Analyzing the Impact of Time & Distance Isochrones in a Distribution Network

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Abstract— The growth in the demand for urban freight transportation has resulted from the parallel advancement in urbanization and population growth. With the use of the Quantum Geographic Information System (QGIS) and its ORS plugin features, a model is formulated to determine the essence of time and distance between origins and destinations in a distribution network. The adopted optimization strategy applies the shortest route as the cost-effective way of managing the transport chain in a company and the fastest route suggests the service dependency and reliability since the time factor is of the essence in this strategy.

Keywords: Isochrones, GIS, Shortest Route, Fastest Route

I. INTRODUCTION

Globalization has been a great influence on the trends of growth in urbanization. Urban centers are being saturated with a high density of population, which sets demand levels at high levels. Rapid urbanization, therefore, results in increasing levels of demand for distribution in these cities, which creates many challenges [1]. Therefore the need to emphasize the efficiency of delivery systems while marginal revenues are decreasing has led various actors to identify new delivery options among emerging technologies, including drop boxes [2], cargo bikes [3], electric vehicles [4], autonomous vehicles [5], and drones [6]. Complicated transport problems are currently addressed mainly by modeling the transportation and transport processes in the given area. Modeling is a process that helps to better determine the problem and its solution options. It is used in every area associated with human creativity [7]. Rapid urban growth has led to constant unsystematic urban conditions and land use and transportation issues, such as urban sprawl and congestion. The high economic activity of society significantly affects reliable urban transport availability [8].

A. Transport Systems as a Key Growth in Urban Advancement

Several factors have to be taken into consideration in infrastructure planning. While many policies and plans focus on optimizing traffic, such policies could compromise environmental protection measures. Achieving both goals require the integration of the two sectors. It's important to note that "the infrastructure policy and planning are a strong sector on their own" and contributes to fragmented policy actions. They both develop their own goals that are implemented regardless of the potentially conflicting objectives formulated in other policy sectors [9]. "Although an integrated planning approach is being put in place to develop transportation development, this approach to the transportation system is seen as land use and environmental systems, with each of these systems wielding direct and indirect effects on the others. This actualizes the overall consideration of mobility, with conflicts and complementarities among the policy fields are taken into account" [9]. An efficient and reliable transport system is the backbone of any national or regional economy [10].

B. Distribution

The impacts of distribution reduce the wellbeing and related attractiveness of urban areas since it faces a growing trend. In addressing such issues, there should be an improvement in city logistics so that there may be a production reduction of diseconomies in the urban context to provide an efficient, good distribution system [11]. The overall problems introduced by urban distribution have become critical in recent times with the significant increase in e-commerce, which has resulted in a low density of customers with high geographic dispersion. These cases cause an increase in distribution costs. To deal with such a problem, it is vital to adopt intelligent delivery points that are located strategically and would allow an increase in the distribution efficiency and focus on customer flexibility [11]. There are complexities in recent times as the demand and needs of the customers keep changing, resulting in a constant struggle to sustain or raise their level of satisfaction [12]. The cargo distribution is very important for the efficiency of the whole supply chain, especially when the deliveries are spatially dispersed [13]. Facility location models determine the most suitable place for inventory prepositioning in the relief network. These models deal with the determination of appropriate locations for prepositioning inventories considering several stochastic and deterministic factors like cost, response time, location safety, demand coverage, distance, etc. [14].

C. Isochrones

Reachability has become an important component for many businesses from all different kinds of domains. This is then the focus of implementing the openrouteservice to help obtain isochrones which will assist in determining areas objects can reach in given times or distances [15]. GIS applications can analyze various planning problems such as collecting, managing, analyzing, modeling and presenting geographic or spatial data [16]. This ability makes it easier for planners to make effective and efficient decisions. GIS is an analytical tool that provides a major influence in delivering solutions to solve transportation problems. Quantum GIS (QGIS) is an open-source Geographic Information System that supports most geospatial vectors and raster data file types and database formats. The system offers standardized GIS functionality, with a variety of mapping features and data editing. The basic model used for this research is applying the Geographic Information System method using the QGIS software.

II. METHODOLOGY

A. Developing Isochrone Map (Iso – Area)

This analysis will provide the details into the reachability between the origin and destination (O – D pairs). Using isochrone maps has several advantages. They are especially useful in analyzing the number of destinations accessible within a given travel time [17] and are useful in visualizing accessibility. People, when traveling, tend to think of accessibility more in terms of time rather than in terms of the actual distance [18]. Emphasis will be placed on the time and distance relationship in this section. To determine reachability areas from any given points on the map, isochrones present these regions as contours of polygons. It responds to an input of time or distance as well as corresponding intervals. An example could be trying to find out the extent to which an object will travel within a specific distance or within a given time. There is also the possibility of knowing the community areas that a particular location has, e.g., schools or shopping precincts [15].

In constructing isochrones, a methodological approach factors the vital decisions that have to be considered when constructing isochrones. These decisions determine the calculation that has to be used. The data is then used as the input variables for the calculation to determine the resulting isochrone's influence. Finally, the visualization stage isochrones, which refers to both the layout of an isochrone map and its representation as a spatial object. Discussing all of these topics provides an overview of differences in isochrones and isochrone maps [19].

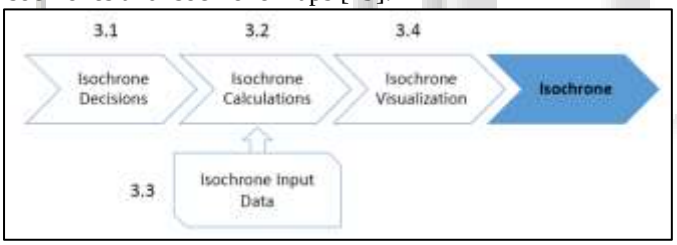

Fig. 1: Isochrone Construction Workflow
Source: [19].

III. MODELING AND ANALYSIS

A. Setting Origin and Destination Points with QGIS

QGIS makes available the use of important packages like the Openrouteservice (ORS) Tools, making it possible to perform an exquisite display of routing analysis. The ORS tools, as said before, make it possible to provide a real situation analysis on mapping, routing and other important functionalities. The first usage of the ORS tools, according to this research, was to help identify both the origin point and destination points on the map, which is shown in the figure below.

Fig. 2: Origin and Destination Points in ORS Tool
Source: [20]

B. Shortest & Fastest Route

The algorithmic application used in this process is the all-pairs shortest path problem. However, the difference between the shortest path and the fastest path is that the shortest path uses the shortest path between the two origins and destination (O – D) points, whiles the fastest path uses the fastest route. For example, routes with a highway with a faster speed limit nearby are highly likely to be used as the fastest route rather than the shortest route, which has slower speed limits as the duration when the highway could be the shortest. The shortest route seeks to minimize travel distance, and the fastest path seeks to minimize travel time. The map below displays both the shortest and fastest routes from the origin point to the destination points. The shortest routes pertaining to a point from the origin point, JSA Logistics, to the other destination points are marked with blue color on the map. On the other hand, the fastest routes are marked with the orange color from the same origin point JSA Logistics to the destination points.

Fig. 3: Shortest route (in blue) & Fastest route (in orange) from origin points to the destination.
Source: [20]

The analysis was done by the algorithm when it was run the results where the differences in the shortest route and the fastest route are easily identifiable. As discussed in the previous chapters on the considerations for the technical involvements in determining the differences.

C. Developing Isochrone Map

An isochrone, as defined above, is an area on the map that can be defined as the boundaries to which point an area lies within a time or distance limit specified by the user. In transportation planning, isochrone maps are commonly used to depict areas of equal travel time. Openrouteservice presents a new and

improved speed-up technique that makes it possible to calculate much larger isochrones than with the existing algorithm. The algorithm works by utilizing the topological characteristics of a road network and can identify cells of the network that are connected to others only via very few roads. This partitioning process can drastically reduce the time required for finding all roads that can be gotten within a certain time limit. It is possible to compute isochrones for hours of traveling time in a matter of seconds—isochrone maps, which given a starting location, show the reachability of places within a certain time span. The Isochrone analogy supports time and distance analyses for one single or multiple locations. This service allows the same range of profile options as the /directions endpoint, which assists in further customizing one request to obtain a more detailed reachability area response.

Isochrones are formed by first generating a 2-D grid in latitude, longitude on the location. This 2-D grid is used to determine the time or cost it takes to get from the target location to each other grid location. The 2-D grid is also used to determine the isochrone contours by applying a familiar contouring method. This process then locates grid cells that have adjoining cells where values lie on opposite sides of the contour value. The contouring algorithm then generates line segments through the grid cell corners based on several possible cases.

Fig. 4: Iso-distance relationship between origin and destination
Source: [20]

The origin-destination isochrones from points utilize an algorithm that computes the network route-based distance relations between points of two layers. This algorithm extends its reach by querying the network's vertices inside a user-defined distance range starting from multiple points provided in a point vector layer. The algorithm then displays and computes the iso-distance from the starting point to the various destination points based on the defined distance range. Based on this elaborated analysis, it is possible to determine the distances within an hour driving distance from the point of origin. The distance isochrones were gauge within an interval of 5000m, 10000m, 15000m and 20000m to determine the distance coverage of the transport department's study area or operational area. The scope that captures the range of 5000m captured only one (1) destination point. Then it was gauged to an area of 10000m, which captured five (5) of the other destination points within the study area. The iso-distance gauge was increased to 15000m which also captured three (3) of the destinations points of the study area. Finally, the iso-distance gauge was lifted to 20000m and it was able to capture one (1) more destination point and the rest of the two destination points rest beyond the distance measurement of 20000m.

Fig. 5*:* Time – Iso relationship between origin and destination points
Source: [20]

The time isochrone analyzes the drive-time isochrones to capture the study area. The drive time isochrones appreciably differentiate simple buffer areas that disregard natural barriers like rivers or slow roads. The time isochrone was gauge within a time interval of 20minutes, and this was able to capture almost all the destination points, that is, ten (10) destination points except two (2) destination points that fall in the scope of 40 minutes of drive time. The time–isochrones give a scope of the capture of time within the study area, which shows the reachability of the destination points from the origin graphically.

IV. RESULTS AND DISCUSSION

A. Isochrone Analysis

The role of isochrones is to check the reachability of the element of the study. Isochrones emphasizing time reachability and distance reachability produces distinctive results. The various time limitations and distance measurements that are gauged provide graphical views that easily allow researchers to know the area scope of the research. Below is an image showing both the time isochrone and the distance isochrone displayed together on the Quick Time Map. Referring to the above chapter on isochrones, the different color regions make it easily identifiable in the below image differences between the time and distance limitations.

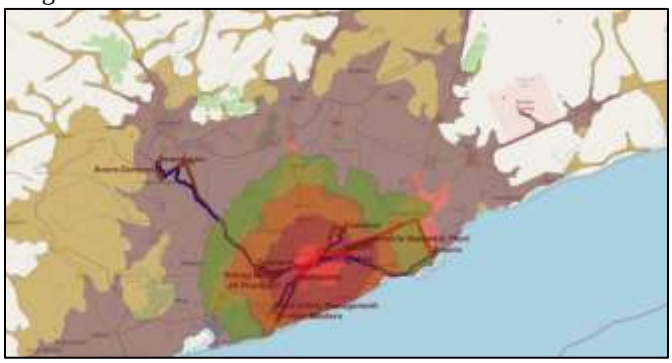

Fig. 6: Iso – distance & Time – Iso relationship analysis
Source: [20]

Looking at the defined tool parameters, the route analysis is based on the requirement tool that places emphasis

on the relationship between two (2) or multiple locations, that is, the origin or destination metric that defines basically the time or distance traveled. Isochrones or the lines with equal traveling time are computed using different modes and types as well as for different times of the day. This can be done for a single address/map point or using a point layer. The advanced isochrone functionality, displayed above, works by activating both the iso–distance and the time–iso point layers from the origin and destination locations. Using the Quick Time Map query tool, the results are generated instantly and added to the map. The algorithm works fast and returns many isochrones at once for entire point layers within seconds. The isolines edge the isochrone area or the time and distance boundaries. Based on the displayed figure above, it is easy to identify the intersection of the time isochrones layers and boundaries from the distance isochrones. It is easily readable that in the time span of twenty (20) minutes, distances within the range of 20000m can be covered from the origin point. However, this takes into account a constant travel time from the origin point to the various destinations, which in reality may not seem to be so due to certain unforeseen circumstances like traffic congestions and others.

V. CONCLUSION AND RECOMMENDATION

The analysis above demonstrates the means of implementing the computation of isochrones in a progressive way, which is made available by the tools provided by OpenStreetMap, which provides a dependable pictorial and graphical view on our distance and reachability relationship between the origin and destination. The study provides ways of computing isochrones in traffic networks. It practically deals with several features like applications that include the reachability relationship transport, geomarketing, reachability analysis in urban planning, and displaying the climatic zones, etc. Based on the above descriptions of the isochrones, we understand that it considers two aspects of analysis: the concept of the isochrone edges and the isochrone pairs. The computation in this study sought to display the region that is reachable within a certain amount of time and the delivery range coverable in a trip. To effectively demonstrate the isochrones in the study, two strategies were adopted: the use of the time isochrone and the distance isochrone. Both to help build ranges of analysis in the data used. As discussed above, both strategies adopted determined the scope of the relationship between the origin point and the destination points.

The use of the time isochrones in this study was to determine the range of reachability by considering a trip from the point of origin. The ranges were set from 20 minutes, 40 minutes and 60 minutes. The analysis produced the results that concluded that in a time range of 20 minutes, a vehicle could cover more than 90% of the destination target, which is made complete 100% when the range is increased to 40 minutes. The result then draws the conclusion that within 40 minutes, the scope of the destination targets could be reached and if there are distribution demands on the vehicle in action, it can accomplish such duty within this time frame. In the case of the distance isochrone, four measurement gauges were given and they were 5000meters, 10000meters, 15000meters and 20000meters. As determined by the research, in the distance range of 5000meters, the iso-lines or the edges were able to capture one destination point, which meant that the range gauge had to be increased to 10000meters. That also covered four (4) destination points which also meant that the range gauge had to be increased to 15000meters to help capture the rest of the destination points. That measurement was also able to capture four (4) destination points. The distance gauge was increased again to 20000meters and it was able to capture one more destination point leaving the two (2) destination points, which meant that two destination points could be concluded ten (10) destination points are captured in the iso area of 20000meters and two (2) destination points lie outside this range.

The use of isochrones in transport planning is very important since it gives a graphical and imaginary view of the traffic operations of a company. Knowing the scope or the range of reachability of a company provides a firsthand resource for decision-making. The isochrones are demarcated by time and distance, and these two factors are key in transport planning. The different times set for the time isochrones were helpful to easily note the time reachability of the various trips from the origin point to the destination points. The same applies to the distance isochrones that give the view on the length of travel reachability of the trips the vehicles are to accomplish. Further study can also focus on the time and distance isochrones from every point as an origin to other points as its destinations to help cater for uncertain delivery demands.

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