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AN IMPROVED EVOLUTIONARY ALGORITHM TO OPTIMIZE TRAFFIC FLOW AT SIGNALIZED INTERSECTIONS

[1]SIDINA BOUDAAKAT, [2]MOHAMED AMINE BASMASSI, [3]AHMED REBBANI, [4]OMAR BOUATTANE, [5]JIHANE ALAMI CHENTOUFI, [6]LAMIA BENAMEUR

[1,3,4] SSDIA Laboratory, ENSET Mohammedia, Hassan II University, Morocco
[2,5]ISO Laboratory, Faculty of Sciences, Ibn Tofail University, Morocco
[6]LIROSA Laboratory, Faculty of Sciences, Abdelmalik Essaadi University, Morocco

E-mail: [1]boudaakat.sidina@gmail.com, [2]basmassi.med.amine@gmail.com, [3]a.rebbani@gmail.com, [4]o.bouattane@gmail.com, [5]lamia_benameur@yahoo.fr, [6]j.alami@uit.ac.ma

ABSTRACT

Traffic congestion remains a hard phenomenon problem to solve. Due to the difficulty and high cost of solutions, many studies are trying to find the most inexpensive solutions. However, with the exponential growth of technology, new opportunities and challenges are opening up to reduce congestion problems. This paper focuses on the minimization of the waiting vehicles at an isolated four arms intersection. The proposed model is divided into two main stages. First, modeling the intersection using a fuzzy system by generating a generalized fuzzy graph based on the intersection situation. Second, an improved greedy genetic algorithm solution is applied to determine the traffic cycle length to reach the maximum performance at the intersection. The results of the experiments used in the simulation of the intersection modeling generalized fuzzy graph and the novel greedy genetic algorithm (IMGFG-NGGA) performed very well compared with traditional fixed-time traffic signal under different traffic demands.

Keywords: *Signalized Intersection, Fuzzy Graph Coloring, Genetic Algorithm, Modeling Intersection, Traffic Signal Control, Traffic management*

1. INTRODUCTION

Traffic congestion is one of the severe problems facing the most significant cities due to the increasing number of vehicles on the world roads, which causes wasting time, a high level of pollution, and road accidents [1]. When traffic jams occur, significant actions are needed to reduce the duration of congestion.

Due to the significant problem, there have been widespread efforts to find solutions. Traffic light control played an important role as a solution used to minimize traffic jams, optimize the traffic light timing and increase intersection safety [2, 3]. However, traffic modeling behavior has been an interesting issue in research for years; helps the researcher to understand the traffic flow behavior, especially modeling an isolated intersection, which, traditionally, has been accomplished using various methods. For example, List et al. [4] used the Petri nets (PN) method to model signalized intersections. The structural analysis demonstrates the performance of the PN model by enforcing the traffic safety rules. Daganzo [5] presented a traffic model on a highway with a single entrance and exit; this model can be used to predict traffic evolution over time and space. By producing, equations can mimic the real-life development of stop-and-go traffic within moving queues. Dotoli et al. [6] treated the modeling of traffic network control using a modular framework based on colored timed Petri nets. Their framework was applied to a natural intersection located in Bari, Italy, to validate and test the model. Babicheva [7] used queuing theory to model traffic flows at signal-controlled road intersections to solve the problem of optimizing the traffic light phase by using the concept of an adequate number of lanes.

In addition to this, some classical graph approaches have performed well when implemented in traffic modeling. They have proven that they can model various networks from real-life problems [3]. Such as, Munoz et al. [8] presented the traffic light problem as a graph by controlling the traffic light system in certain security levels. Besides, Rosyida et al. [9] proposed an application of two signalized intersections as a graph to determine the number of phases and degrees of safety for an integrated traffic light system.

The bio-inspired algorithms [10] are beneficial to solve complex nonlinear problems, especially the optimization of traffic light control. As an example of Çeltek et al. [11] suggested controlling the traffic light control according to the instant traffic situation to optimize the traffic control problem with the swarm-based heuristic optimization algorithms. Likewise, Hao et al. [12] proposed a Tabu search-artificial bee colony algorithm under unsaturated flow conditions called a robust optimization model. On the other hand, Genetic Algorithms (GA) is one of the most popular bio-inspired techniques widely used. For instance, Lu et al. [13] proposed a solution using GA for priority vehicles, specifically emergency vehicles. They show that their proposed GA can decrease the travel times of emergency vehicles. Furthermore, in [14], they presented a GA-based solution for the autonomous vehicle-sequencing problem at intersections. In addition, Sofronova et al. [15] worked on a variational GA to solve the traffic flows control in urban road networks.

This paper offers a new model for understanding modeling the intersection using graph theory and GA. The optimization objective is to minimize the traffic light delays using a novel greedy genetic algorithm (NGGA) on an isolated signalized intersection [16], the results have shown that the NGGA optimization model can effectively deal with the different traffic flow and reduce traffic delays.

The proposed methods are tested in the real traffic data and evaluate performance via the SUMO traffic simulator. The work was accomplished in four steps to achieving the maximum performance of the proposed approach:

- Modeling an isolated signalized intersection by a generalized fuzzy graph coloring
- Defining the crisp graph after determining the appropriate α-cut.
- Applying the NGGA for every generated crisp graph to determine the chromatic number.
- Calculating the time and giving priority to each subgroup that represents the phases.

The remainder of the paper is organized as follows. Section II describes the related work, and section III discusses the proposed IMGFG-NGGA approach. The experimental results are presented in section IV. Finally, the conclusion is given in section V.

2. RELATED WORK

Previous studies have investigated the problem of traffic light signal optimization. These studies aim to improve traffic efficiency over the road network and reduce vehicle waiting delay time at the signalized intersections. More recently, there has been an increasing interest in the Graph Coloring Problem (GCP), where it has been studied widely as a combinatorial optimization problem [17]. Several studies have been used in many practical applications such as traffic light signal [18], air traffic flow management [19], circuit board testing [20], bandwidth allocation [21], and many other fields. However, the GCP objective is to identify the minimum number of vertex clusters with respecting the adjacency constraint by placing every two connected vertices at different clusters [22]. Each cluster uses color to mark its vertices. On the other hand, when the graph is colored with minimum k accepted coloring, k is called the chromatic number χ.

In real-world applications, compatibility between items cannot be determined definitely (compatible or incompatible). Another GCP extension based on a fuzzy connection between vertices had appeared to deal with this problem.

The Fuzzy-set theory was introduced by Zadeh [23, 24] and applied for the first time to graphs by Kaufmann [25], while Rosenfeld [26] presented another developed definition, including fuzzy vertices and fuzzy edges. Mainly, there are two types of colorings, vertex coloring, and edge coloring. Frequently, Fuzzy Graph Coloring Problem (FGCP) can be defined in three ways fuzzy set of vertices with crisp edges or fuzzy edges with crisp vertices set, or fuzzy vertices and fuzzy edges [27]. In this paper, we deal with Fuzzy vertices and fuzzy edges. Many works deal with the FGCP in the literature, such as Munoz et al. [4], where they introduce the concept of the chromatic number of a fuzzy graph in two different approaches. The first one is based on the successive coloring functions of crisp graphs, and the second approach is based on an extension of the concept of coloring function through a distance defined between colors. Besides, Eslahchi et al. [28] define the chromatic fuzzy sum and strength of fuzzy graph to color it by separate the vertices into different classes, and the number of distinct color classes is the fuzzy chromatic number. Meirong et al. [29] designed a new algorithm using a semi-tensor product and α-cuts with two conditions for the fuzzy graph to find all the feasible coloring schemes.

Furthermore, Gómez et al. [30] define a set of pixels where fuzzy edges represent the distance between pixels to get a more flexible hierarchical structure of colors by dealing with the image classification as a fuzzy graph problem. Moreover, Keshavarz et al. [31] work on crisp vertices and fuzzy edges; they formulated a binary programming problem and a hybrid local search genetic algorithm to solve the binary programming. Recently, Rosyida et al. [5] constructed a fuzzy chromatic number of the union of two fuzzy graphs through α-cut graphs coloring and verified the connection between the fuzzy chromatic numbers through a defuzzification. Furthermore, Rosyida et al. [32] explored some properties of the fuzzy chromatic set of the FGCP and constructed it through δ-chromatic number and showed that the fuzzy chromatic set is a discrete fuzzy number called the fuzzy chromatic number. Also, Basmassi et al. [18] design a new hybrid genetic algorithm to solve the FGCP, using the α-cuts of the graph and the chromatic number as a fuzzy set containing a chromatic number for every crisp graph.

In all FGCP, there is a common property that edge membership value is less than the minimum of its vertices membership values. However, some real-world applications can be represented as FGCP that do not respect that property. A generalization of the FGCP concept was instituted to remove the edge restrictions by many researchers like Samanta et al. [33]. They propose a generalized fuzzy graph problem (GFGCP) where they remove the edge restriction by establishing two new definitions of the relation between vertices and edges. In [34], Samanta et al. had enriched the precedent work with generalized directed fuzzy graphs and extended fuzzy r-cuts to fuzzy n-tuple cuts. Furthermore, Sebastian et al. [35] proved real application related to human trafficking by redefining the existing connectivity parameters (super and complete fuzzy graphs) with pre-fixed connectivity values and a new class of fuzzy graphs called generalized t-connected fuzzy graphs. However, the relationship between vertices and edges may take other definitions, as in the case of [36].

Many Traffic modeling works have succeeded in proving the efficiency. Kim et al. [38] propose an extended version of Deganzo work Cell Transmission Model by adding the agent concept to handle complex signalized intersections in urban traffic. The proposed model accounts for the turning and traffic signal modeling in intersections and the lane changing behavior. The proposed model shows the performance of urban traffic phenomena adequately. Boudaakat et al. [36] introduce modeling of an isolated intersection as a generalized fuzzy graph with fuzzy vertex and fuzzy edge sets through two modeling phases. Lewis [38] provides a list of the emerging science of network applications. The graphs are one of the robust data structures to represent the network of roads and cities. Also, graphs are used as a kind of modeling activity. Muñoz et al. [4] Introduce concepts of fuzzy graphs and two new fuzzy optimization problems, which can be very useful to model and solve real-life issues without unnecessary simplifications. Rosyida et al. [39] suggest a possible application of theoretical results to solve a traffic light problem. The proposed model is arranging traffic flows by using a different number of phases in different traffic intensities. The

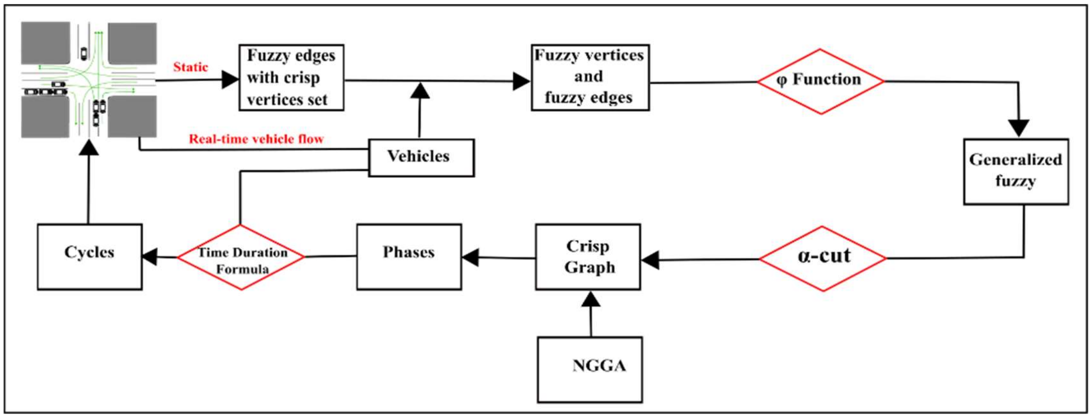

Figure 1. Illustration of the process of the IMGFG-NGGA approach

fuzzy graph model creates a dynamic traffic light system.

3. THE IMGFG-NGGA APPROACH

The IMGFG-NGGA process is divided into the IMGFG modeling and NGGA algorithm (Fig.1).

The IMGFG modeling starts by reading every step of the simulation to decide which graph is suitable for the current situation1 then the NGGA algorithm defines the number of the phases and the sequence set of each phase to reach maximum traffic safety during traffic congestion. Finally, a separate function calculates the priority of phases and green time duration.

3.1 The Generalized Fuzzy Graph Definitions

The main objective of the proposed approach is to minimize the waiting time at an intersection, and the ideal case would be when the vehicles could cross the intersection without stopping at all. The isolated signalized intersection shown in (Fig.2) is selected to facilitate the comprehension of the proposed method. This intersection is composed of four arms, with variant input lanes and output lanes.

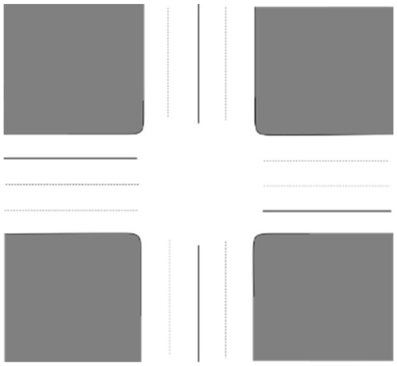

Figure 2. Illustration of four arms intersection

The IMGFG process occurs in two stages. First, a fuzzy graph $\tilde{G}_s$ is created and then after identifying all the elements a generalized fuzzy graph (GFG) $\tilde{G}_d$ is generated with the help of the waiting vehicles.

In the first stage, a fuzzy graph $\tilde{G}_s$ is created where each vertex represents a lane, and an edge between vertices is defined as the membership value.

Let $\tilde{G}s$ = (V, $\tilde{E}$, μ) be the fuzzy graph of the isolated intersection where:

- V: Set of lanes in the intersection.
- E: Set of confluences between lanes in the intersection.
- μ: VxV→ (0,1]: The membership value function of the conflict degree between two lanes.

According to the analysis of the conflict zones, the conflict types are categorized into three basic types. First, low-risk conflict (L) where two lanes enter into a wide lane (Fig.3.b). The second medium-risk conflict (M) is when two lanes enter into the tight lane. (Fig.3.c) and finally high-risk conflict (H) when two lanes cross each other inside the

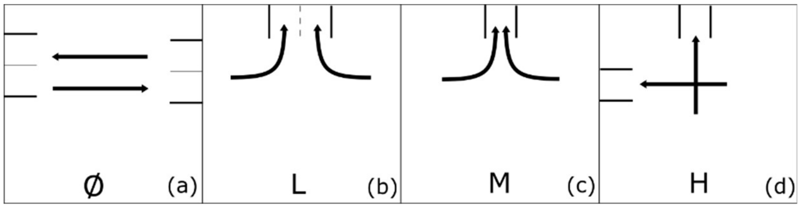

Figure 3 Illustration of conflicts type.

intersection (Fig.3.d). Otherwise, when no conflict risk between lanes exists, it is denoted by (∅).(Fig.3.a).

The membership value of the edge depends on the type of confluence and the place where they conflict. With this notion, the membership values of edges will be defined by the corresponding values of the set {L, M, H} ⊆ (0, 1] see (Fig.3).

There are three kind of edges $\{A_1B_2\}$, $\{B_1A_2\}$ and $\{B_2A_3\}$ get, the membership values H, M, L, respectively, see (Fig.4).

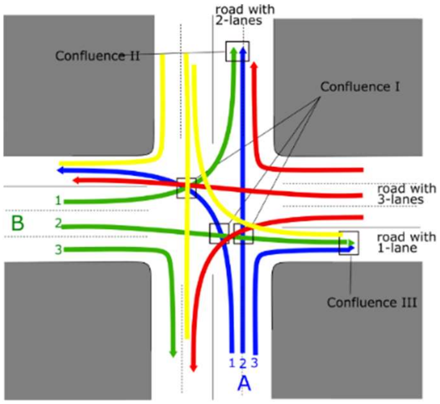

Figure 4. Illustration of the four arms intersection with conflicts between lanes.

In the second stage, a generalized fuzzy graph (GFG) is generated with fuzzy edges and fuzzy vertices, representing the intersection dynamic situation. Each vertex represents a lane, and its membership value describes the waiting vehicles on the lane head. Further, the membership value of an edge e_{ij} is calculated based on the membership value of e_{ij} from $\tilde{G}_S$ and the corresponding vertices membership values with the following function φ: VxV → (0,1] defined by :

$$\varphi(v_i, v_j) = \max((\sigma(v_i) \oplus b_{ij}), (\sigma(v_j) \oplus b_{ij})) \qquad (1)$$

Where: ⊕ is the average of two values, $b_{ij} \in \tilde{G}_S$ and $\sigma(v_i), \sigma(v_j) \in \tilde{G}_d$.

Let $\tilde{G}_d$ = (V, E, σ, μ) be the GFG of the isolated intersection where:

- V: Set of lanes in the intersection.
- E: Set of confluences between lanes in the intersection.
- σ: V → (0,1]: The membership value function of the saturation degree associated with the lane.
- μ: VxV→(0,1]: The membership value function of the edge prohibition degree.

The function σ represents the degree of lane saturation; each lane has a maximum waiting unit equal to its length. The vertices membership values are categorized similarly to the edges membership value, where the lane is divided into three parts. The first part is 10% of the lane beginning from the lane head, representing the lowest level of congestion denoted by L=] 0, 10] %. The second part represents the medium level of saturation in the lane M=] 10, 60] %, last part is the high level of saturation where the vehicles exceed 60% of the lane length H=] 60, 100] %. Finally, when no vehicle is waiting at the lane membership value of vertex get ∅.

As depicted in (Fig. 1), the IMGFG modeling process consists of two main stages which are responsible for modeling and transforming the intersection into a generalized fuzzy graph $\tilde{G}_d$ which represents the intersection situation. The $\tilde{G}_d$ graph it will be sent to NGGA algorithm for determining the phases.

The modeling process uses the IMGFG technique [36] where a generalized fuzzy graph coloring approach is used to model any signalized intersection.

All types of conflicts at the intersection translated into congestion level are presented in the generalized fuzzy graph. In this generalized fuzzy graph, the vertices represent lanes, the vertices membership values are the level of congestion, the edges express the existing conflicts between those lanes, and the edges membership value are the kinds of these conflicts.

3.2 The Novel Greedy Genetic Algorithm

In this work, an NGGA is proposed to solve the GCP using the GA and the greedy sequential algorithm (GSA). The NGGA is applying for every generated crisp graph to generate the specific chromatic number and the optimal solution. The NGGA was designed to optimize the vehicle arrival, which would maximize the average intersection crossing and reduce the waiting time. The proposed NGGA combines GA and GSA to solve the GCP. The NGGA behavior starts with the initial population; this function begins with a population p of n feasible or non-feasible coloring graphs.

In our case, the upper bound is used to generate different chromosomes with a random number of colors. Then, the fitness function where each chromosome has a fitness score that shows the ability of the chromosome to survive.

The chromosomes with optimal fitness scores have more chance to mate and transfer their genes to produce new offspring. The population size is stable. So, the parent chromosomes (the old population) and the new arrivals compete to pass in the next generation. The chromosomes with the best fitness score move to next-generation during the least fit die.

Followed by the parent selection function, which is one of the GA outlines, chromosomes are selected from the population to be parents and mate to create offspring for the next generation.

The parent selection is a susceptible process that impacts the GA convergence rate and avoids being stacked in an optimal solution. The tournament selection was used to select the parent. It is a strategy used for selecting the fittest candidates from the current population; these selected candidates are then moved on to crossover. In a k-way tournament selection, k-chromosomes are selected and run a tournament among them. The weak candidates have a smaller chance of getting chosen when the tournament size is more significant. Due to that, the competition becomes stronger between chromosomes.

In this work, four chromosomes are randomly selected from the population, and then the best of them is selected to become a parent. After that, the crossover function is applied, where two parents are chosen, and two offsprings are produced using the parent genetic material. In this approach, a three-point crossover is used. The uniform mutation is used to maintain and introduce diversity in the genetic population, and it is applied with a small probability.

The pseudo-code of the NGGA method is as follows:

```
Begin
    Generate the initial population POP (0);
    Evaluate POP (0);
    Repeat
        Select parents;
        Generate new chromosomes using crossover;
        Applied mutation on the new chromosomes;
        Applied greedy sequential function;
        Evaluate POP (t);
    Until (Terminating condition is reached);
End;
```

Sequential correction algorithm (GSA) is injected as an operator in GA to accelerate the search and improve chromosome fitness. There are two stages to solve the GCP based on the greedy approach: scanning the items and optimizing items. For each new child, all the genes that do not verify the problem constraints are checked. In this case, a different color from its neighbor is affected, but it should be one of the used colors in the chromosomes; else, no modification is performed.

The pseudo-code of the sequential correction algorithm function is given as follows:

```
Begin
   CH: New Chromosome.
   Palette ← Get used colors in CH;
   Repeat
      V ← Select gene from CH;
      CH ← CH \ {V};
      if V does not satisfy the constraint, then :
         Invalid Colors ← Adjacent Gene Colors of V;
         Valid Colors ← Palette\Invalid Colors;
         If Valid Colors ≠ Ø then:
               V ← Any color from Valid Colors;
      End if;
   End if;
   Until (Terminating condition is reached);
End;
```

3.3 Priority and Time Duration

Each sub-group SG_i in the final crisp graph represent phase. The amount of time necessary to service all phases for each direction of an intersection before returning to the starting point, or the first phase of the cycle, is defined as cycle length. The cycle lengths are determined by traffic volumes.

Typical traffic light cycle lengths may range from one minute to three minutes; our traffic light cycle length duration is two minutes. Every phase has a limited time duration T_{max} = 60s and T_{min} = 10s. When the phase exceeds the T_{max}=60s, the phase is split into different phases (the first 60s will serve now and the rest will serve first in the next cycle).

The following formula gives the time duration of each phase:

$$T(SG_i) = \frac{SG_i}{\sum_{j\epsilon\chi_G} SG_j} * T_{Total} \qquad (2)$$

Where: $T(SG_i)$ is the phase lengths and T_{Total} is cycle length.

The traffic light cycle contains different number phases depending on the situation of the intersection. The phase with the most number of vehicles will be served first and so on. (Fig.5). Shows sample phase example.

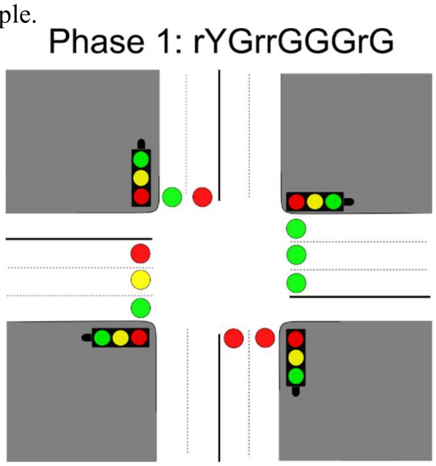

Figure 5.Illustration of sample phase.

4. THE EXPERIMENTAL RESULTS

The scenarios tested on Simulation of Urban MObility (SUMO) [40], Sumo is a widely used microscopic and continuous road traffic simulation package. Two simulation methods have been defined to manage the intersection:

- The fixed traffic light signal.
- The IMGFG-NGGA traffic light signal.

For the GA used in this work, the crossover probability used is Pc=90% and Pm=1% for the mutation probability. The algorithm is run for 100 generations, and the population size used is 200. The optimal coloring solution generated by IMGFG-NGGA represents traffic light signal phases, every group of vertices colored with the same color describes a phase of traffic light junction.

The experiment has been carried out on an HP computer using a sumo simulator and python 2.7 editor. Note that the pedestrians have not been considered in our proposed approach.

The network has been created to test the simulation scenarios. The intersection consists of four legs, 16 lanes, with a length of 100 meters and the number of the vehicle is variant for each scenario at each lane; the speed is the default speed of Sumo (31 m/s).

To measure the results of the simulation scenarios, the vehicles are inserted at step zero at the intersection. The two methods of managing the intersection involve inserting the same number of vehicles at low, medium, and high traffic volumes. To compare the proposed IMGFG-NGGA results with the fixed traffic control, the IMGFG-NGGA scenario is run fifty times to compare with the fixed traffic light under different demands. The results are shown in (Fig 6).

Fig 6 illustrates the simulation time of an isolated intersection fifty times. It can be seen that during the low and medium traffic demand, all the values below the fixed time control excepting one value. Similarly, during the high traffic demand, seven values are above the fixed time control value. Overall, the simulation time scenario of an isolated intersection is better than the fixed time control by 98% for low and medium traffic demand and 86% for high traffic demand.

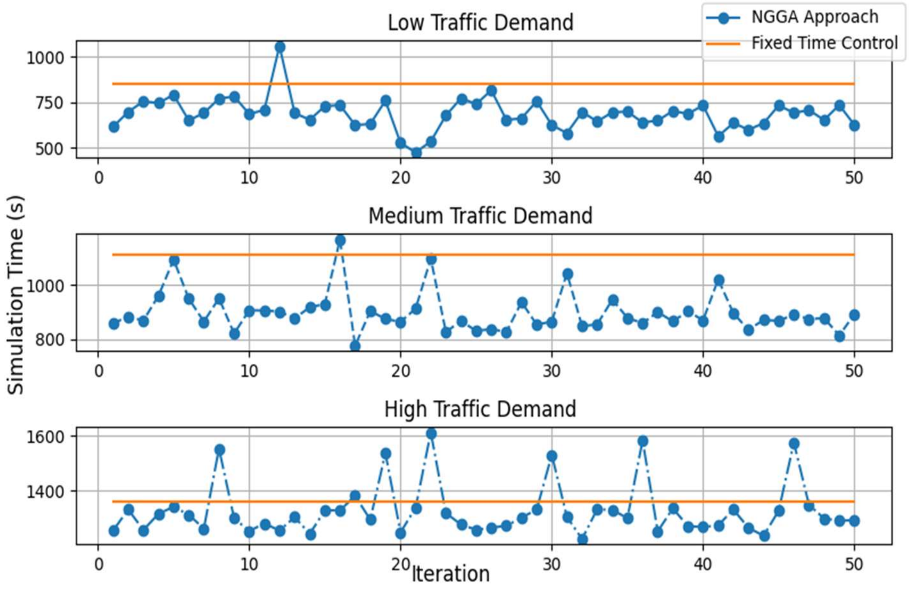

Figure 6.Illustration of simulation time for different traffic demands.

Fig 7 shows, the accumulation of the waiting time of vehicles during the simulation. The vehicles entering at the intersection at time zero. The IMGFG-NGGA gives a reduced waiting time compared to that obtained by the fixed time control. The average waiting time of vehicles using "IMGFG-NGGA" was reduced by "65%" for low demand, a "19%" for medium demand, and a "7%" for high demand compared to the fixed traffic control.

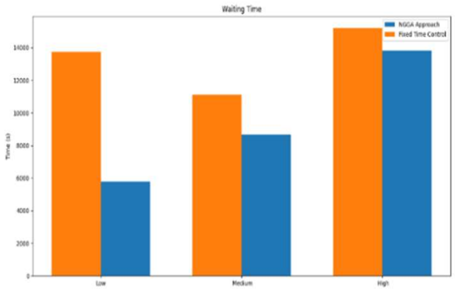

Figure 7. Illustration of waiting time.

However, (Figs 8, 9, 10), which show the queue lengths during the simulation, the IMGFG-NGGA gives a visibly reduced occurrence number of 4, 5, and 6 queue lengths for the different traffic demands. The queue length of the intersection road varies between 0 and 6 vehicles during the simulation (0 means that all vehicles move without stopping).

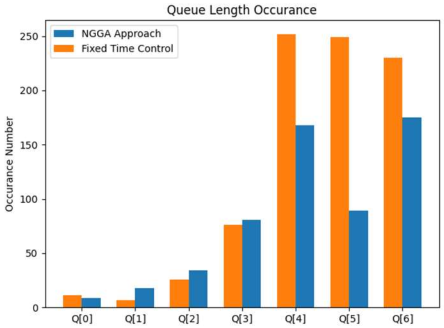

Figure 8. Illustration of queue length for the low demand.

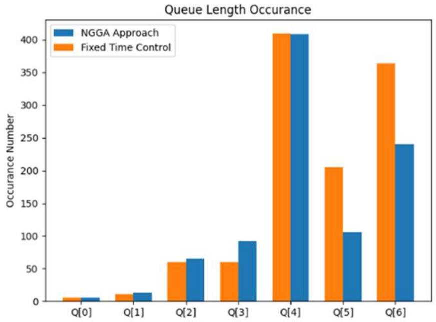

Figure 9. Illustration of queue length for medium demand.

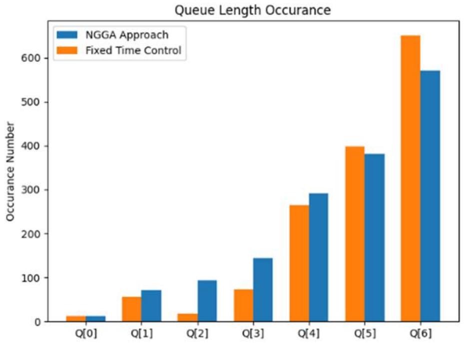

Figure 10. Illustration of queue length for high demand.

As a result of the above graphs, the CO2 and CO have been significantly reduced. Due to the shorter waiting time and reduction of queue length of vehicles. The IMGFG-NGGA solution reduced CO2 and CO emissions produced by vehicles, as depicted in (Fig. 11, 12).

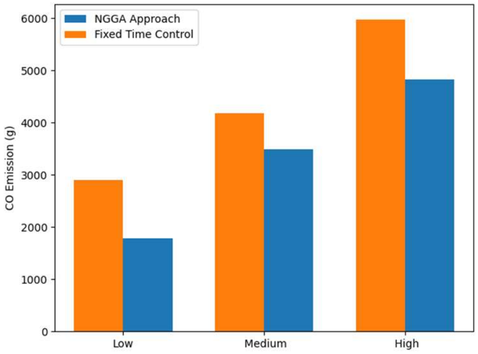

Figure 11. Illustration of CO emission of vehicles

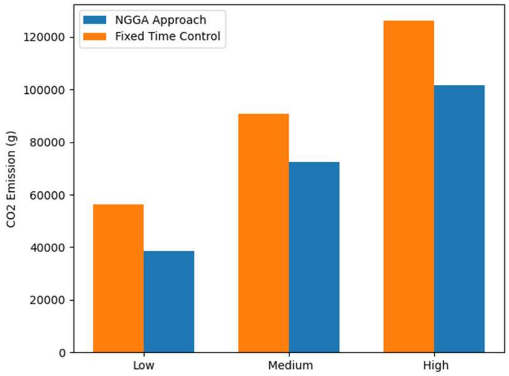

Figure 12.Illustration of CO2 emission of vehicles

The experiments determined that IMGFG-NGGA can generate traffic signal controllers flexible to traffic variation for the intersection scenario of different traffic densities. The method was compared with a fixed traffic light control. The generated solutions were tested using scenarios with different traffic densities.

The NGGA uses the information provided by the IMGFG to generate the signal traffic light flexibility. However, the model can certainly be extended to consider different aspects such as the communication between lights or between lights and vehicles. The IMGFG-NGGA has been able to obtain an excellent solution comparing to the traditional traffic light control.

5. CONCLUSION

This paper describes an IMGFG-NGGA solution that can reduce the waiting time delays of vehicles and accelerate the vehicle travel time at an isolated intersection. The approach has proven to be very effective as the modeling system is able to take into account all the elements of the intersection, which leads to the real situation of the intersection.

Based on the results, it can be concluded that the approach provides good results for the different traffic flow volumes compared with the traditional traffic light management. The IMGFG-NGGA solution proves the ability to apply to any intersection. In our future research, we intend to merge the IMGFG-NGGA solution with a multi-agent paradigm for a portion of a congested city.

REFERENCES

[1]. Falcocchio, John C., and Herbert S. Levinson. "The costs and other consequences of traffic congestion." *Road Traffic Congestion: A Concise Guide*. Springer, Cham, 2015. 159-182.

[2]. Zhao, Dongbin, Yujie Dai, and Zhen Zhang. "Computational intelligence in urban traffic signal control: A survey." *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)* 42.4 (2011): 485-494.

[3]. Rodrigue, Jean-Paul, Claude Comtois, and Brian Slack. The geography of transport systems. Routledge, 2016.

[4]. List, George F., and Mecit Cetin. "Modeling traffic signal control using Petri nets." IEEE Transactions on intelligent transportation systems 5.3 (2004): 177-187.

[5]. Daganzo, Carlos F. "The cell transmission model: A dynamic representation of highway traffic consistent with the hydrodynamic theory." Transportation Research Part B: Methodological 28.4 (1994): 269-287.

[6]. Dotoli, Mariagrazia, and Maria Pia Fanti. "An urban traffic network model via coloured timed Petri nets." *Control Engineering Practice* 14.10 (2006): 1213-1229.

[7]. Babicheva, T. S. "The use of queuing theory at research and optimization of traffic on the signal-controlled road intersections." Procedia Computer Science 55 (2015): 469-478.M.

[8]. Munoz, Susana, et al. "Coloring fuzzy graphs." Omega 33.3 (2005): 211-221.

[9]. Rosyida, I., Ch R. Indrati, and D. Indriati. "Some properties on fuzzy chromatic number of union of fuzzy graphs through α-cut graphs coloring." Journal of Physics: Conference Series. Vol. 1306. No. 1. IOP Publishing, 2019.

[10]. Castillo, Oscar, et al. "Comparative study of bio-inspired algorithms applied to the optimization of type-1 and type-2 fuzzy controllers for an autonomous mobile robot." *Information sciences* 192 (2012): 19-38.

[11]. Celtek, Seyit Alperen, Akif Durdu, and Muzamil Eltejani Mohammed Alı. "Real-time traffic signal control with swarm optimization methods." Measurement 166 (2020): 108206.

[12]. Hao, Wei, et al. "Robust optimization of signal control parameters for unsaturated intersection based on tabu search-artificial bee colony algorithm." *IEEE Access* 6 (2018): 32015-32022.

[13]. Lu, Qiang, and Kyoung-Dae Kim. "A genetic algorithm approach for expedited crossing of emergency vehicles in connected and autonomous intersection traffic." Journal of Advanced Transportation 2017 (2017).

[14]. Yan, Fei, Mahjoub Dridi, and Abdellah El Moudni. "An autonomous vehicle sequencing problem at intersections: A genetic algorithm approach." International Journal of Applied Mathematics and Computer Science 23.1 (2013): 183-200.

[15]. Sofronova, E. A., A. A. Belyakov, and D. B. Khamadiyarov. "Optimal control for traffic flows in the urban road networks and its solution by variational genetic algorithm." *Procedia Computer Science* 150 (2019): 302-308.

[16]. Basmassi, M. A., L. Benameur, and J. A. Chentoufi. "a Novel Greedy Genetic Algorithm to Solve Combinatorial Optimization Problem." The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 44 (2020): 117-120.PM. Pardalos et al., "The graph coloring problem: a bibliographic survey,".In: Du DZ, Pardalos PM, editors. Handbook of combinatorial optimization, Boston: Kluwer Academic Publishers, vol. 2, 1998, p. 331–95.

[17]. Pardalos, Panos M., Thelma Mavridou, and Jue Xue. "The graph coloring problem: A bibliographic survey." *Handbook of combinatorial optimization*. Springer, Boston, MA, 1998. 1077-1141

[18]. Basmassi, Mohamed Amine, Sidina Boudaakat, Lamia Benameur, Omar Bouattane, Ahmed Rebbani, and Jihane Alami Chentoufi. "Hybrid Genetic Approach for Solving Fuzzy Graph Coloring Problem." In Sensor Network Methodologies for Smart Applications, pp. 54-64. IGI Global, 2020.N. Barnier et al., "Graph coloring for air traffic flow management,". Annals of operations research, 130(1-4) , 2004, pp. 163-178.

[19]. Barnier, Nicolas, and Pascal Brisset. "Graph coloring for air traffic flow management." *Annals of operations research* 130.1 (2004): 163-178.

[20]. Garey, Michael, David Johnson, and Hing So. "An application of graph coloring to printed circuit testing." *IEEE Transactions on circuits and systems* 23.10 (1976): 591-599.

[21]. Bar-Yehuda, Reuven, Gleb Polevoy, and Dror Rawitz. "Bandwidth allocation in cellular networks with multiple interferences." Discrete Applied Mathematics 194 (2015): 23-36.M. Pal et al., "Coloring of Fuzzy Graph. In: Modern Trends in Fuzzy Graph Theory,". Springer, Singapore. 2020.

[22]. Pal, Madhumangal, Sovan Samanta, and Ganesh Ghorai. *Modern trends in fuzzy graph theory*. Springer, 2020.

[23]. Zadeh, Lotfi A. "Fuzzy sets." Fuzzy sets, fuzzy logic, and fuzzy systems: selected papers by Lotfi A Zadeh. 1996. 394-432.

[24]. Zadeh, Lotfi Asker. "Probability measures of fuzzy events." *Journal of mathematical analysis and applications* 23.2 (1968): 421-427.

[25]. Kaufmann, Arnold. "Introduction à la théorie des sous-ensembles flous à l'usage des ingénieurs (fuzzy sets theory)." (1973).

[26]. Rosenfeld, Azriel. "Fuzzy graphs." *Fuzzy sets and their applications to cognitive and decision processes*. Academic press, 1975. 77-95.

[27]. Alami, J., A. El Imrani, and Abdelaziz Bouroumi. "A multipopulation cultural algorithm using fuzzy clustering." *Applied Soft Computing* 7.2 (2007): 506-519.

[28]. Eslahchi, Changiz, and Bi Naimeh Onagh. "Vertex-strength of fuzzy graphs." *International Journal of Mathematics and Mathematical Sciences* 2006 (2006).

[29]. Meirong, Xu, Wang Yuzhen, and Jiang Ping. "Fuzzy graph coloring via semi-tensor product method." *2015 34th Chinese Control Conference (CCC)*. IEEE, 2015.

[30]. Gómez, Daniel, Javier Montero, and Javier Yáñez. "A coloring fuzzy graph approach for image classification." *Information Sciences* 176.24 (2006): 3645-3657.

[31]. Keshavarz, Esmail. "Vertex-coloring of fuzzy graphs: a new approach." *Journal of Intelligent & Fuzzy Systems* 30.2 (2016): 883-893.

[32]. Rosyida, Isnaini, Ch Indrati, and Kiki A. Sugeng. "A new approach for determining fuzzy chromatic number of fuzzy graph." *Journal of Intelligent & Fuzzy Systems* 28.5 (2015): 2331-2341.

[33]. Samanta, Sovan, et al. "Completeness and regularity of generalized fuzzy graphs." *SpringerPlus* 5.1 (2016): 1-14.

[34]. Samanta, Sovan, and Biswajit Sarkar. "A study on generalized fuzzy graphs." *Journal of Intelligent & Fuzzy Systems* 35.3 (2018): 3405-3412.

[35]. Sebastian, Arya, John N. Mordeson, and Sunil Mathew. "Generalized fuzzy graph connectivity parameters with application to human trafficking." *Mathematics* 8.3 (2020): 424.

[36]. Boudaakat, Sidina, Mohamed Amine Basmassi, Ahmed Rebbani, Jihane Alami Chentoufi, Lamia Benameur, and Omar Bouattane. "Intersection modeling using generalized fuzzy graph coloring." In *The Proceedings of the Third International Conference on Smart City Applications*, pp. 1479-1489. Springer, Cham, 2020.

[37]. Kim, Yeeun, Seongjin Choi, and Hwasoo Yeo. "Extended Urban Cell Transmission Model Using Agent-based Modeling." *Procedia Computer Science* 170 (2020): 354-361.

[38]. Lewis, Ted G. *Network science: Theory and applications*. John Wiley & Sons, 2011.

[39]. Rosyida, Isnaini, Ch Rini Indrati, and Diari Indriati. "On fuzzy chromatic number of join of fuzzy graphs with an application." *2018 International Symposium on Advanced Intelligent Informatics (SAIN)*. IEEE, 2018.

[40]. Krajzewicz, Daniel, Jakob Erdmann, Michael Behrisch, and Laura Bieker. "Recent development and applications of SUMO-Simulation of Urban MObility." *International journal on advances in systems and measurements* 5, no. 3&4 (2012).