DOI: 10.2478/ijasitels-2022-0007

An empirical study of large transportation networks and solutions for the cost optimization

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Abstract

We all know how important transportation is nowadays - from one street to another, from one city to another, from one county to another, from one region to another, from one country to another, from one continent to another and this list can go on with examples. The question we ask ourselves is: Can we find a better way? A better solution? A more accurate way? A more efficient, faster route to travel? All things take more or less time. All journeys matter. Whether you're going for a walk, on a trip, stuck in traffic on your way to work, have a small business and want to save money on bills, or you are one of the world's biggest entrepreneurs, for all of us, every second matters. That is why our transport, or our things, goods and so on, must be as efficient, accurate, correctly planned as possible, but at the same time safe. Nowadays, when everything is in a very accelerated continuous evolution, the efficiency and speed of achieving our goals are very important. There is a lot of emphasis on as little wasted time as possible and as many successes as possible. The expected productivity can only be achieved if all transport features are worked out with great care. Every little detail must be considered, mathematically, computationally, logically and chronologically, so that the overall result is the best, the most suitable, the most efficient for our problem.

This work aims to study some examples of transport networks, following their advantages and limitations, and looks for all kinds of solutions, ideas to improve and optimize their costs. We tested two existing applications on some large datasets (Section 2 and Section 3).

Keywords: Transport network, route, time, efficiency, optimization.

1. Introduction

Transport networks are found everywhere around us, from couriers, to public transport and to grocery store chains, retail store chains and pharmacy chains. Some examples of couriers are DPD, Fan Courier, Sameday, DHL, FedEx. Among the grocery store chains, we can mention Profi, Cora, Selgros, Kaufland, Lidl. When we refer to retail store chains, we mention Dedeman, Leroy Merlin, Obi (also in the field of DIY), Amazon (which is the largest online store). Among the pharmacy chains we can talk about Catena, Sensiblu, Dona, Salofarm, Pfizer, Johnson & Johnson, etc. It is obvious that all these merchant chains have behind them a fleet and a logistics network very well set up to bring as much productivity as possible to the company [1].

1.1 Other approaches regarding the optimization of transport networks

In this chapter, some other approaches that have been made over time on this theme of optimizing transport networks will be studied. The purpose of this chapter is not to make a comparison between this paper and others but is exclusively to highlight the common ideas and the fact that transport, respectively computer and mathematical solutions for network optimization represent a field, a direction of great interest in the days of today.

A very interesting work that addresses the topic of transport, more specifically the one in the metropolitan area of the city of Bacau in Romania is [2].

The work highlights the need to identify new solutions to streamline the traffic in the city of Bacau, which is very congested at peak hours, because many people go to work by personal car. Another argument is that many parents take their children to school with their personal car.

Another problem caused by the very congested traffic and the fact that most cars are based on classic fuel (gasoline or diesel) is environmental pollution. A very good solution proposed in that work is to use public transport more often, to use shared transport services as often as we can and another idea is to gradually switch to the use of hybrid or fully electric vehicles, to reduce emissions of CO2 in the atmosphere. Thus, the air in the city will be cleaner and the traffic will be less congested. The solutions proposed for decongesting traffic do not exclusively refer to the use of buses, but to the presentation of transport ideas for several people at the same time who have the same daily route.

The study analysed various areas of the city of Bacau and the circulation of people at various times of the day. The report showed that there are quite a lot of people with very common routes and the proposed solutions are some computer applications called intelligent transport systems that offer the user the possibility to fill in the point of departure and the point of destination and the program returns him several routes. The routes are for several people at the same time who have similar destinations.

Therefore, we conclude that finding new solutions for streamlining transport networks is a current and very important problem.

Another work that analyses and comes up with solutions for transport networks is [3].

This follows the Mass Transport Vehicle Routing Problem. The idea is to find a solution to route n vehicles in real time to pick up and deliver m passengers. The goal of the problem is to minimize the total passenger travel time (including vehicle travel time as well as waiting time). Just like the previously mentioned work, this highlights the fact that many people travel on very similar routes throughout the day. The paper compares this people transportation network with a directed graph that contains many arcs (since it is a very large graph). “The arcs here can be viewed as global vehicle corridors between nodes which represent areas (or even transfer hubs) in a large urban area. The intent is to find the flow (or frequency) of vehicle movement on these corridors, and to find how many vehicles travel on paths that go over such nodes, so that a global estimate can be made for mass transport vehicle movements”. More than that, the author specifies that there are already very well-defined transport networks such as urban bus transport in highly frequented urban areas, only that those have a limitation, namely the fact that they circulate with a certain frequency and at specific times. The paper specifies that people's routes and the frequency with which they travel must be analysed very deeply and this network must be adapted to their behaviour. Again, an exact solution cannot be given here because human habits are not always the same, they vary according to time. However, it is specified that there will be 3 levels of constraints: The first is the condition that all requests are satisfied. The second is that the number of passengers traveling on a vehicle route at a given time is less than the total number of seats available. The third constraint is that the total number of vehicles in use be less than the total number of available cars of that fleet.

So, by analogy with the previously mentioned work, here too we observe the very clear need to adapt the solutions to optimize the transport networks to the current needs of the society in which we live, highlighting the practical utility and not just purely theoretical aspects.

Finally, a very good paper that deserves to be mentioned is [4]. The work brings analogies between this genetic algorithm and transport networks. It will be explained briefly in the following lines.

The genetic algorithm is an intelligent algorithm, generally used to solve the main method of VRP (Vehicle route problem). In 1975, Professor Holland first proposed a global search the method based on natural and genetic selection, the evolution process of organisms is simulated by genetic operators such as selection, crossover and mutation and fitness function is used to represent chromosomal excellence, the genetic algorithm simulates Darwin's natural the theory of evolution and the theory of genetic variation and has strong robustness and global optimization capability. The algorithm is suitable for solving complex multi-extrema optimization problems and combinatorial problems and has a wide range of applications the values.

The author mainly analyses the optimization problem a logistics transport network and building a two-layer network complex network-based optimization model. The first layer is mainly to optimize large regional logistics transport network, analysis of urban transport capacity in the large regional logistics transport network from a global perspective and provide data support for the optimization of the logistics and transport network on small areas. The second layer mainly targets comprehensive logistics capabilities of each city in a small area, the regional logistic transport network optimization model is built, combined with the factor analysis and cluster analysis, to optimize small regional logistic transport network. From the results from case simulation solution in logistics optimization transportation network, this computational model and theoretical algorithm are relatively accurate and efficient and have a certain role in promoting development logistics.

2 Computer application for discrete optimization in a transport network

Major transport networks are owned or operated by merchants, transport retailers, for example the world's large chain stores, courier companies, public transport and so on. Each of the categories listed above needs a specialized IT department for the maintenance, administration and management of databases of routes, departure points, intermediate areas and, last but not least, destinations [5].

So, the optimization is a very important principle that underlies most things, actions, processes, phenomena and services.

We briefly list some problems or situations, from simple things to complex things, problems that require attention in terms of optimizing or making more efficient the established, defined or chosen route, road, itinerary or transport network:

Example 1:

You are a student and attend university classes. You have a well-chosen schedule, you know quite well when you come, where you come, which labs, courses you go to and when you return home (if you haven't made other plans in the meantime). Especially when you're rushing to class, like most students do, you don't want to waste time, but more than that, you want to get there and finish as quickly as possible. So, you must be efficient.

Example 2:

You go to work. Whether you walk or use bike, e-scooter, e-bike, scooter or personal car, a colleague brings you or you use public transport, even more so when you depend on others, you need to have the route, the plan or the very well established schedule, to know exactly when you are leaving, where you are going, how long you will be making and what choices acquired from your experience, you expect to be good or less good. Anyway, in the morning the traffic is congested and also when you come back you know which streets to go on and which not to, because they are too crowded, because it would take too much time, also you certainly don't choose routes in which to travel extra kilometres without sense.

Example 3:

You are a small to medium entrepreneur, and you want to buy some goods from a supplier. Everything costs money. You will determine the route to travel, the cargo to be loaded and the schedule for that day. You just don't want to waste money, time and good mood. Fuel is expensive, especially for a truck, where the difference between a good road and a less well-chosen one is very easy to feel.

Example 4:

You are coordinating the moving or transportation of a very large propeller (of the order of tens of meters), already assembled [6], to be taken from New York to Chicago (the distance between the two areas is ~ 1200 km). You have the army with you and an order given by the government, in the moments when you reach their right and as long as you move in their direction, the streets you will cross are closed to citizens and available exclusively for the very important transport you are carrying out. Your speed is only 10 km/h, so that the propeller required for the huge project set is transported in complete safety. Your shipment takes 2 weeks. Millions of dollars are being spent on this project. The problem of optimizing the transport network, choosing the shortest, best and safest route, is a critical issue.

Example 5:

You are one of the world's greatest entrepreneurs. You have developed a network of stores, a huge network of transportation for your goods, from suppliers to you, between your stores and especially from you to customers. How important would it be to your calculations, considering that you must pay tens of thousands in wages and taxes every month, if there was an unexpected change to the transport network database? How much would a wrong or not good enough decision about your transport network affect you? How important is and how seriously should this vague idea, shall we say, at first, of optimizing a transport network be approached?

Considering the above, in a totally non-random order of the chosen examples, starting, in other words, from small to large, we can agree that optimization for a transport

network is essential and is directly proportional to everything will run on that transport network.
The problem studied in this chapter has the following statement:
To find the shortest route between a retailer who has an extensive network of stores throughout Romania and a customer who lives at a randomly chosen address in the country.
In other words, this common situation is every customer's desire. He wants to purchase a product or service from a certain store that has several subsidiaries in the country. For the problem chosen and which will be presented and illustrated in the following pages, we will consider the ideal case, namely a simple transport network, consisting only of sources and destinations, without intermediate points and without flow restrictions for each road, the network which has identical stores in the area and assume they all have the same products and stock for the product the customer is interested in. We will only be interested in the shortest path between source and destination. So, we have the problem of minimum cost, this cost will be the number of kilometres between the store and the customer (which is, directly proportional to the price of transport).
The program considers the transport network defined in the form of a graph, more precisely a tree. The root is the address of the customer and the leaves are the addresses of all stores. The algorithm analyses all the edges and chooses the shortest one among them.
The store chain is theoretical, but the data are real values, here referring to street, number, city, county and geographic coordinates. They are real because an well-known retail store chain in Romania, namely the Dedeman chain of stores was analysed and studied. Store information (such as geo-positioning) was taken from their website [7] to have real information and conclusive results. The information about the stores is public on the website www.dedeman.ro.

We created a database containing 50 stores. Each of them has an id, name, street, number, city and county, latitude and longitude.
In the next lines, is the function that is the basis of solving the problem. The function that was implemented in PHP has the following mathematical and historical provenance.

Haversine formula

The haversine formula determines the shortest distance between two points on a sphere, given their coordinates, i.e., latitude and longitude [8]. Important in navigation, this is a special case of the set of trigonometric formulas in spherical trigonometry.
Haversine's law shows the sides and angles of spherical triangles. The first English table of haversines was published by James Andrew in 1805, but Florian Cajori gives credit for an earlier use to José de Mendoza y Ríos in 1801. The term haversine was coined in 1835 by James Inman.
These names come from the haversine function, given by hav (θ) = sin2 (θ/2).
The formulas can be written equivalently using any multiple of the haversine, such as the older haversine function (twice the haversine). Before the advent of computers, the elimination of division and multiplication by factors of two proved convenient enough that tables of Haversian values and logarithms were included in navigation and trigonometric texts of the 19th and early 20th centuries. Nowadays, the haversine form is also convenient in that it has no coefficient in front of the sin2 function.

The function, which will be presented below, uses a mathematical formula that calculates the distance between two points in a straight line. There may be differences compared to the distance using the streets.
The related source code is as follows [9]:

```
"<?php
/*
*This function calculates the absolute distance (not the one using
the streets)
* @param latitude1 (customer)
* @param longitude1 (customer)
* @param latitude2 (store)
* @param longitude2 (store)
* @return float Distance in Kilometers.
*/
function getDistanceBetweenPointsNew($latitude1, $longitude1,
$latitude2, $longitude2,
$unit = 'Mi') {
$theta = $longitude1 - $longitude2;
$distance = sin(deg2rad($latitude1)) * sin(deg2rad($latitude2)) +
cos(deg2rad($latitude1)) *
cos(deg2rad($latitude2)) * cos(deg2rad($theta));
$distance = acos($distance);
$distance = rad2deg($distance);
$distance = $distance * 60 * 1.1515;
$distance = $distance * 1.4;
switch($unit)
{
case 'Mi': break;
case 'Km' : $distance = $distance * 1.609344;
}
return (round($distance,2));
}
?>"
```

The application interface where the closest stores to the customer's address are calculated and displayed in order (**Figure 1**).

Figure 1 - Identification of the nearest store

3 Digital management of transport schedules in a company

This section presents an IT application through which a customer can make arrival appointments to the company's headquarters. The appointment page (where the appointment date and time must be chosen) is the one in **Figure 2.**

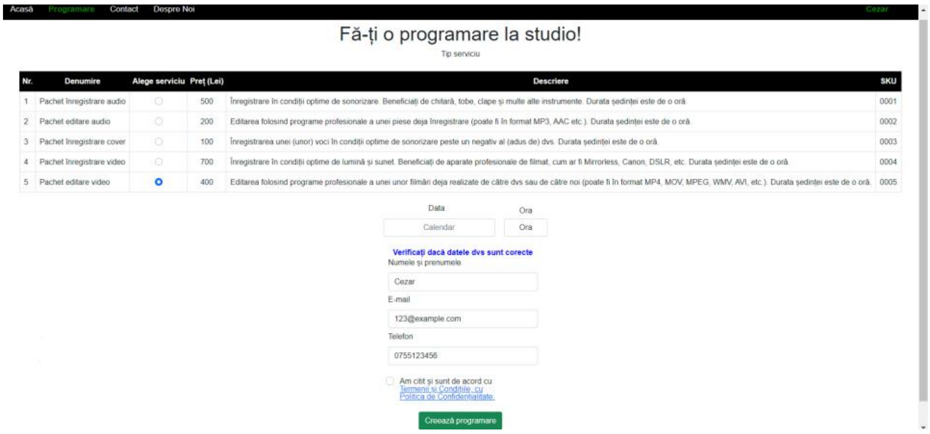

Figure 2 - Creating an appointment

The problem brought into discussion is the automation of processes in society and, more specifically, those in the service field.

For all types of small, medium and large companies whose object of activity is to offer a service to a client who needs to reach their headquarters, for example a recording studio for music or video production, a law firm, a medical office, etc., most appointments are still made by phone and the company manually checks the availability in the directory.

The solution is an application available to customers through which they can make an appointment by themselves at the company's headquarters. The algorithm behind checks and considers employees' s vacation days, days off that are national public holidays, weekends when it is closed, hours that are during and outside the schedule and especially the other existing schedules so that one schedule does not overlap with another.

By analogy, for a large company that owns a chain of stores and has a transport network behind it, there must be very clear management and optimal planning of the time, the arrivals and departures of trucks with goods between the logistic units.

The very large retail company called Dedeman deserves to be analysed from this point of view.

Short history [10]:

The company, founded in 1992 in Bacău, created and fully controlled by businessmen Dragoș and Adrian Pavăl, is the national leader in the retail of construction materials and interior design. Dedeman has become the leader of the DIY market since 2010. Currently, the company has over 12,000 employees. In 2022, Dedeman has 57 stores open in Romania (the store network can be found in **Figure 3**).

Figure 3 - Map of Dedeman stores

(Source [7])

Like many companies that have a huge transport fleet, the retailer uses an application for managing freight transport. This kind of application brings many advantages. Some public information found that can be mentioned are:

It considers the existence of all stores as work points and logistics centers where goods are stored before being sent to stores, there are administrators in the system for all work units, transport coordinators, guardians, etc., appointments are of the type arrival or departure, the teams and their roles are taken into account (loading, unloading, palletizing, etc.), it considers the working hours, public holidays, many rules can be established that automate the system so that the exclusive intervention of an operator is not a system required for each operation and so on.

The application is intended for internal transport as well as suppliers who have an account in the platform, so that they can create their own appointments with the company.

By analogy, large transport networks also exist for very large hypermarket chains) present in Romania such as Kaufland, Auchan, Selgros, Carrefour, etc. Below, in **Figure 4**, there is a map with information from the year 2015 regarding the distribution of supermarkets and hypermarkets at the level of large cities in Romania. All these merchants have an impressive number of stores for customers, but they also have logistics centers (which are much larger than a normal store) where the goods that arrive from the supplier and which are later sent to the stores are received and stored.

Figure 4 - Distribution of supermarkets in the big cities in Romania since 2015

(Source [11])

In Romania, large courier companies such as Fan Curier, DPD, Sameday, etc. have developed over time, which covered the whole country with their network of warehouses. They made sure that they had a warehouse in every important point in the country. In the case of couriers, there are local warehouses (final warehouses) from where parcels are taken out for delivery to customers, but also there are hubs or large central warehouses where parcels coming from senders are concentrated in the first phase. Below, in **Figure 5** is a map provided by Fancourier in 2019 with all their logistics centers.

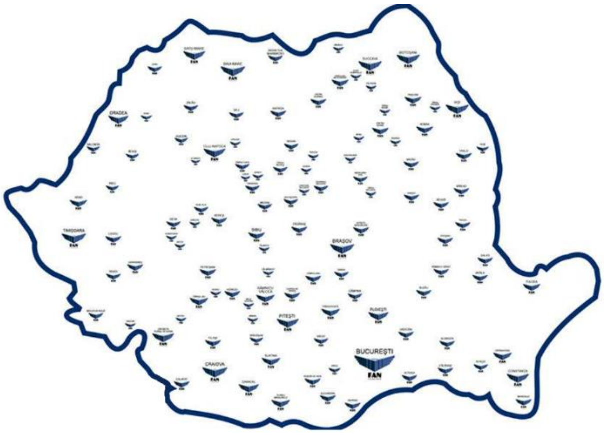

Figure 5 - Fan Courier Map since 2019

(Source [12])

What do all these large chains of traders or couriers have in common? Well, their transport network is constituted as follows: Apart from stores (in the case of retailers) or local delivery warehouses (in the case of couriers), they also have some very large logistics centers in the country, one in each large region. In other words, there are local stores or warehouses in each county, and there are large logistics centers or central warehouses in several regions in Romania (for example in Bacau, in Bucharest, in Cluj, in Constanta, in Oradea, in Timisoara, in Ploiesti, etc.). The difference between central or logistic warehouses and local stores or warehouses is that the goods (from suppliers or shippers) first arrive in the central warehouses and from there they are sent to each store (or local warehouse).

Thus, the suppliers know where to send the goods the first time (in logistics centers that are even more spacious and have more gates for trucks than a store) and there is a very well controlled flow. In Figure 6 is an example of a transport network and the importance of logistics centers in the flow of goods transport can be seen.

Figure 6 - Example of transport network

4 Solutions for cost optimization in transport networks

The idea behind this work is the existence of a transportation network that has all work points (nodes) very clearly defined in terms of location and utility.

If we are talking about a delivery from a store (from a chain of stores) to a customer, the management and ordering of transports can be done by effectively establishing for each store an internal map of the respective county, with certain areas (for example A, B, C, D) indicating the distance to the locality where the customer lives. For each area, a standard delivery price can be established that must be paid by the customer. If a certain amount of purchased products, called the free threshold, is exceeded, then the shipping price will be free.

The transport network can be even more efficient in terms of costs. In order to be as fair as possible for the customer, some weight thresholds can be established depending on which the price varies (0-10 kg, 11 -20 kg, 21-30 kg, 31-40 kg, 41-50 kg, 51-100 kg, 101-500 kg, 501-1000 kg, 1001-2000 kg and over 2000 kg).

Moreover, in order to protect the transport costs of the sender, the transport of products that are heavy materials (such as brick, for example, or pavers or cement, which also require pallets, etc.) or bulky products (such as polystyrene, mineral wool etc.) delivery costs must be charged regardless of the amount of products ordered, because these materials are either very heavy (the order of tons) or very voluminous and immediately fill all the storage space of the truck.

A new proposal would be that for preferential delivery (i.e., on a day and at a time desired by the customer) an additional amount should be charged, because this means changing the driver's delivery list established in advance for that day.

In addition, as solutions for optimizing transport costs, specifically financial, fuel, time costs, etc., we specify the following:
Deliveries from suppliers to logistics centers should be made at night because the traffic is not congested, the outside temperatures are not high, so the engines don't heat up as much, deliveries to customers can be made during the day but peak hours will be avoided (7- 9; 16-18). Delivery planning must consider how congested the traffic is, the roads that can be driven on, because there are roads with tonnage restrictions, broken roads, closed roads, toll roads, roads where a lot of time can be lost.

Using the current infrastructure and hoping that in the future there will be more European roads and highways, the routes can be made in such a way as to drive on those roads to be able to drive at the best possible speed (optimal and legal), towards unlike national or county or communal roads where there are not the same traffic conditions.

A very big help here is provided by the Google Maps service and better than this, the Waze application (which is currently also owned by Google) which provides real-time information about traffic, accidents, broken, closed, congested roads, etc. (all these information being updated in real time and being truthful because they are added by drivers in traffic who use the application and are rechecked by other drivers, the problems being confirmed or denied thanks to this).

In most transport networks, delivery planning is done manually by one or more operators from the transport department. A solution for this would be to create an application that has as an input data set all the delivery schedules for the given day and that will automatically calculate the route for the truck driver to arrive at each delivery point (to each customer), based on distance.

The program will calculate that each stop should be made in order, so that the problem is reduced to the existence of a complete graph and finding the shortest path that passes through all the desired points and finally returns to the store (so the shortest cycle from that graph need to be found).

Certainly, during the day there will be all kinds of changes because in theory we have the ideal situation, but in reality, it often happens that some customers delay delivery, refuse delivery, stop answering the phone, indicate wrong delivery addresses of goods, but as we know, these are specific situations and will be handled on a case-by-case basis.

5 Conclusions and future work

A first conclusion is how much the work, study, deepening, development and elaboration to the final form of a concept can matter. By comparison, behind an optimal result that may seem, at first glance, simple, there can be weeks, months, even years of work and involvement, dedication and devotion, good and less good results, successes and failures, but all these equally important because we learn from mistakes.

A second conclusion is how beautiful and complex this field named Computer Science with all its branches and sub-branches, how much it matters to the world around and can be noted with amazement and pleasure in how many fields it appears in, fields that apparently do not have no direct relation to IT.

In addition, this subject reveals how much a correct and complex administration, with qualified and dedicated people matters for a transport network. Basically, what would be the purpose of these very extensive studies and approaches to optimizing a network, other than time and money?

As for any other totally different and chosen process than optimization in a transport network, carrying out the actions in the most suitable and best order will bring a much more precious gain than money (which they can't buy it) – time.

One of the things that deserves to be studied in future works on transport networks is the round-trip flow of parcels in the courier system, which is the flow of lost or damaged parcels, the parcel delivery system at Emag's Easybox and, finding of new solutions for the optimization of these transport network concepts.

Acknowledgement

The research was funded by the Ministry of Education and Research, through the National Council for the Financing of Higher Education, Romania, grant number CNFIS-FDI-2022-0208: Development of the research capacity of "Vasile Alecsandri" University of Bacau by strengthening the infrastructure, collaboration and multidisciplinary approaches (acronym: UBc-ConCoRD).

References

[1] Rodrigue, J.P., C. Comtois and d B. Slack, “*The geography of transport systems*”, London: Taylor & Francis Group, 2013.

[2] E. Nechita, G. C. Crişan, S. M. Obreja and C. S. Damian, "*Intelligent Carpooling System A Case Study for Bacău Metropolitan Area*".

[3] L. Pagès, R. Jayakrishnan and C. E. Cortés, "*Real-Time Mass Passenger Transport Network Optimization Problems*".

[4] H. Liu, P. Zhan and M. Zhou, "*Optimization of a Logistics Transportation Network Based on a Genetic Algorithm*".

[5] "*The Intelligent Transportations Systems Joint Program Office (ITS JPO)*" [Online]. Available: https://www.its.dot.gov/index.htm. [Accessed 17 08 2022].

[6] "*Federal Aviation Administration (FAA), DOT., Federal Register Volume 87, Number 78, From the Federal Register Online via the Government Publishing Office*" [Online]. Available: [https://www.gpo.gov/]. [Accessed 17 08 2022].

[7] "*Reteaua Dedeman*" [Online]. Available: https://www.dedeman.ro/bacau/retea-dedeman.html. [Accessed 17 08 2022].

[8] R. A. Azdy and F. Darnis, "*Use of Haversine Formula in Finding Distance Between Temporary Shelter and Waste End Processing Sites*" J. Phys.: Conf. Ser. 1500 012104, 2020.

[9] "*PHP: Haversine Formula function*"
[Online]. Available: https://thisinterestsme.com/php-haversine-formula-function/. [Accessed 18 08 2022].

[10] "*Dedeman - Despre noi*"
[Online]. Available: https://www.dedeman.ro/bacau/despre-noi.html.
[Accessed 19 08 2022].

[11] "*Harta retailului*"
[Online]. Available: https://www.analizeeconomice.ro/2015/01/harta-retailului.html. [Accessed 20 08 2022].

[12] "*Fan Courier Map*"
[Online]. Available: https://www.facebook.com/FANCourier/posts/5835804946466647/. [Accessed 20 08 2022].