The use of the genetic algorithms for optimizing public transport schedules in congested urban areas

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Abstract Transit operators face with travel time variability issues related to the design of new transit lines or related to the improvement of the performances of existing lines, especially when transit vehicles without exclusive line. Nowadays, the availability of large data through automated monitoring allows more in-depth this phenomenon of variability in timetables to be pointed out with recorded data. The lack of schedule stability confuses the traveling public and thus the degree of dissatisfaction increases. This leads to a decrease of the public transportation users, especially because of those users having travel alternatives to public transportation. The reliability of the travel time and the vehicle operation according to a stable timetable are the most relevant attributes for the users fidelisation. At the same time, it is well known that the demand for public transportation in congested networks has a large variability over space and time. In this paper, we analyse the deviations from the planned (declared and publicly) schedule for a tram line in Bucharest city in different stations, in different times of the day and in different days of the week, in order to build an optimisation model for needed adjustments to the planned schedule. The data are collected with the Automatic Vehicle Location (AVL) system installed on trams’ board. The number of the adjustments solutions is very large and the genetic algorithm is engaged for the optimisation model solving.

1. Introduction
A major impediment to scientific progress in many fields is the inability to make sense of the huge amounts of data that have been collected via experiment or computer simulation.

In public transportation the lack of schedule stability confuses the traveling public and thus the degree of dissatisfaction increases, leading in some cases to a decrease in the number of users of urban public transport, especially when they are not fully dependent on this transport system.

A traffic schedule must be correlated with traffic conditions. Starting from this principle, we analyzed the traffic schedule of tram line no. 10, during the peak periods of the day, in 4 days of the week (Monday, Wednesday, Friday and Sunday) between April 2019 and May 2020, to identify the size deviations and to propose solutions for improving the schedule for at least certain stations, where the highest values appear.

Reliable long-term travel time forecasts availability is one of the most relevant attributes for transit operators, to be used for improving transit service planning in terms of optimization of timetable and
vehicle scheduling. In urban areas the demand for public transport is unevenly distributed over space and time [12].

Traffic congestion is one of the most annoying problems nowadays. It expresses the side effect for the many benefits obtained from urban agglomeration and economic activities. Due to the fact that the supply of land is limited, and the construction of road infrastructure is not necessarily cheap, it would be expensive to invest in order to reach the capacity to permanently ensure traffic regimes close to the free one. Even if at present, assuming that, through the development of infrastructure, this regime would have achieved, over time, the stimulating effects on demand will certainly again lead to congestion [12].

Public passenger transport must take over the most important flows of systematic travel to/from work, and the attractiveness of public transport is represented, in particular, by the observance of the displayed/planned traffic schedule, in each station within the transport network.

Strathman et al. point out that by changing traffic patterns, delays caused by traffic congestion in the case of public transport can be integrated into business plans, thus reducing the impact on deviations and delays. On the other hand, there are factors that need to be addressed in real time due to the unpredictability and impact on the service. This group of factors is more difficult to manage, even in terms of the operator’s ability to operate quickly [15].

According to several authors (Pignataro, 1973; Gazis, 1974; Bell, 1997), congestion is defined by prolonging the travel time in relation to free flow conditions. The maximum level of congestion occurs when this delay exceeds the threshold of accepted limits (norms) [12].

The conditions in which this type of congestion occurs must be analyzed differently depending on the economic and natural space that determines different behaviors and perceptions of travelers.

The travel times used to determine the degree of congestion can be observed (relevant) or estimated, if they cannot be observed. Of course, the observed data are those that allow assessments of the dynamics of congestion on a certain portion, the spatial determination of blockages or the efficiency of traffic management systems and measures to reduce polluting effects [12].

The traffic schedule for each transmission line must meet two requirements: to ensure the necessary transport capacity and to ensure a minimum frequency of service (for the maximum tracking interval) necessary in terms of the level of service.

The information required to carry out a program for a transport line is given by the estimated volume of passengers and their distribution in time and space.¹

The paper presents a solution for optimizing public transport schedules that is working with genetic algorithms. GA is a local search algorithm, which works starting from an initial collection of strings (or a population) representing possible solutions of the problem. Each string of the population is called a chromosome, and has associated a value called fitness function that contributes in the generation of new populations by means of genetic operators (denoted reproduction, crossover and mutation, respectively). At each generation, the algorithm uses the fitness function values to evaluate the survival capacity of each string i of the population using simple operators in order to create a new population which try to improve on the current fitness function values by using pieces of the oldest ones [10].

2. Literature review

There are many genetic algorithms applied to various parts of transportation research since it was introduced in 1975, and it is expanding more and more its boundary. Several utilizations of GA in transport and traffic have been reviewed and the most important ones synthesized as follows.

The travel times considering the degree of congestion can be observed or estimated. Of course, the observed data are those that allow the assessment of the dynamics of congestion on a certain part of road, the location of traffic jams or the efficiency of traffic management systems and measures to reduce polluting effects [12].

¹Dinu, O.A., Proiectarea programelor de circulaţie ale transportului public în condiţiile neuniformităţilor spaţiale şi temporale ale cererii, Buletinul AGIR, 2009
The accurate prediction of travel time in congestion conditions is difficult to provide, especially due to the very dynamically changing of the traffic flow.

In such cases, exhaustive and random search techniques are useful. The biggest disadvantage of these methods is that they often require thousands of function evaluations, even for the simplest functions to reach an optimal level. The genetic algorithms proposed by J. Holland are based on exhaustive and random search techniques, which prove to be robust for optimizing nonlinear and non-convex functions [13].

Most recent studies using GAs in transit network problem can be found for optimization of route network design in which bus scheduling is usually a part of route optimization function. Development of optimal schedules is an extremely difficult task even for small transit network. The difficulty arises because of large number of variables and constraints. The discrete nature of variables and non-linearity involved in the objective function and the constraints further increase the complexity and computational burden. Chakroborty et al. highlighted similar type of problem. Even after linearizing the problem the complexity remains very large. The benefit obtained through linearization is offset by the increase in the number of variables and constraints [13].

Park S.J has focused to develop new computerized optimization models for the bus scheduling problem in a coordinated bus network, namely, new models to find optimized bus headways and slack times. In the new models bus headways are optimized first under the deterministic arrival process, and then slack times are introduced to optimization problem for the stochastic arrival processes with a dispatching strategy that a bus arriving at transfer center earlier than its departure time leaves on time, regardless of the arrival time of passengers transferring from other routes [10].

3. Methodology of research
3.1. Study area
For the study presented in this paper, there has been selected a tram line (line no. 10) which make the connection of the southern area of Bucharest with the western area, the section with the ends of Romprim (station 1011) and Banu Manta Blvd (station 10124) (figure 1). The trams are monitored on the entire route, when passing through the stations, where they must make stops to pick up passengers.

Line 10 takes over 34000 passengers on average every day, along the route being transfer points to other urban surface lines, but also to subway lines.

Figure 1. Line no. 10 route (Source: www.moovitapp.com)
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Characteristic data of the selected line

**Table 1.** The time required to cover the 23 stations of line no 10 for a typical working day/for a weekend day

| Current number | Name of stations/code | Distance [m] | Average travel time between stations for outward journey/return journey [min] | Average travel time between stations for outward journey/return journey during peak periods [min] |
|----------------|-----------------------|--------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| 1              | Romprim-Șoseaua Vitan Bărăștești/1011-1012 | 520          | 2.15/2.09                                                                    | 2.35/2.29                                                                            |
| 2              | Șoseaua Vitan Bărăștești-Stadion/1012-1013 | 691          | 2.86/2.78                                                                    | 3.12/3.04                                                                            |
| 3              | Stadion-Lunca Bărăștești/1013-1014        | 520          | 2.15/2.09                                                                    | 2.35/2.29                                                                            |
| 4              | Lunca Bărăștești-Piața Sudului/1014-1015 | 531          | 2.20/2.14                                                                    | 2.40/2.34                                                                            |
| 5              | Piața Sudului-Piața Sudului/1015-1016    | 127          | 0.53/0.51                                                                    | 0.57/0.56                                                                            |
| 6              | Piața Sudului-Huși/1016-1017             | 386          | 1.60/1.55                                                                    | 1.74/1.70                                                                            |
| 7              | Husși-Bd. Constantin Brâncoveanu/1017-1018 | 462          | 1.91/1.86                                                                    | 2.08/2.03                                                                            |
| 8              | Bd. Constantin Brâncoveanu-Opriș Ilie/1018-1019 | 515        | 2.13/2.07                                                                    | 2.32/2.27                                                                            |
| 9              | Opris Ilie-Cimitirul Șerban Vodă/1019-10110 | 379         | 1.57/1.52                                                                    | 1.71/1.67                                                                            |
| 10             | Cimitirul Șerban Vodă-Piața Eroii Revoluției/10110-10111 | 712     | 2.94/2.86                                                                    | 3.21/3.13                                                                            |
| 11             | Piața Eroii Revoluției-Ștefan Hepîtes/10111-10112 | 388       | 1.60/1.56                                                                    | 1.75/1.71                                                                            |
| 12             | Ștefan Hepîtes-Dr. Constantin Istrati/10112-10113 | 354      | 1.46/1.42                                                                    | 1.60/1.56                                                                            |
| 13             | Dr. Constantin Istrati-Spătarul Preda/10113-10114 | 664      | 2.75/2.67                                                                    | 3.00/2.92                                                                            |
| 14             | Spătarul Preda-Calea Rahovei/10114-10115  | 711          | 2.94/2.86                                                                    | 3.21/3.13                                                                            |
| 15             | Calea Rahovei-Inox/10115-10116           | 414          | 1.71/1.66                                                                    | 1.87/1.82                                                                            |
| 16             | Inox-Calea 13 Septembrie/10116-10117     | 608          | 2.51/2.45                                                                    | 2.74/2.67                                                                            |
| 17             | Calea 13 Septembrie-Cartier Panduri/10117-10118 | 368   | 1.52/1.48                                                                    | 1.66/1.62                                                                            |
| 18             | Cartier Panduri-Piața Danny Huwe/10118-10119 | 481     | 1.99/1.93                                                                    | 2.17/2.12                                                                            |
| 19             | Piața Danny Huwe-Bd. Vasile Milea/10119-10120 | 579    | 2.39/2.33                                                                    | 2.61/2.55                                                                            |
| 20             | Bd. Vasile Milea-Bd. Iuliu Maniu/10120-10121 | 756    | 3.13/3.04                                                                    | 3.41/3.33                                                                            |
| 21             | Bd. Iuliu Maniu-Pod Grozăvești/10121-10122 | 1011   | 4.18/4.07                                                                    | 4.56/4.45                                                                            |
| 22             | Pod Grozăvești-Pasajul Basarab/10122-10123 | 1115   | 4.61/4.48                                                                    | 5.03/4.90                                                                            |
| 23             | Pasajul Basarab-Bd. Manu Manta/10123-10124 | 515     | 2.13/2.07                                                                    | 2.32/2.27                                                                            |

-the commercial speed on line no 10, in a working day, is 14.51 km/h and the speed considered in the peak periods is 13.30 km/h, so a decrease of 8.4% when the degree of congestion increases.

-the frequency of scheduled departures, from the station 1011 to 10124, in the time interval 7:00-8:00 am, has a value of 6.62 minutes and the scheduled duration (for the morning peak) to go through the 23 stations mentioned in table 1 is 53 minutes.

-the commercial speed on line 10, in a weekend day, is 14.92 km/h and the speed considered in the peak periods is 13.64 km/h, so a decrease of 8.6% when the degree of congestion increases.

**Table 2.** Line no 10 indicators (Source: the public transport operator STB SA)

|                  | Working day | Weekend |
|------------------|-------------|---------|
| Average speed    | 14.51 km/h  | 14.92 km/h |
| Average speed in peak periods | 13.30 km/h | 13.64 km/h |
| Average used transport capacity | 1791 passengers/h | 1531 passengers/h |
| Maximum capacity | 2241 passengers/h | 1915 passengers/h |
The highest values of deviations are recorded in the connection stations (Dr. Constantin Istrati – station 10112, Cartier Panduri – station 10117, Piața Danny Huwe – station 10118 – these stations are located at the edge of heavily trafficked intersections, where frequent blockages occur during peak hours). In addition, it can be noticed that the biggest deviations are recorded on Sundays, because due to a smaller number of users and a lighter road traffic, the vehicles travel in advance along the entire route.

3.2. Adjustments of planned schedule with GA

A genetic algorithm performs specific operations in a reproductive process governed by genetic operators. The new solutions are created by selecting and recombining existing chromosomes, in order to optimize an evaluation function specific to each problem. The significance of this function is not relevant to the algorithm, what matters is only its value.

They generally start from a randomly generated population of chromosomes, and each new population generated by reproduction partially or completely replaces the previous generation. The global evaluation function is moving towards the optimal and offers better and better solutions to the problem. The process is analogous to the neo-Darwinian theory of biological evolution, which states that organisms continuously adapted to environmental changes have the highest chances of survival [7], [11].

To find the optimal solution to a problem, a genetic algorithm starts with a given or randomly generated set of potential solutions and improves it by going through a number of iterations (generations), the performance of each solution is evaluated through the fitness function [3].

The population of chromosomes will be:

\[ C_1 = x_1, x_2, \ldots, x_n \]
\[ C_2 = x_2, x_3, \ldots, x_n \]
\[ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \]
\[ C_{10} = x_{10}, x_{11}, \ldots, x_n \]
\[ C_{11} = x_{11}, x_{12}, \ldots, x_n \]
\[ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \]
\[ C_{20} = x_{20}, x_{21}, \ldots, x_n \]

(1, n) = (1; 60) = (1.04.2019; 22.05.2020)

Fitness function \( f(x) = X_{\text{planned}} - X_{\text{real}} \), \( X = \text{arrival time in the station} \)

\[ f(x) = \Delta X_t \]
We establish the following:
-the chromosomes used have a constant length;
-the number of chromosomes is constant.

Each chromosome (vector element) represents a potential solution to the problem and it is implemented in the form of an S data structure. Each solution is evaluated as a measure of "fitness" or life expectancy. This fitness represents the quality of the chromosome. Usually, the more promising the chromosome, the higher the fitness. In the case of our problem, fitness function must be minimized in the idea of optimizing the traffic schedule for line no. 10.

A new population (iteration t+1) is formed by selecting several individual matches, choosing the most promising chromosomes (selection step) from the current population (from iteration t). Some of the newly formed members of the population undergo transformations (the step of modification) through the "genetic" operation of the new solutions.

The number of iterations is essential in achieving the optimization mechanism. This is justified by the fact that only after a certain number of iterations the values of the fitness function tend to a constant, which means that the best solution of the latest generation is very close to the optimal solution. [14]

The following describes how the experiment is performed and the results obtained for a run are presented.

The parameters of the genetic algorithm used are as follows: population size $P_{\text{op.size}} = 60$ (same for each type of day).

Objective function:
\[
\text{minimize } \{ M \left[ \sum_{n=1}^{60} |x_{n,j_1}|, |x_{n,j_2}|, \ldots, |x_{n,j_{13}}| \right]; \ W[\sum_{n=1}^{60} |x_{n,j_1}|, |x_{n,j_2}|, \ldots, |x_{n,j_{13}}|]; \ F[\sum_{n=1}^{60} |x_{n,j_1}|, |x_{n,j_2}|, \ldots, |x_{n,j_{13}}|] \}
\]

$x_{n,j_i}$ – deviation in n day and in station $i$; $i = 1, 23$, $n = 1, 60$

$M$ – Monday, $W$ – Wednesday, $F$ - Friday

The initial population was created as follows: a chromosome was considered as the string formed by the values obtained by the difference between the planned time and the actual time of passage through each station, being a total of 23 stations, meaning the string will have a length of 23 bits represented by real positive and negative values.

The population comprises 60 chromosomes, each corresponding to a day of Monday/Wednesday/Friday/Sunday, during 60 weeks, starting with 01.04.2019.

Following the evaluation, the best individual was determined as $C_5$, and the weakest as $C_{33}$ - for Mondays; $C_{21}$ - the best and $C_{34}$ - the weakest for Wednesdays; $C_{35}$ – the best and $C_{30}$ the weakest for Fridays; $C_{46}$ – the best and $C_{23}$ the weakest for Sundays.

$P_{t+1} = \{C_1, C_2, \ldots, C_{60}\}$

### Table 3. The initial population of deviations obtained for Monday

|        | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ | $S_7$ | $S_8$ | $S_9$ | $S_{10}$ | $S_{11}$ | $S_{12}$ | $S_{13}$ | $S_{14}$ | $S_{15}$ | $S_{16}$ | $S_{17}$ | $S_{18}$ | $S_{19}$ | $S_{20}$ | $S_{21}$ | $S_{22}$ | $S_{23}$ |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| $C_1$  | 109.06| -1.14 | -0.68 | 0.99  | -2.37 | -3.84 | -3.57 | -3.97 | -5.26 | -5.12    | -5.56    | -5.42    | -5.22    | -5.67    | -5.78    | -5.74    | -5.37    | -5.33    | -5.12    | -5.22    | -5.67    | -5.74    |
| $F(x)$ | 109.06|       |       |       |       |       |       |       |       |          |          |          |          |          |          |          |          |          |          |          |          |          |
| $C_2$  | 49.75 | -1.38 | -2.21 | -1.76 | -2.37 | -3.84 | -3.57 | -3.97 | -5.26 | -5.12    | -5.56    | -5.42    | -5.22    | -5.67    | -5.78    | -5.74    | -5.37    | -5.33    | -5.12    | -5.22    | -5.67    | -5.74    |
| $F(x)$ | 49.75 |       |       |       |       |       |       |       |       |          |          |          |          |          |          |          |          |          |          |          |          |          |
| $C_3$  | 111.33| -1.59 | -1.20 | -2.74 | -3.88 | -5.04 | -3.02 | -3.57 | -3.97 | -5.26    | -5.56    | -5.42    | -5.22    | -5.67    | -5.78    | -5.74    | -5.37    | -5.33    | -5.12    | -5.22    | -5.67    | -5.74    |
| $F(x)$ | 111.33|       |       |       |       |       |       |       |       |          |          |          |          |          |          |          |          |          |          |          |          |          |
|        |       |       |       |       |       |       |       |       |       |          |          |          |          |          |          |          |          |          |          |          |          |          |
For Mondays, given the values of the fitness function, we will establish as a condition that value of \( f(x) \) is not greater than 66, so that 14 chromosomes will be removed before the crossover operation.

The blue color indicates the minimum value of deviation in the respective chromosome and the yellow color indicates the maximum value.

The value of the fitness function for each chromosome in the initial population is calculated as follows:

Each chromosome is made up of a series of values of the deviations in each station, from the respective day with the departure time, initially established. These values were summed, the negative ones being taken in the module:

\[
F(x) \text{ for } C_{55} = \sum |x_{51,j1}, |x_{52,j2}|, \ldots, |x_{58,j8}| = 1.41 + 0.68 + \ldots + 5.22 = 109.6
\]

\[
F(x) \text{ for } C_{60} = \sum |x_{60,j1}, |x_{60,j2}|, \ldots, |x_{68,j8}| = 1.08 + 0.63 + \ldots + 0.41 = 15.78
\]

|   | \( S_1 \) | \( S_2 \) | \( S_3 \) | \( S_4 \) | \( S_5 \) | \( S_6 \) | \( S_7 \) | \( S_8 \) | \( S_9 \) | \( S_{10} \) | \( S_{11} \) | \( S_{12} \) | \( S_{13} \) | \( S_{14} \) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| \( C_{55} \) | 45.9 | 5.08 | 5.04 | 5.50 | 5.67 | 5.40 | 4.86 | 4.94 | 4.78 | 5.36 | 5.23 | 4.82 | 4.91 | 5.00 |
| \( F(x)=23.17 \) | -0.24 | -0.31 | 5.01 | 4.86 | 4.86 | 4.97 | 4.97 | 5.36 | 5.23 | 4.82 | 4.91 | 5.00 | 4.97 | 5.00 |
| \( C_{56} \) | 3.83 | 3.98 | 3.47 | 3.81 | 3.53 | 3.81 | 3.34 | 3.34 | 3.25 | 3.12 | 3.29 | 3.00 | 3.00 | 3.00 |
| \( F(x)=36.96 \) | -3.83 | -3.98 | -3.47 | -3.81 | -3.53 | -3.81 | -3.34 | -3.34 | -3.25 | -3.12 | -3.29 | -3.00 | -3.00 | -3.00 |
| \( C_{60} \) | 5.38 | 4.92 | 4.73 | 5.00 | 4.14 | 4.32 | 4.52 | 4.06 | 4.00 | 4.14 | 4.32 | 4.52 | 4.06 | 5.00 |
| \( F(x)=15.78 \) | 3.77 | 3.42 | 3.42 | 3.42 | 3.42 | 3.42 | 3.42 | 3.42 | 3.42 | 3.42 | 3.42 | 3.42 | 3.42 | 3.42 |

Table 4. The initial population of deviations obtained for Wednesday
The procedure is generative. It makes use of three main operators; reproduction, crossover and mutation. Each generation of a genetic algorithm consists of a new population produced from the previous generation.

For Mondays, given the values of the fitness function, we will establish as a condition that F(x) is not greater than 66, so that 14 chromosomes will be removed before the crossover operation.

For Wednesdays, given the values of the fitness function, we will establish as a condition that F(x) is not greater than 66, so that 13 chromosomes will be removed before the crossover operation.

For Fridays, given the values of the fitness function, we will establish as a condition that value of F(x) is not greater than 66, so that 21 chromosomes will be removed before the crossover operation.

For Sundays, given the values of the fitness function, we will establish as a condition that value of F(x) is not greater than 88, so that 29 chromosomes will be removed before the crossover operation.

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**Table 5. The initial population of deviations obtained for Friday**

|    | S1     | S2     | S3     | S4     | S5     | S6     | S7     | S8     | S9     | S10    | S11    | S12    | S13    | S14    | S15    | S16    | S17    | S18    | S19    | S20    | S21    | S22    | S23    |
|----|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| C1 | 36.05  | 0.26   | 0.60   | 0.98   | 0.08   | 0.40   | 0.88   | 0.30   | 0.36   | 0.06   | 0.66   | 1.48   | 1.51   | 1.69   | 2.37   | 2.94   | 3.28   | 2.38   | 2.54   | 2.92   | 0.85   | 0.77   |        |
| C2 | 47.62  | 2.18   | 1.56   | 1.21   | 1.35   | 1.03   | 0.40   | 0.30   | 0.36   | 0.06   | 2.25   | 3.04   | 3.28   | 3.28   | 3.40   | 3.50   | 3.93   | 3.59   | 3.82   | 3.04   | 3.28   | 4.05   | 3.40   | 3.82   |
| C3 | 16.08  | 0.09   | 0.22   | 0.20   | 0.30   | 0.64   | 0.99   | 0.59   | 0.93   | 0.32   | 0.18   | 0.80   | 1.08   | 2.31   | 4.00   | 0.24   | 2.54   | 3.04   | 2.38   | 0.85   | 0.77   |        |

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**Table 6. The initial population of deviations obtained for Sunday**

|    | S1     | S2     | S3     | S4     | S5     | S6     | S7     | S8     | S9     | S10    | S11    | S12    | S13    | S14    | S15    | S16    | S17    | S18    | S19    | S20    | S21    | S22    | S23    |
|----|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| C1 | 151.82 | 3.26   | 1.95   | 1.20   | 0.47   | 2.77   | 4.18   | 4.48   | 4.47   | 2.26   | 9.14   | 2.91   | 3.99   | 3.28   | 4.00   | 3.40   | 3.93   | 3.59   | 3.82   | 3.04   | 3.28   | 4.05   | 3.40   | 3.82   |
| C2 | 58.94  | 0.88   | 1.62   | 2.31   | 0.90   | 0.11   | 0.48   | 2.07   | 0.98   | 0.26   | 0.13   | 1.96   | 1.26   | 1.14   | 2.00   | 1.30   | 2.37   | 2.94   | 3.28   | 3.40   | 3.82   | 0.85   | 0.77   |        |
| C3 | 152.07 | 0.30   | 0.22   | 2.83   | 1.83   | 4.48   | 4.47   | 4.47   | 2.26   | 9.14   | 2.91   | 3.99   | 3.28   | 4.00   | 3.40   | 3.93   | 3.59   | 3.82   | 3.04   | 3.28   | 4.05   | 3.40   | 3.82   |

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In the table below I have centralized (for working days) the results obtained by crossing selected chromosomes (two by two) from the initial population of solutions generated by the function: \( f(x) = X_{\text{planned}} - X_{\text{real}} \)

| \( x \) | \( f(x) = 26 \) | \( f(x) = 15.61 \) | \( f(x) = 33.17 \) | \( f(x) = 12.08 \) | \( f(x) = 15.29 \) | \( f(x) = 24.40 \) |
|---|---|---|---|---|---|---|
| R_{1311} | -1.38 | -0.70 | -0.26 | -0.34 | -0.20 | -0.37 |
| R_{1321} | -1.54 | -0.26 | -0.20 | -0.30 | -0.37 | -0.37 |
| R_{1341} | -1.54 | -0.26 | -0.20 | -0.30 | -0.37 | -0.37 |
| R_{1342} | -1.54 | -0.26 | -0.20 | -0.30 | -0.37 | -0.37 |
| R_{1343} | -1.54 | -0.26 | -0.20 | -0.30 | -0.37 | -0.37 |
| R_{1344} | -1.54 | -0.26 | -0.20 | -0.30 | -0.37 | -0.37 |
| R_{1345} | -1.54 | -0.26 | -0.20 | -0.30 | -0.37 | -0.37 |
| R_{1346} | -1.54 | -0.26 | -0.20 | -0.30 | -0.37 | -0.37 |
| R_{1347} | -1.54 | -0.26 | -0.20 | -0.30 | -0.37 | -0.37 |
| R_{1348} | -1.54 | -0.26 | -0.20 | -0.30 | -0.37 | -0.37 |
| R_{1349} | -1.54 | -0.26 | -0.20 | -0.30 | -0.37 | -0.37 |

The fitness value of each result obtained can be found in the first column, and depending on this value, the following chromosomes will be chosen for the crossing operation.

The crossover operation was performed as follows: the elements of the parent chromosomes were compared and the smallest bit was selected. (if \( |x_{1,j}| > |x_{2,j}| \) choose \( x_{1,j} \))

4. Conclusions

Considering the characteristic data of the selected tram line, as well as the traffic analysis in the period 01.04.2019 – 22.05.2020, the conclusions are as follows:

the time needed to go through each station was calculated both during peak periods and in the rest of the day. The resulting values are often exceed by the values of the deviations from the planned program.

The planned program for this selected line, displayed on the official website of the public transport operator of Bucharest (STB SA) was over 2 years old, which lead us to think that this program was no longer correlated with current traffic conditions, where the degree of congestion increased by over 4% compared to 2018 [18].

The largest deviations are generally recorded in stations 10116-10120, and some values may decrease towards the last station 10124, others increase to the end and in this case it is not possible for the respective tram to recover the time lost on the route.

Related to the GA involving for the adjustments of the planned schedules, the main conclusions are as follows:

Regarding the use of genetic algorithms in solving the studied problem, the following can be said:

- there are many solutions to the problem, and identifying one needs to be proven as overall optimal in future research. Therefore, up to now the involved genetic algorithm are used to obtain at least an optimal solution;
- a wide range of genetic algorithms can be designed to solve a problem. There are thus difficulties in choosing the most appropriate genetic algorithm, the literature providing too little information in this regard.

There are no strict rules to identify situations in which genetic algorithms are the most appropriate option to solve a problem, but we chose this method to optimize the traffic schedule of a public transport
line because: the search space for solutions is large enough that an exhaustive search would be virtually impossible; it is not necessary to determine the global optimum, but to find a good enough solution in a relatively short time.

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