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ROUTING ANALYSIS ON PRESENCE OF FLASH FLOODS IN THE CITY OF BARRANQUILLA

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ABSTRACT

This paper describes the behavior of different routing algorithms under simulated flash floods conditions in the city of Barranquilla. It was motivated by the human and economic losses in industry produced by the flash flood phenomena during heavy rain in the city, a situation that goes back to the early years of urban planning, but unfortunately so far, it hasn't been resolved due high economic costs. This research is related to the design of an autonomous alert system based on precipitation levels using mobile applications and fixed signaling through the streets that has been under development for several years between the Universidad de la Costa and the Sena Barranquilla that could reduce threats for civil population and reduce the statistics of people killed or injured by the strong flows of water that goes through the city when rain appears.

Keywords: *Routing, Dijsktra, Flash Floods, PGRouting, Qgis, Barranquilla*

1. INTRODUCTION

In the city of Barranquilla, urban growth has developed for decades in a disorderly way and without long term planning, resulting in consequences as: misuse of terrains not suitable for living, massive invasion of terrains solely dedicated to rainwater torrents and the lack of generation of new "green spaces", as a result every day there´s more concrete and stone than gardens.

The most harmful effect of this disorganized urban growth in the city, has been the absence of a rain drainage system, which was first detected since 1920, but public administration so far, has evaded their responsibility with this issue, and has produced an aggravation of the problem, affecting a wider urban area and percentage of the population each year.

1.1. Economic And Social Effects

The economic and social effects have become devastating, first the urban traffic flow is almost paralyzed in certain areas, restricting the economic activities, people have gotten to stop most of their transportation during heavy rain, commercial and personal dates won't be fulfilled, local shipments will be delayed, and students prefer to stay at home, instead of risking their lives in a flash flood. Another economic effect is the high costs of maintenance of streets and vehicles due to water damage.

Unfortunately, social effects are measured in human losses, increase in diseases in population surrounding flash floods path and environmental damage due to raging waters in the city streets.

1.2. Media Coverage

The media has covered the disasters produced by this problem, and has been widely commented by the international community; next there are some examples of that coverage, that clearly shows the magnitude of the situation.

Figure 1: Piled Up Vehicles As Toys After A Flash Flood In 43th Street. May 14, 2011

Figure 2: Vehicle Through Flash Flood In 84th Street. May 5, 2012

1.3. Proposed Solutions

To this date, most solutions proposed has involved some kind of structural street design modification, usually reconstruction of them, having a box culvert or drainage partial o total in some streets, and all of them has been rejected due their expensive costs, given the extension of the drainage network needed to really provide a solution for it.

Since 2011, a new research started by Universidad de la Costa and Sena Colombo Alemán, has given a new approach to the problem, focusing in prevention and education of the citizens, a new flash flood alert system is in the works, looking to reduce the damage produced by them, focusing in restricting access to the most dangerous street crossings and giving visual and sound alerts to population.

In the present paper a routing analysis based on PgRouting library is proposed, involving three different routing algorithms, A*, Dijkstra and Shooting Star, and using a personalized cost formula, to obtain a comparison between the different routes and the behavior of each routing, under several floods conditions.

In the next section, a comparison of the different routing algorithms is made, the platform used for experimentation, and the routes selected for initial routing comparison, in Section 3 the vehicle categories used, based on [4], the terminal velocity formulas, and the cost formulas designed for the experiment can be found, and finally in section 5 you can find the ending results of the experimentation, the final routes used for it and the conclusions found through the process.

2. ROUTING ALGORITHMS COMPARISON

First, an analysis of the behavior of each routing algorithm was conducted, in normal and under flash floods conditions, using the virtualized modeling environment based on the tools listed in Table 1.

Table 1: Modeling Routing Algorithms Platform

Package	Description
Windows 8 x64	Native Operating System
VMware 9.0	Virtualization Engine
Debian 7.1 x64	Virtualized Operating System
PostgreSQL 8.4	Database Management System
Postgis 1.5.8	GIS Library
PGAdmin 1.17	Database Utility
QGIS 1.9.0	Geographic Information System
PgRouting 1.05	Routing Algorithms Library

PgRouting extends Postgis and PostgreSQL, providing access to routing capabilities that include, in version 1.0, the Dijkstra Shortest Path, Shooting Star and A* algorithms.

The algorithms used are described next.

Dijkstra Algorithm

Objective: Shortest Path Tree based on greedy search

Conditions: Graph with non-negative edge costs

Additional: Base Algorithm for many implementations, including A*, still stands as one of the best general routing algorithms.

A*Algorithm

Objective: Shortest Path Tree based on greedy search using heuristics

Conditions: Graph with non-negative edge costs

Additional: It shows good performance and accuracy, but it depends entirely in defined heuristics.

Shooting* Algorithm

Objective: Shortest Path Tree based on greedy search using heuristics

Conditions: Graph with non-negatives edges

Additional: Especially used for turns limitations or restrictions in edges in graphs.

The comparison between them took into account directed and undirected modes and modeling adverse conditions in the course of one of the biggest flash floods in the city.

Using three different routes, with different intersection points and length, all of them crossing the flash flood path, the behavior of each algorithm was recorded in four different items: arcs, cost, km used, and execution time. Figures 3, 4 and 5 depict the map of the city with the routes used in blue and the flash flood path in red.

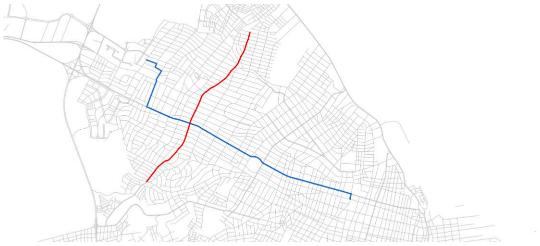

Figure 3: Route 1. Long Route – Start Point: Lat: 10.98784 Lon: -74.78904 End Point: Lat: 11.0130856 Lon: -74.827104.

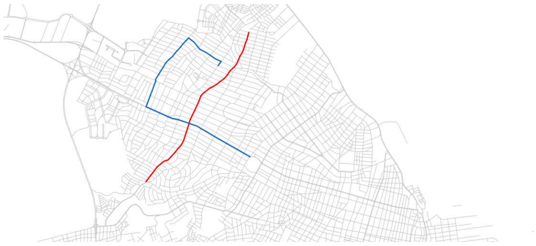

Figure 4: Route 2. Medium Route – Start Point: Lat: 10.9955084 Lon: -74.807878 End Point: Lat: 11.012664 Lon: -74.813360.

Figure 5: Route 3. Short Route – Start Point: Lat: 11.01510 Lon: -74.8142 End Point: Lat: 11.01763 Lon: -74.8065.

The comparison results are shown in Fig. 6, 7, 8 and 9 one for each category that was studied between the three routing algorithms.

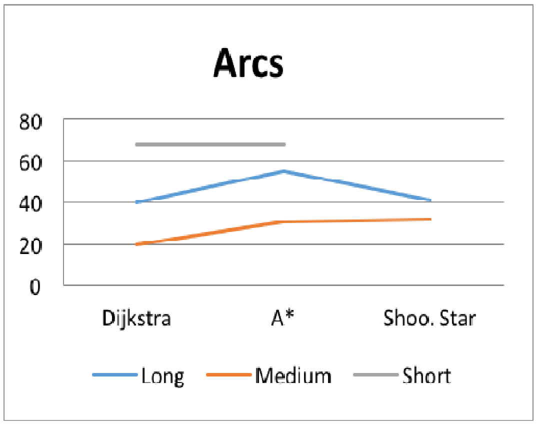

Figure 6. Total number of arcs used in each route.

In Figure 6, the lowest value in the number of arcs (jumps) used for the three algorithms is Dijkstra. Shooting Star did not have a valid routing for the shorter route.

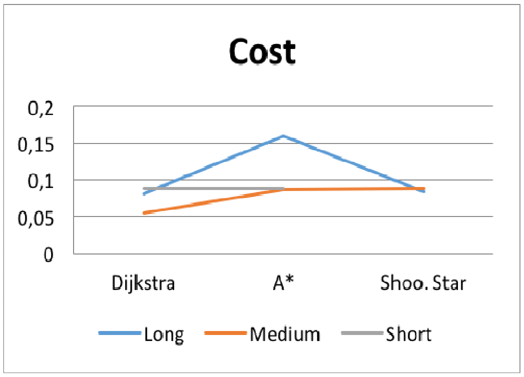

Figure 7. Total cost used in each route.

In Figure 7, the lowest value in the total cost of the path produced by the three algorithms is Dijkstra. Shooting Star did not have a valid routing for the shorter route.

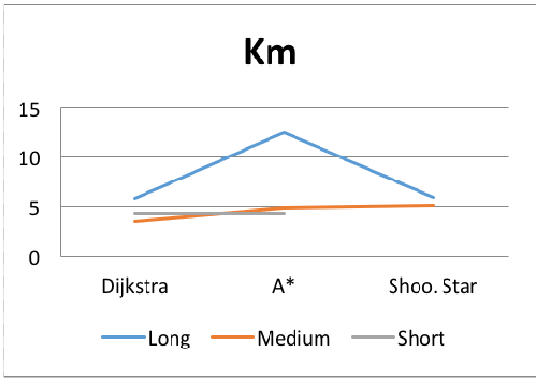

Figure 8. Total km used in each route.

In Figure 8, the lowest value in the total amount of kilometers used by the path produced by the three algorithms is Dijkstra. Shooting Star did not have a valid routing for the shorter route.

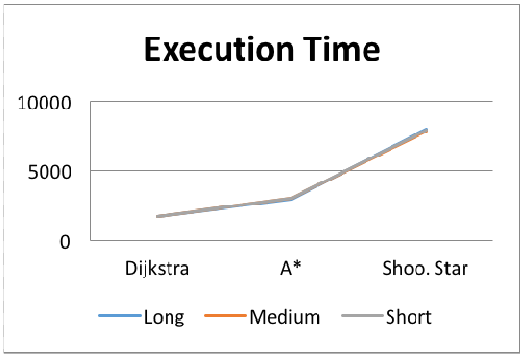

Figure 9. Total ms used in each route

With these results, the best algorithm to continue experimentation was Dijkstra, having the best performance and better values in arcs, costs and km used. In addition, there was a problem with Shooting Star working on short routes that needs further study. Another finding was that all three algorithms have a uniform execution time for all the routes tested, even with having all different lengths.

3. VEHICLE CATEGORIZATION AND ROUTING MODEL

A estimation of the behavior of a vehicle in a situation similar to being dragged through a flash flood was needed; the vehicle categorization used was based on [4], since they did a study quite similar to it. A small passenger vehicle, a middle van and a SUV prototype were modeled and their terminal velocity formulas can be found in Table 2, which are pretty good examples of the most common vehicles in a city.

Table 2: Terminal Velocity of the Vehicles Partially Submerged

Category	Terminal Velocity Formula
Small	$1685.65x^2 - 129.14 + 2.57$
Medium	$759.26x^2 - 88.64 + 2.14$
Large	$1379.80x^2 - 167.99 + 4.34$

Categories Small and Medium are quite close to their values, given the dimensions of the prototypes, their comparison shows in Figure 10.

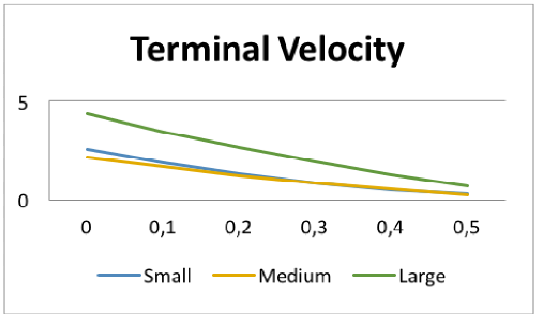

Figure 10. Terminal Velocity for each category.

Based on the terminal velocity formula, next a cost formula was built for each vehicle; the first approach was to take the entire flash flood course and block all traffic, but certainly this was a solution too rigid to implement, since it would restrain any flexibility on the vehicles traffic. Second approach was to set a variable cost to each sector of the flash flood course, this way it could enable passing through some areas and block others that would be considered dangerous, behaving in a more dynamic manner. To do that, the cost formula was modified to set the values of each sector based on the flood levels. The best performance obtained is described next and the three different categories with their costs can be found in Figure 11:

$$CV = \frac{TopCategoryValue}{100TV} \quad (1)$$

Further studies can determine the best-cost formula for each flash flood or determine a single formula to be used for all of the streams in the city.

Finally, after setting a dynamic cost to each sector of the flash flood, an extra cost value was added, taking into account the specific characteristics of the flood path and the hazard risk of each section, this is described in the next section.

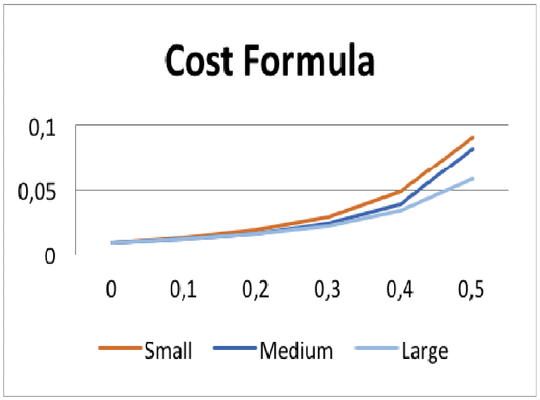

Figure 11. Cost formula for each category.

4. ROUTING EVALUATION

4.1. Flash Flood Sectors

The flash flood used for the study, is one of the bigger and stronger on the city, and creates a shortage of traffic once settled. The 84th Street flash flood, goes through that section of the city, as can be seen in Figure 12. The analysis was made on three different sections, since by their behavior the flash flood becomes stronger and more dangerous going east –west direction. Each section was given a different extra cost, to model the increase of strength of the flash floods, since there are no present studies that can verify real level of water during rain. The extra costs can be found in Table 3. The column sector defines the streets range where extra cost column value was applied

Table 3: Extra Cost For 84th Street Flash Flood.

Sector	Extra Cost
42A – 46	0.00001
46 – 51B	0.0001
51B – 74	0.001

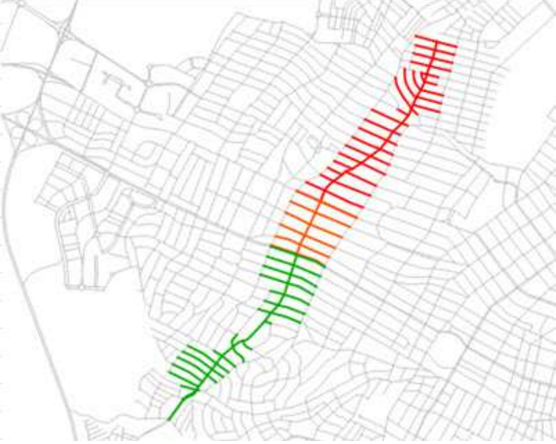

Figure 12. Extra Costs Sectors, in green: 0.00001, orange: 0.0001 and red 0.001.

4.2. Paths

First, it was decided to used four main streets of the city in the analysis, K43, K46, K51B, K54, in two different directions, from south to north and vice versa, but the results obtained were that Dijkstra always chose two of them as best routing option in their best path, K43 and K46. Figure 13 and 14 show their location on the city and the flash flood.

Figure 13. K46 path used for simulation in blue, in red the 84th street flash flood path.

Figure 14. K54 path used for simulation in light blue, in red the 84th street flash flood path.

4.3. Results

The simulation used 5 levels of water for the flash flood (0.1 m to 0.5 m) comparing the routing results of Dijkstra between categories and levels. More water wasn't considered, since most of the vehicles would go under full submersion and the hydraulics would be entirely different.

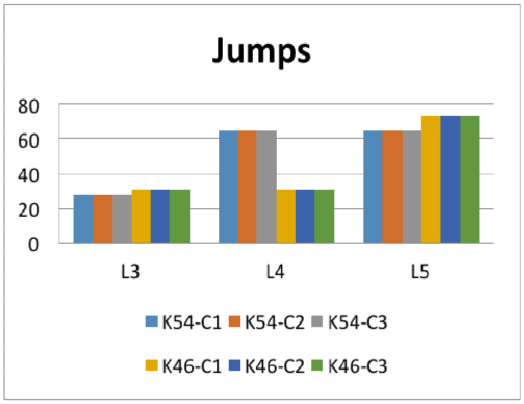

Figure 15. Jumps used in routing between the two routes analyzed and the three categories.

In Figure 15, the results of the number of jumps used through levels 0.0 m to 0.5 m of water, where it can be highlighted the following:

- Vehicle Categories behave uniformly through levels, but at 0.4 m of water, it's clearly easier to go through the K46, since their cost sector is lower, so all type of vehicles have no issues going through it.

- With level 0.5 m of water, the routing jumps are higher on K46, alternate routes on K54 are shorter and less jump expensive.

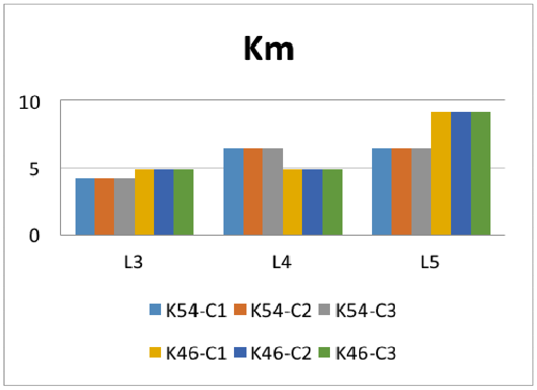

Figure 16. Km used in routing between the two routes analyzed and the three categories

In Figure 16, the results of the kilometers used through levels 0.0 m to 0.5 m of water, where the analysis determined:

- At level 0.4 m of water, the behavior noticed with jumps comparison is confirmed, but the difference between the amount of kilometers used is meaningless.

- On the contrary, with level 0.5 m of water, the kilometers used in K46 are way higher than K54, so it´s difficult to conclude that the number of jumps is entirely a good indicator of better routing, since jumps could be higher but the route could be shorter in length, like this case.

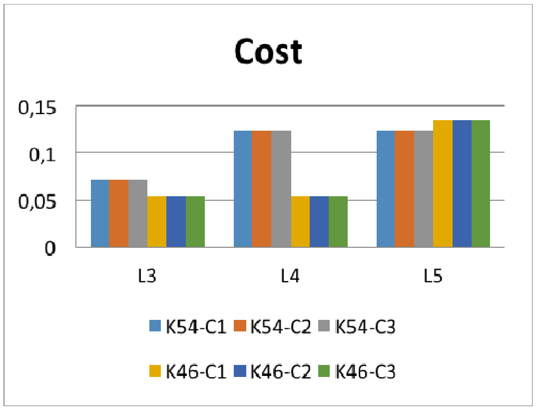

Figure 17. Total cost used in routing between the two routes analyzed and the three categories.

In Figure 17, the results of the total cost used through levels 0.0 m to 0.5 m of water, conclusions are:

- At level 0.3 m and 0.4m it's always less expensive to go through K46, which means it's also safer for vehicles to do so.

- On the contrary, with level 0.5 m of water, the total cost used in K46 is higher than K54, so we can say that the cost exceeds going to east of the city, and is better to take an alternate route to the west, avoiding the flash flood.

5. DISCUSSION

Flash floods have become an increasing threat to population in the city of Barranquilla, human and economic losses need to be minimized but so far, a real solution for this hazard hasn't been achieved, this study focus in a prevention based solution, where focus on bringing the flash flood information at real time, can help to reduce the impact of this natural phenomena in society. The results indicate that an algorithm like Dijsktra have better results routing in normal conditions and also on flash flood presence, and definitely a specific hydrologic study for the city is needed, combined with a cost effective formula for more types of vehicles, which can be refined to do a proper modeling of the critical traffic situations involved when flash floods appear. The final conclusion is that a traffic routing model, taking into account the specific conditions of the city, would be the next step towards a definitive cost effective solution to avoid human losses and diminish economic detriment through upcoming years in the city.

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