges. With this context, Euler's motivation was to walk through the entire town crossing each single bridge only once. Taking this into consideration, Euler started representing on paper a schematic map of Königsberg divided by nodes and connecting edges. From there, Euler started drawing different path combinations through this graph. However, he realized that it was not the most efficient schema and he started altering the number of nodes and direction of edges by having the general rule of just being able to walk through each edge once. With this, Euler's Graph Theory was created (Najera, 2018).

This discrete mathematical theory, which represents the world (or abstractions of it) within nodes (or vertices) and edges, has been and it currently is a very appropriate method to model real world systems (e.g. integrated circuits for electronic devices, graph databases, telecommunications systems…). According to that, it is one of the mathematical methods which is more present in our current daily lives.

As the name shows, the Graph Theory studies the graphs, which are understood as mathematical systems that model relations and relationships between elements or objects. These objects, as stated before, refer to the vertices or nodes and the relationships or interactions between them are represented as edges or lines that connect with one another. Within this theory, two types of graphs are distinguished: directed graphs and undirected graphs. On one hand, the directed graphs edges' are unidirectional and therefore, they indicate a single way relationship. On the other hand, undirected graphs contain bidirectional edges and consequently, they indicate reciprocal relationships (see illustration of both types in *Figure 3*).

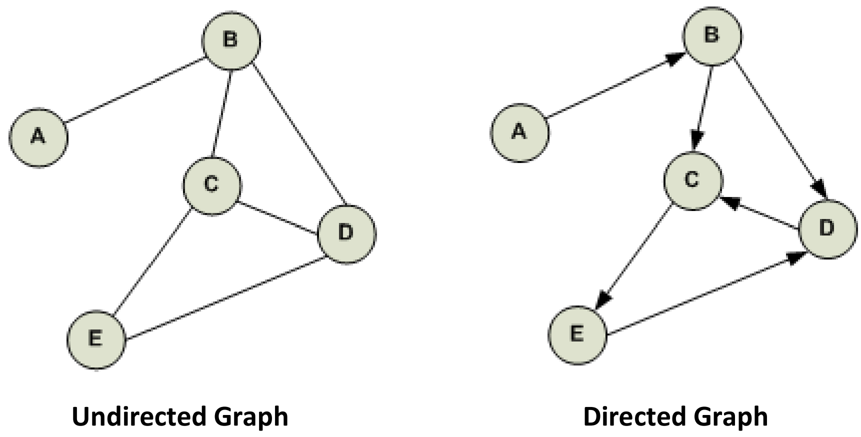

Figure3. Respective schemas of an undirected and a directed graph. According to that, a directed graph will always have arrows specifying the direction of the relationship whereas an undirected graph not, since it has a bidirectional relationship as mentioned (Source: way2net.co.il).

According to Pressl (2012), the main elements of a graph are nodes, edges, polygon points, isolated points, arcs and weights. Nodes and edges have been already defined. Polygon points are points to model a curved link (or another type of complex shape) between nodes. Isolated points, usually used in transportation networks, are for example points of interest within the area of the specific network. Arcs represent the direction on edges in the directed graphs. Weights specify the relationships between nodes.

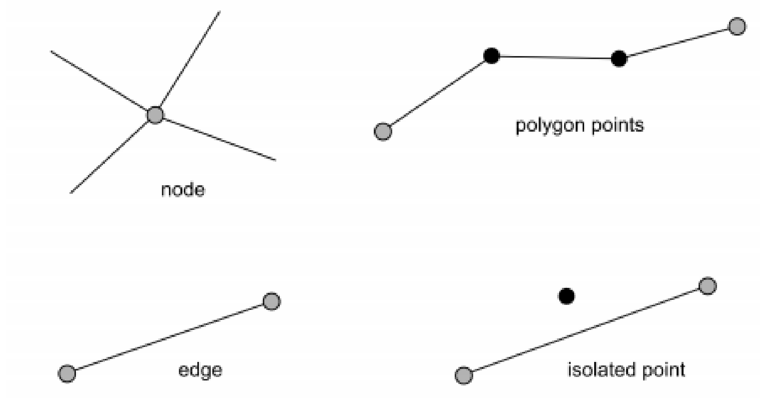

Figure4. Some of the main graph elements (Source: Pressl, 2012).

Within a graph, there can also be loops, which represent recursive relationships of nodes. However, the aim of this subsection is to give a general understanding of the Graph Theory and according to that, it has not and it will not dig deep into specific technical concepts of the theory.

Taking this principles into account, the Graph Theory composes the bases in network and system modelling for many scientific and professional fields. Route planning, as stated before, is one of the most common ones. In this field, this graph based approach is omnipresent in front and behind the scenes as the base for most of the multi-stop route planning and optimization algorithms. In agreement with that, this project will use the “father” of these algorithms: Dijkstra’s Algorithm.

2.3. The Dijkstra’s algorithm

Within the network based environment, Dijkstra’s algorithm is a mathematical method which is used for finding the shortest path between nodes in a graph. This algorithm was developed by the Dutch computer scientist Edsger W.Dijkstra during the 1950s and published in 1959. It triggered a revolution in the route planning field by giving a solution to one of the most common problems: the shortest path problems (SPP). Mainstream applications such as Google Maps or Uber have many of their functionalities built upon this method.

Originally, this algorithm was developed to find the shortest distance between two nodes. However, it has been modified and updated in many different ways according to specific needs. For example, a very common and useful form of this algorithm is the one which will be used in this project: finding the optimal (shortest and costless) path between many nodes by creating a short path tree (basis of multi-stop route planning – see *Figure 5*). According to this, Dijkstra’s Algorithm assigns different weights to all the study network edges’, and from here, it calculates the different paths by selecting the weightless edges. The units of these weights can obviously be modified depending on the planning criteria (e.g. shortest route by time, shortest route by distance, cheapest route…). With this, the algorithm assumes that “the local minimum leads to the global optimal". In other words, by choosing the local minimum costs (usually distance or time), it ensures the creation of an optimal route.

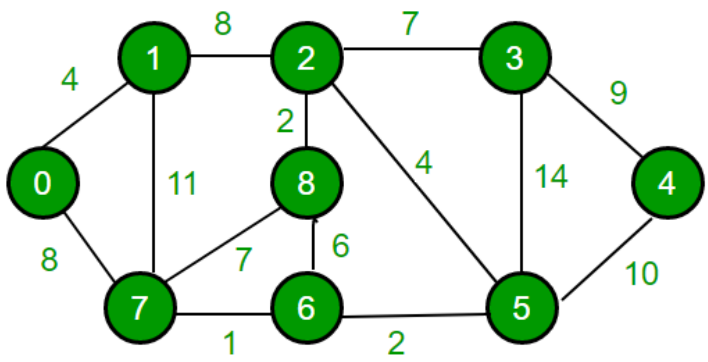

Figure5. Sample of a graphical illustration of Dijkstra's Algorithm model (Source: tutorialspoint.dev).

According to *Figure 5*, this method selects and generates the optimal route by first creating this, previously mentioned, short path tree model as input. From here, the algorithm iterates through the model, and in each loop, it chooses the paths with the smaller cost number (see full iterative workflow in *Figure 6* with another model).

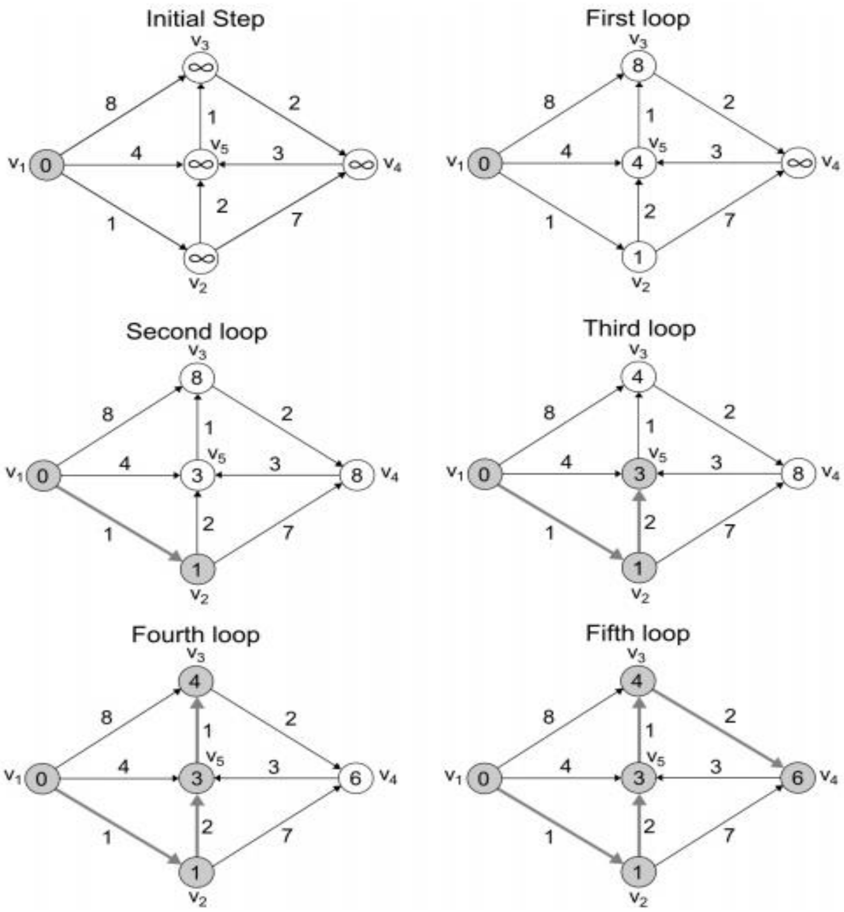

Figure6. Dijkstra's Algorithm workflow (Source: Pressl, 2012).

2.4. Application to the case of study

With an understanding of how Dijkstra's Algorithm works and its fundamental principles from the Graph Theory, it is time to focus on the project scenario and the application of the algorithm on it. In this case, the nodes have been manually created as patrol stopping points, in which the police is going stop and be around for 20 minutes (so their presence is noticeable). Additionally, an event collection function from ArcGIS has helped in the nodes allocation process, in order to specifically detect and distinguish the different crime areas.

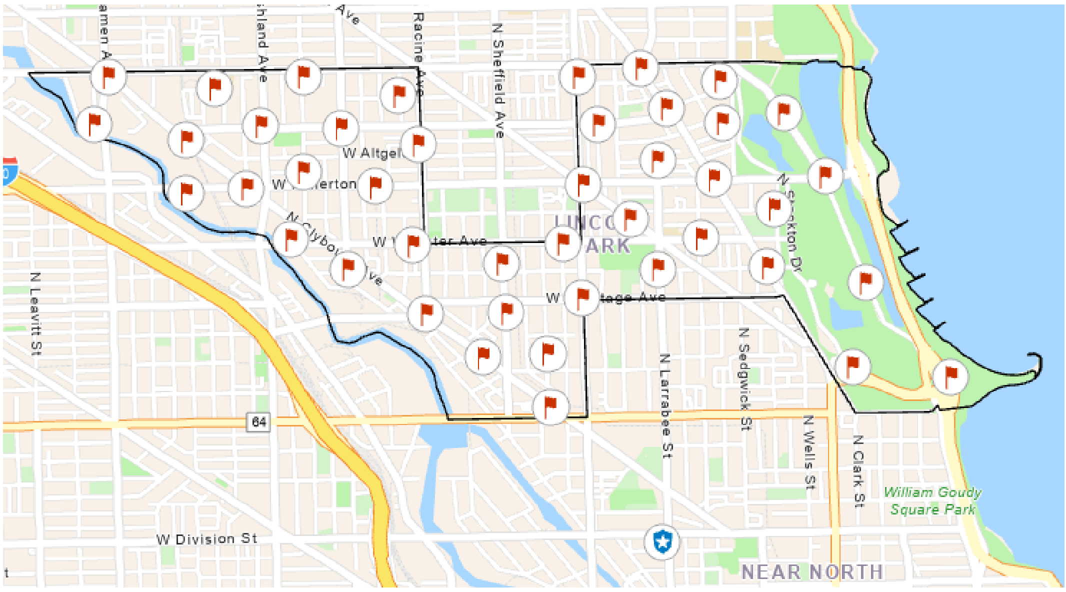

Figure7. Map of created police patrol stops (red flag) and police station as the starting node (outside the neighborhood bounds, in the South of the provided map) (Source: own elaboration).

According to that, *Figure 7* shows the already defined nodes of the study area (stops –with the red flag- and starting node –police station-) in which the Dijkstra's Algorithm will be based on. Proof of the optimal location of these manually created stops has been given by creating a 250m buffer around each stop (see *Figure 8*). This 250 meter radius is established by taking into account that the police presence will be effective throughout this area during the 20min stop. From here, the explained algorithm has already enough features to run and generate an optimal network for the Lincoln Park neighborhood night police patrols; a network basically because it will be composed by some routes which will be carried out simultaneously by different police cars.

Additionally, the edges will be represented by the streets and depending on each street roads and directions, these will be weighted and selected (or not) for the optimal routes.

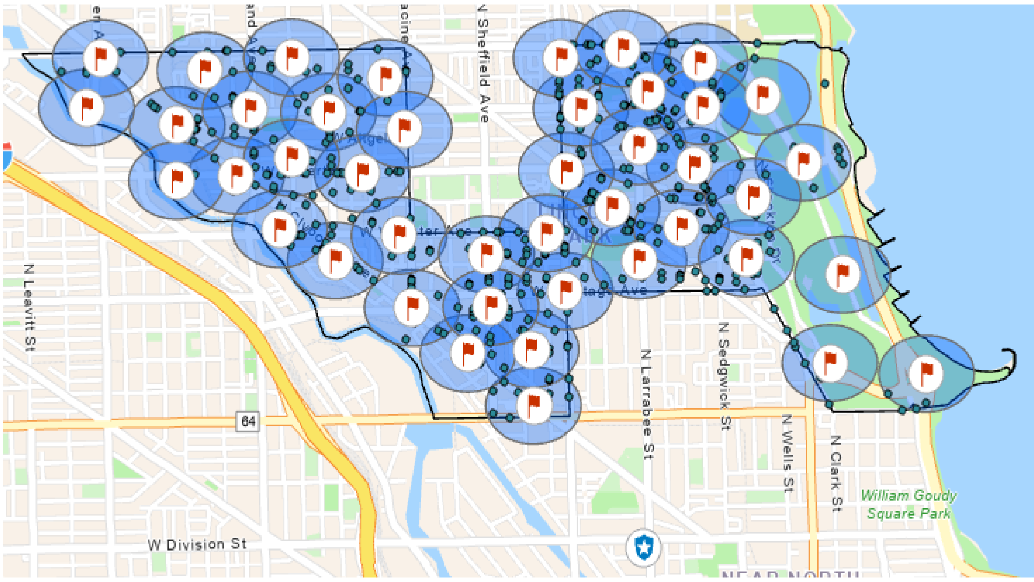

Figure8. Buffer areas (250m) for each single patrol stop. According to this map, most of the crimes get covered, which means that the stops are well allocated (Source: own elaboration).

As mentioned, ArcGIS Pro and ArcGIS Online environments have Dijkstra's Algorithm implemented as one of their multiple available tools. In this case, the online software will be used and therefore, the layers must be previously shared as web layers in order to be able to work on ArcGIS Online. The tool is encompassed within the "Use Proximity" tools and stands for "Plan Routes". Taking this into consideration, the entire analysis part will be carried out within this cloud environment. Having said that, the architecture of the entire project is defined below (*Figure 9*).

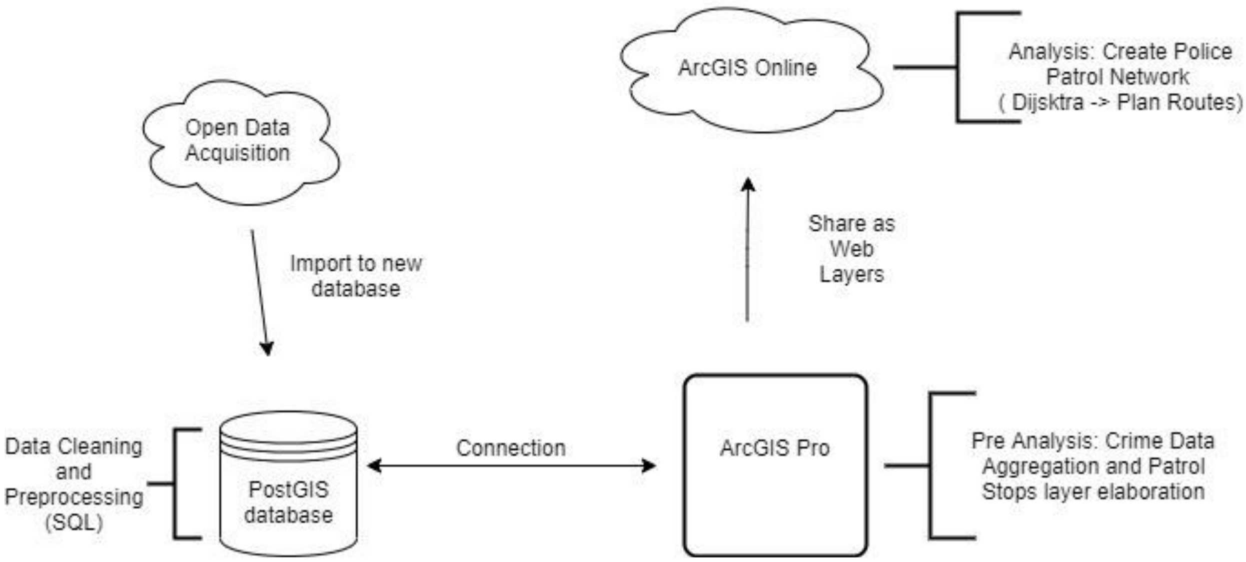

Figure9. Architectural diagram of the Project (Source: own elaboration with draw.io).

3. Results

This section is going to present the results and outputs elaborated from the entire analysis phase, which was led by the Dijkstra's Algorithm implementation (using ArcGIS tools) in order to create the night police patrol routing network for the Lincoln Park neighborhood. As mentioned in the previous section, the tool "Plan Routes" from the cloud-based GIS environment of ArcGIS (ArcGIS Online) has been the key method to apply this algorithm and get the desired network of routes (see *Figure 10*).

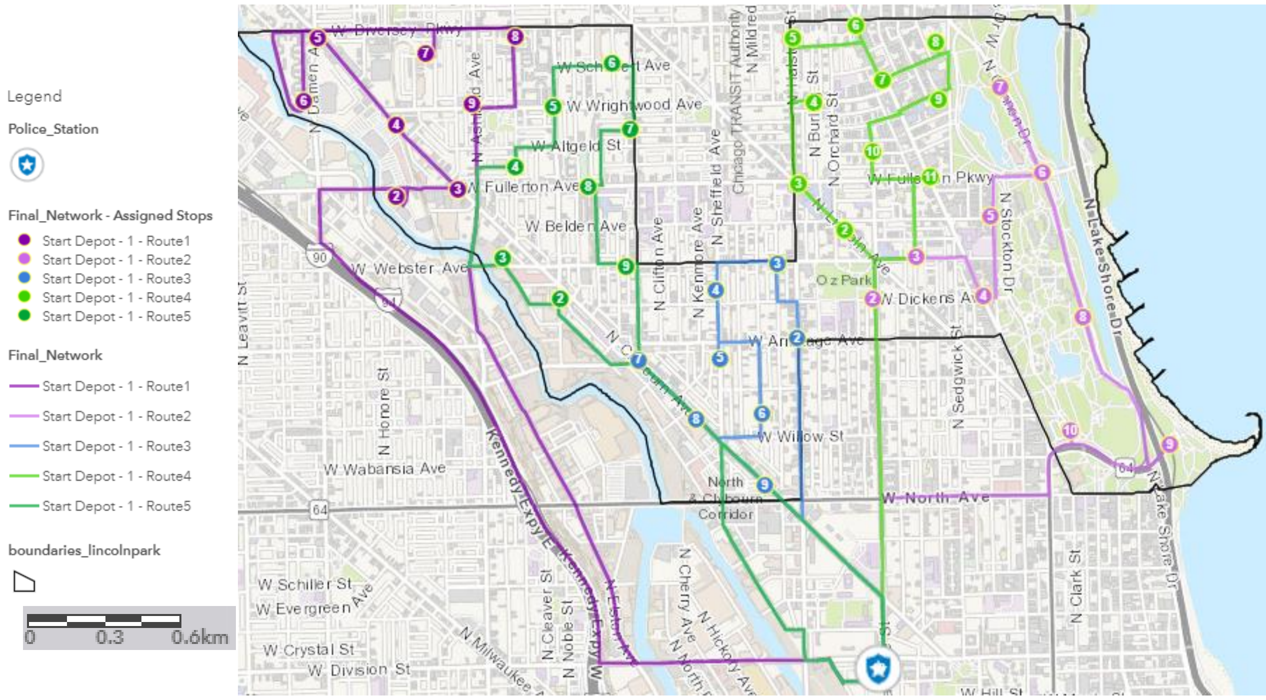

Figure10. Night Police Patrol Network for Lincoln Park (Source: own elaboration).

According to *Figure 10* map, an optimal network of five routes throughout the Lincoln Park neighborhood has been established. Taking into consideration the already explained Dijkstra's Algorithm workflow, each single network edge (or road) has been automatically selected depending on travel time and therefore, all the routes have been generated.

The elaboration process of this route has had some specific parameters which will be subsequently explained. The tool "Plan Routes" needs some inputs: starting/ending points, nodes of the network, travelling mode (driving time, trucking time, rural driving time or walking time) , starting time, maximum nº of vehicles, maximum nº of stops/vehicle, time spent at each stop, limit total route time per vehicle and as an optional field, adding barrier layers.

Tool Parameters:

- Start/End point: Chicago Police Department
- Nodes: Created Patrol Stops point layer
- Travelling mode: Driving Time
- Starting time: 21h (night patrol goes from 21h until 6h)
- Max. nº of vehicles: To give the tool a broad range for choosing the optimal number, 10 vehicles were introduced. Although, it has found that the optimal nº is 5 police cars.
- Max. nº stops/vehicle: 10
- Time spent at each stop: 20min (enough for the police to make presence)
- Limit route time/vehicle: 5h (it is important to get shorter routes so they can be operated several times per night and therefore, ensure a higher level of security)

Having given an overview of the network elaboration process (by using the "Plan Routes" tool), it is time to zoom into the resultant network and therefore, the different routes which compose the network will be subsequently exposed.

Route 1: North West Lincoln Park

This first route covers the far north-western part of Lincoln Park; some of its industrial area and the public housing Lathrop Homes quarter. Even though it is the farthest route (5km to get to the 1^{st} stop), its accessibility through the Kenedy Expressway is optimal (just around 9 min drive). It is composed by 8 stops, which are covered in a total of 13.91km, and a patrol through it takes around 3 hours and 14 minutes. The stops are quite close to each other due to the tendency to clustered distribution of the crimes in this area (2019 crimes). This brief description is graphically supported in the upcoming *Figure 11* map and *Figure 12* table.

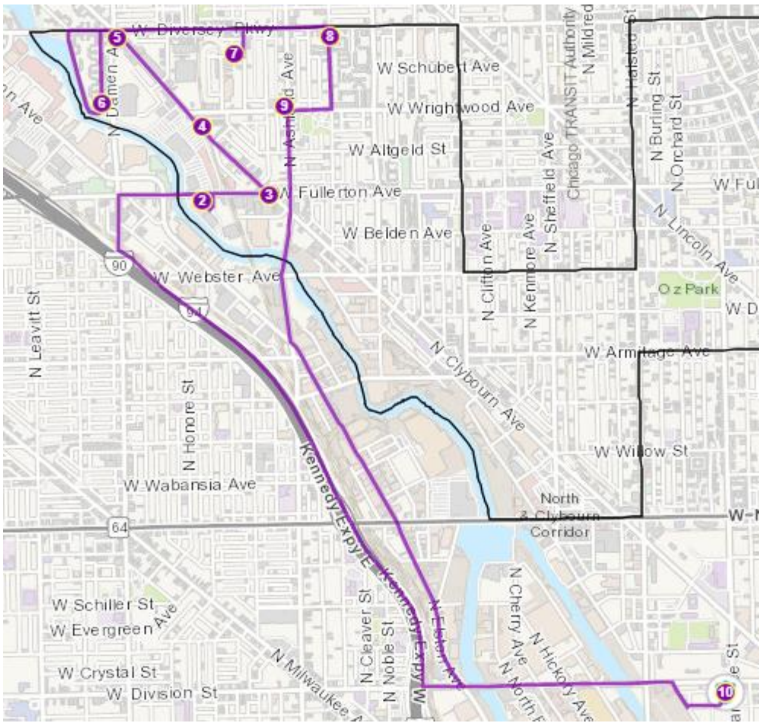

Figure11. Map of the route 1- North West Lincoln Park and Lathrop Homes area (Source: own elaboration).

Sequence	Travel Distance from Previous Stop (Kilometers)	Arrive Time	Depart Time	Stop Type
1	0.00	5/2/2020, 9:00 PM	5/2/2020, 9:00 PM	Route start
2	5.03	5/2/2020, 9:09 PM	5/2/2020, 9:29 PM	Stop
3	0.40	5/2/2020, 9:31 PM	5/2/2020, 9:51 PM	Stop
4	0.45	5/2/2020, 9:52 PM	5/2/2020, 10:12 PM	Stop
5	0.60	5/2/2020, 10:13 PM	5/2/2020, 10:33 PM	Stop
6	0.75	5/2/2020, 10:35 PM	5/2/2020, 10:55 PM	Stop
7	1.20	5/2/2020, 10:59 PM	5/2/2020, 11:19 PM	Stop
8	0.64	5/2/2020, 11:21 PM	5/2/2020, 11:41 PM	Stop
9	0.76	5/2/2020, 11:43 PM	5/3/2020, 12:03 AM	Stop
10	4.08	5/3/2020, 12:14 AM	5/3/2020, 12:14 AM	Route end

Figure12. Attribute table regarding stops, time and distance of route 1 (Source: own elaboration).

Route 2: Lincoln Park and North Avenue

In this second route, the entire far eastern area of Lincoln Park is covered (*Figure 13*); starting at Oz Park, it goes until North Pond and ends up covering the whole Lincoln Park (main park and naming reason of the neighborhood). Most of the last year crimes were clustered between the first and the forth stop, although, the rest of the stops (situated along the main park in parallel with North Avenue) had some very severe crimes due to the "isolation" of some of its areas. With this, the route is composed by 9 stops, which are covered in 9.86km, and it has an estimated temporal length of 3h 25min per operation. Even though this route is 4km shorter than the previous Route 1, it has an additional stop and therefore, that is the reason why this one has longer duration. Taking this into consideration, the route length is not the biggest conditioning fact; it is the number of stops (see *Figure 14* for specifications).

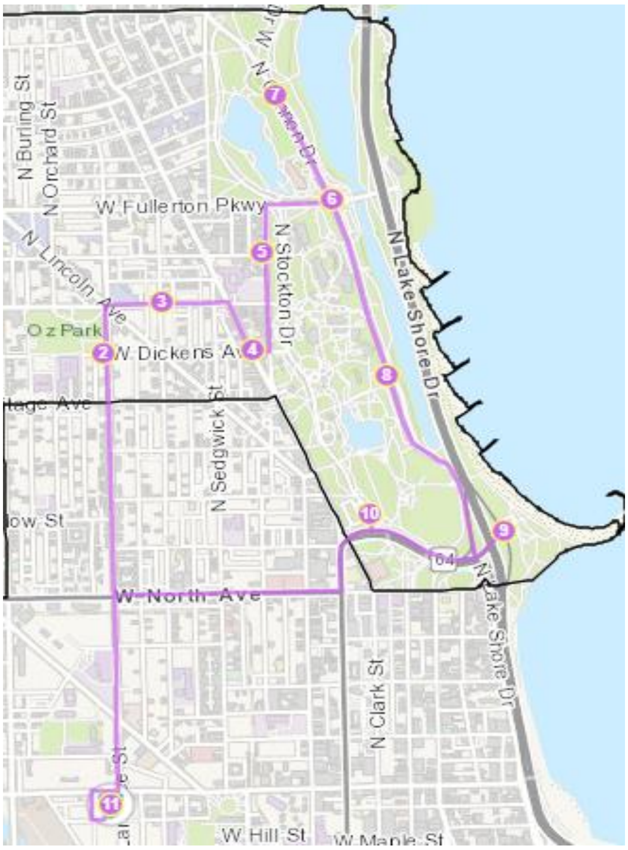

Figure13. Map of the route 2: Lincoln Park and North Avenue areas (Source: own elaboration).

Sequence	Travel Distance from Previous Stop (Kilometers)	Arrive Time	Depart Time	Stop Type
1	0.00	5/2/2020, 9:00 PM	5/2/2020, 9:00 PM	Route start
2	2.16	5/2/2020, 9:05 PM	5/2/2020, 9:25 PM	Stop
3	0.43	5/2/2020, 9:26 PM	5/2/2020, 9:46 PM	Stop
4	0.47	5/2/2020, 9:48 PM	5/2/2020, 10:08 PM	Stop
5	0.48	5/2/2020, 10:09 PM	5/2/2020, 10:29 PM	Stop
6	0.48	5/2/2020, 10:30 PM	5/2/2020, 10:50 PM	Stop
7	0.48	5/2/2020, 10:51 PM	5/2/2020, 11:11 PM	Stop
8	1.24	5/2/2020, 11:14 PM	5/2/2020, 11:34 PM	Stop
9	1.04	5/2/2020, 11:38 PM	5/2/2020, 11:58 PM	Stop
10	0.70	5/2/2020, 11:59 PM	5/3/2020, 12:19 AM	Stop
11	2.39	5/3/2020, 12:25 AM	5/3/2020, 12:25 AM	Route end

Figure14. Attribute table regarding stops, time and distance of route 2 (Source: own elaboration).

Route 3: Central area- Ranch Triangle & Sheffield Neighbors

The third route operates between the Ranch Triangle, Sheffield Neighbors and Oz Park (illustrated in *Figure 15*). It is the closest route from the Police Department and its 7.3km length is proof of that. In addition, 8 stops are distributed along its path and a total of around 3 hours (2h 59min) are needed to patrol through it (*Figure 16*). This route nº 3 has half of the length (km) of route nº1, but the same number of stops and therefore, their time difference just varies in 15 min. This proves how the total time duration is mostly affected by stops number rather than route distance. In route morphology terms, the area covered has a quite abundant night criminal activity which tents to be homogeneously distributed and consequently, the path is comprised in the area.

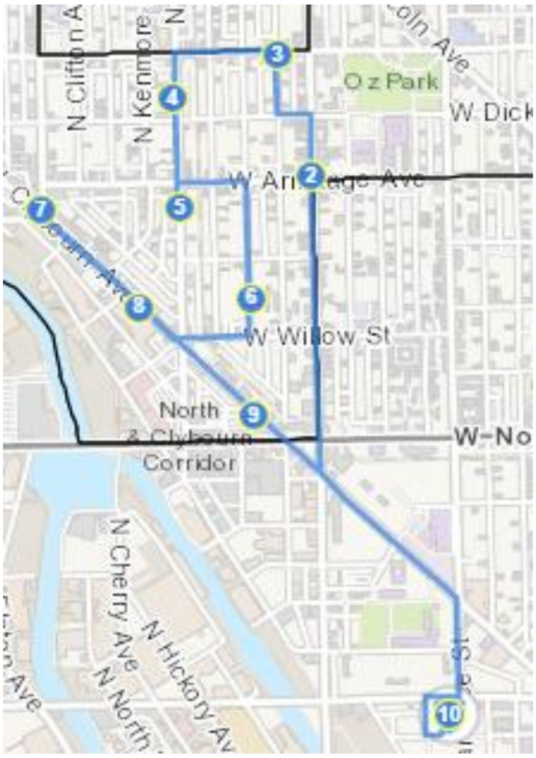

Figure15. Map of the route 3: Central area – Ranch Triangle & Sheffield Neighbors (Source: own elaboration).

Sequence	Travel Distance from Previous Stop (Kilometers)	Arrive Time	Depart Time	Stop Type
1	0.00	5/2/2020, 9:00 PM	5/2/2020, 9:00 PM	Route start
2	2.11	5/2/2020, 9:05 PM	5/2/2020, 9:25 PM	Stop
3	0.48	5/2/2020, 9:27 PM	5/2/2020, 9:47 PM	Stop
4	0.46	5/2/2020, 9:48 PM	5/2/2020, 10:08 PM	Stop

5	0.34	5/2/2020, 10:09 PM	5/2/2020, 10:29 PM	Stop
6	0.65	5/2/2020, 10:31 PM	5/2/2020, 10:51 PM	Stop
7	0.91	5/2/2020, 10:53 PM	5/2/2020, 11:13 PM	Stop
8	0.42	5/2/2020, 11:14 PM	5/2/2020, 11:34 PM	Stop
9	0.48	5/2/2020, 11:35 PM	5/2/2020, 11:55 PM	Stop
10	1.45	5/2/2020, 11:59 PM	5/2/2020, 11:59 PM	Route end

Figure 16. Attribute table regarding stops, time and distance of route 3 (Source: own elaboration).

Route 4: Park West

In this route nº4 the Central-East area of the neighborhood, so called Park West, is covered: its path is comprised between Oz Park, North Pond and De Paul University Campus (see *Figure 17*). Even though the 2019 crimes in the neighborhood tended to have a regular distribution, there are still some hotspots and many of these are located over this area. With this and according to *Figure 18*, route 4 is composed by 10 stops, a total distance of 9.38km and a total patrol duration close to 4 hours (3h 47min). Taking this into consideration, this route is the longest (in duration terms) with the largest number of stops due to the aforementioned fact.

Figure17. Map regarding route 4: Park West (Source: own elaboration).

Sequence	Travel Distance from Previous Stop (Kilometers)	Arrive Time	Depart Time	Stop Type
1	0.00	5/2/2020, 9:00 PM	5/2/2020, 9:00 PM	Route start
2	2.56	5/2/2020, 9:06 PM	5/2/2020, 9:26 PM	Stop
3	0.34	5/2/2020, 9:27 PM	5/2/2020, 9:47 PM	Stop
4	0.54	5/2/2020, 9:49 PM	5/2/2020, 10:09 PM	Stop
5	0.43	5/2/2020, 10:10 PM	5/2/2020, 10:30 PM	Stop
6	0.45	5/2/2020, 10:31 PM	5/2/2020, 10:51 PM	Stop
7	0.31	5/2/2020, 10:52 PM	5/2/2020, 11:12 PM	Stop
8	0.38	5/2/2020, 11:14 PM	5/2/2020, 11:34 PM	Stop
9	0.36	5/2/2020, 11:35 PM	5/2/2020, 11:55 PM	Stop
10	0.54	5/2/2020, 11:57 PM	5/3/2020, 12:17 AM	Stop
11	0.44	5/3/2020, 12:18 AM	5/3/2020, 12:38 AM	Stop
12	3.04	5/3/2020, 12:47 AM	5/3/2020, 12:47 AM	Route end

Figure18. Attribute table regarding stops, time and distance of route 4 (Source: own elaboration).

Route 5: Wrightwood-West De Paul

Last but not least, route nº5 covers the Central-West area of Lincoln Park: it is comprised between Wrightwood Neighbors, West DePaul, North Branch of Chicago River and Sheffield Neighbors. It covers a wider area in comparison to route nº3, basically because the crimes of this Central-West zone are more dispersed and heterogeneous. Due to this fact, the stops which compose this route tent to be more distant from each other in comparison to previously exposed routes (see *Figure 19*).

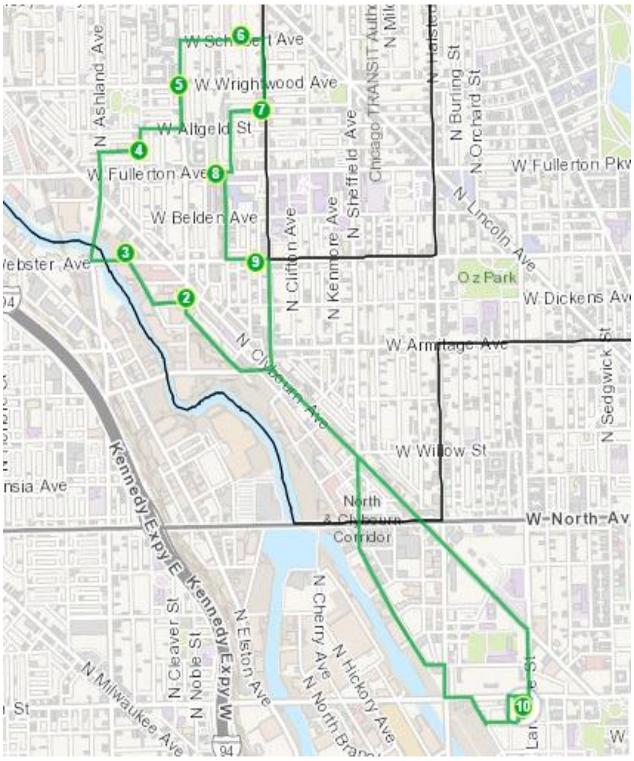

Figure 19. Map of the route 5- West DePaul (Source: own elaboration).

It has a distance of 9.84km, it is composed by 8 stops and an approximated operational time duration of 3h 6min (specified in subsequent *Figure 20*).

Sequence	Travel Distance from Previous Stop (Kilometers)	Arrive Time	Depart Time	Stop Type
1	0.00	5/2/2020, 9:00 PM	5/2/2020, 9:00 PM	Route start
2	2.98	5/2/2020, 9:07 PM	5/2/2020, 9:27 PM	Stop
3	0.43	5/2/2020, 9:28 PM	5/2/2020, 9:48 PM	Stop
4	0.91	5/2/2020, 9:51 PM	5/2/2020, 10:11 PM	Stop
5	0.52	5/2/2020, 10:12 PM	5/2/2020, 10:32 PM	Stop
6	0.52	5/2/2020, 10:34 PM	5/2/2020, 10:54 PM	Stop
7	0.46	5/2/2020, 10:55 PM	5/2/2020, 11:15 PM	Stop
8	0.51	5/2/2020, 11:17 PM	5/2/2020, 11:37 PM	Stop
9	0.60	5/2/2020, 11:39 PM	5/2/2020, 11:59 PM	Stop
10	2.91	5/3/2020, 12:06 AM	5/3/2020, 12:06 AM	Route end

Figure20. Attribute table regarding stops, time and distance of route 5 (Source: own elaboration).

4. Discussion

After presenting and exposing the results accordingly, it is time for the exposure of some shortcomings or critiques, which have arisen throughout the multi stop route planning analysis.

In methodological terms, Dijkstra's algorithm acts perfectly when solving a shortest path problems from one node to another, but it does not solve other route planning issues. In this sense, it is a bit limited, because in route planning terms there is also another major fact to take into consideration: the order of the stops (nodes). For example, Dijkstra provided us with a network around Lincoln Park in which each route selected the closest paths between patrol stops. However, this tool did not go into altering the order of the stops in order to find a potential better route like in the heuristic approaches. With this, an important consequent remark is that Dijkstra only focuses on the local optimal and takes for granted that it will reach the global optimal.

In thematic terms, this research aimed to provide a night police patrol network in order to increase the security and mitigate the crimes in Lincoln Park, but most important, to find an applied use case for the implementation of a multi stop route planning research. According to this, it did not approach in a deep manner any social or human component, which should have been taken into account if it would have been implemented in the real life. Even the stops were allocated in a simple and orientative way (by aggregating the points and collecting the crime events in order to visually see where more crimes were taking place). According to all these facts, this investigation is merely an example of a multi stop route planning implementation and the thematic must be taken into account only as a framework for the application of this method.

Regarding software tools, the strict analysis part and therefore, the core of the project has been carried out with commercial software (ESRI tools). This fact might be a strong shortcoming for the universal reproducibility of this project. Although, there are some Open Source tools which can be used for multi stop route planning and Dijkstra's algorithm implementation: PgRouting, GraphHopper or OpenRouteService are some popular examples. Unfortunately, the author had no knowledge of these tools until almost the end of the research and therefore, the analysis was already carried out.

Nevertheless, ESRI offers a great range of tools which can support very nicely the user throughout the different project phases and be very easily synchronized; desktop client (ArcMap/ArcGIS Pro), cloud based GIS (ArcGIS Online) or great geomedia for storytelling and presentations (Story Maps and Dashboards).

In a nutshell, these are some issues which should be taken into account for subsequent route planning research in order to further enhance in a holistic manner this network analysis subfield.

5. Conclusion

Getting to the last section of this project, some observations and final conclusions are going to be exposed. First of all, an IMRaD structure has been successfully applied in order to carry out the investigation and therefore, to accomplish each single objective that was exposed in the introductory section. Basically, by getting a complete understanding of the Dijkstra algorithm and proceed with an application of this to the study case. According to this, this research has followed a method-based approach.

In terms of data availability, the acquisition of the data has been a very smooth process due to the high availability of crime data in the US which can be easily retrieved by using open APIs, GIS services (e.g. Living Atlas) or simply by downloading the file right away from open data portals. A part which has been bit more complex was the data cleaning and management in order to set up the environment for implementing the aforementioned network analysis method. This, as stated previously, has been the reason which triggered the use of a DBMS (PostgreSQL). Following with the nodes establishment and the complete set up for the subsequent analysis phase (ArcGIS Pro), then sharing all the data to the cloud based GIS environment (ArcGIS Online) and finally presenting it by using Story Maps from the same online environment. With this, the project has successfully applied a distributed architecture (illustrated in *Figure 9*).

Last but not least, the study case in which the research method has been implemented is a good proof of the vital importance of location in society; a fact which has been for many years marginalized. In the current days, with an information revolution going on and multiple technologies available, location is acquiring a key role in studying any kind of societal phenomenon. In other words, the geospatial approaches and solutions have been and still are rapidly emerging as crucial methods and technology for the current and future developments.

6. References

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Other internet resources (online documentation or informal posts):

- Matlab documentation regarding graph types from MathWorks: https://de.mathworks.com/help/matlab/math/directed-and-undirected-graphs.html
- Basic workflow documentation of the Dijkstra algorithm from GeeksforGeeks: https://www.geeksforgeeks.org/dijkstras-shortest-path-algorithm-greedy-algo-7/
- Graph data structures in Javascript from Way2net: https://www.way2net.co.il/javascript-data-structures-graph/