# Analysis of Simulated Annealing Algorithm to Decongest Traffic in a Multi-Road Coordinated Intersection

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**ORIGINAL RESEARCH**

**Abstract-** Since it increases the likelihood of accidents and has a bad influence on the environment, researchers are constantly working nonstop to find solutions to the problem of traffic congestion on the roads. However, it is necessary to have a solution for coordinated cases with enhanced assumptions even as some of them have employed isolated junctions (cross or T) junctions. In this paper, we focused on MATLAB for simulation using Simulated Annealing (SA) Algorithm as the scheduling algorithm. We created an objective function which in turn generated the fitness values using an equation, while the traffic model consisted of 14 radio buttons, 12 text boxes and edit boxes splitting into a cross road and adjoining T-junction separated by a distance to make it coordinated. There were six traffic phases after the signal time cycle, each displaying the decongestion time and fitness function. In Case 1, the decongestion time ranged between 9 and 41 seconds, whereas the second's ranged between 2 and 58 seconds. Further analysis revealed the relationships between generated fitness values and decongestion times. Another table was designed to show the analysis of the lanes' decongestion times, the phases and cycles involved. It was shown that the six lanes were touched in at most two cycles in the two cases considered. In future, researchers should compare the theoretical values to real-life cases, including emergency conditions (ambulance & police vans), consideration of amber signals and hybridisation with other algorithms.

**Keywords-** Coordinated intersection, cycle, simulated annealing, traffic congestion, traffic model

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## 1 INTRODUCTION

A common theme in engineering is the necessity to handle optimisation problems related to traffic congestion (Bala *et al.*, 2022; Zhai *et al.*, 2022; Akinola *et al.*, 2016). Despite the fact that many analytical and numerical optimisation strategies have been developed (Haddouch *et al.*, 2019), there are still sizable sets of functions that provide major challenges for both analytical and numerical methods. In addition to the high expenses associated with lost productivity time, traffic jams significantly increase the likelihood of accidents and have a negative impact on the environment (Amer *et al.*, 2019; Priambodo *et al.*, 2021). Due to more frequent idling, accelerating, and braking, they waste fuel and produce more air pollution. These also result in stress and frustration of commuters and/or motorists. When too many vehicles try to use a single, constrained transportation infrastructure, road traffic congestion results (Ganiyu *et al.*, 2011).

Kirkpatrick and colleagues introduced the Simulated Annealing (SA) technique in 1982 (Kirkpatrick *et al.*, 1983). Simulated annealing was defined by Jeffheaton (2008) as a programming technique that makes an effort to mimic the actual annealing process. As a benefit, SA shows convergence to the best solution to a problem, such as traffic congestion (Akinola *et al.*, 2016). It also functions as a hill-climbing search technique that occasionally permits advances in less advantageous goal directions to evade nearby minima. The algorithm is typically not any quicker than its counterparts, though (Mohammad, 2008). This study focuses on using a soft computing technique (SA), even as different approaches had been applied to road traffic management - traffic wardens (Ndoke, 2006) and traffic lights (Gottlich and Ziegler, 2014). This is consistent with dynamic traffic control's intention to lessen traffic congestion in modern cities, which has a negative impact on people's quality of life and surroundings, in addition to providing fairness among traffic flows that may result in long queues and increased delay in commuting.

Our proposed SA algorithm considered two cases (1 and 2) having short and long distances respectively using MATLAB, and thereafter evaluating its performance.

## 2 LITERATURE REVIEW

### 2.1 RELATED WORK

Qi *et al.* (2020) used the Particle Swarm Optimisation approach to build a coordinated intersection signal for mixed traffic flow of Human-Driven and Autonomous cars utilising a loop detector (sensor) and mixed flow platoon dispersion model. Nittymaki and Pursula (2000) had also applied fuzzy logic to traffic signals at the intersection. Similarly, Wunderlich *et al.* (2008) proposed a maximal weight matching algorithm that lowered the average vehicle delay greatly using Lyapunov function - based analysis. They used a cross road intersection instead. Similar to this, Haddouch *et al.* (2019) used, for the sake of highway traffic modelling, the work of Nagel and Schreckenberg (1992). Additionally, More *et al.* (2016) presented research on the use of Artificial Neural Networks to estimate road traffic; hence reducing congestion and enhancing traffic flow.

Considering software complexity and simulation duration, using MATLAB version R2015a, Oyeleye *et al.* (2020) assessed the effectiveness of the Genetic and SA Algorithms. The results revealed that the runtimes for Genetic Algorithm (GA) and SA were 11.23s and 6.20s,

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**Section B-** ELECTRICAL/COMPUTER ENGINEERING & RELATED SCIENCES
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respectively. The GA outperformed the SA in the majority of the analysed parameters, according to these authors (Oyeleye *et al.*, 2016). But in a different study, Akinola *et al.* (2016) used MATLAB to carry out an experiment comparing the GA and the SA on a crossroad and a neighbouring T-junction. The time it took for traffic to clear throughout ten cycles of fitness values was recorded. The time it took for traffic to clear throughout ten cycles of fitness values was recorded. A statistical T-test was then used to compare the data, which revealed that SA had a longer decongestion time than GA, with peak values of 51 and 48 seconds, respectively. Despite mean disparities between the two strategies, the statistical analysis revealed that there were no statistically significant variations in how well each performed.

Nunes *et al.* (2021) proposed an SA approach to solve the Multi-objective Bike Routing challenge (BRP) in order to find a solution to the challenge. The methodology was put to the test in real-world use cases and was successful in producing a number of high-calibre solutions. On Intelligent Traffic Control, Okoh *et al.* (2022) proposed a 4 Input/Output Programmable Logic Controller (PLC) in application to circuitry of a traffic light system. This provided feedback based on the signal from the input sensors linked to the PLC. The controller was an Allen Bradley MicroLogix 1000 PLC, along with a decade counter (4017), 555 timers, and light-emitting diodes (LEDs). The outcomes demonstrated that the strategy demonstrated a distributed and orderly flow of automobiles. Meanwhile, Liu *et al.* (2021) married prediction and optimisation algorithms together when, for them to achieve a prediction performance of greater accuracy, they suggested a model that combines the seasonal support vector regression model and the chaotic cloud simulated annealing process. In the same vein, Lavander *et al.* (2021) proposed a heuristic solution to the aviation sector when selective simulated annealing was developed to fix traffic assignment in the industry.

In addition, Amer *et al.* (2016) developed a technique for calculating optimal traffic routes dynamically, when the suggested approach is used to discover the best paths in two test situations in Birmingham and Sheffield, both in the United Kingdom, using two variables (the length of roads and the average traffic's travel speed). A novel approach to determining the best vehicle routes was put forth by Amer *et al.* (2019), who used a cost function of the VIKOR type to identify the best paths. Ola *et al.* (2014) had solved the challenge of road traffic intersection, an isolated and T-type intersection using MATLAB as a simulation tool. Though their work is similar to this, it differs because they do not consider a coordinated intersection (four -way with an adjoining T), in addition to updated assumptions and consideration of two cases in the proposed work. Compared with Akinola and Abdulhameed (2016), this work is equally different as they considered two algorithms (GA and SA), and this has updated assumptions. Earlier, Hong (2011) did provide a traffic flow model that anticipates inter-urban traffic flow using a combination of the seasonal support vector regression model and chaotic SA method (SSVRCSA). In other works, researchers had developed a SA and reinforcement learning (RL) algorithms-based hybrid intelligent control to reduce the congestion issues in asynchronous transfer mode (ATM) networks (Li *et al.*, 2007).

## 2.2 THEORETICAL BACKGROUND

### 2.2.1 The S.A. Algorithm

SA is a technique that helps in solving an optimisation problem. It was heralded by Kirkpatrick and his co-workers (Kirkpatrick *et al.*, 1983), following its imitation of the process of annealing (Akinola *et al.*, 2016). Different definitions are required when discussing the main components associated with an SA algorithm for optimisation issues. Assuming the solution space equals $\boldsymbol{\Omega}$ (i.e., the collection of every potential answer). Equally, if an assumption is made that an objective function is defined on the solution space. It is intended to identify a variable for the global minimum $\boldsymbol{\omega}^*$ such that for all $\boldsymbol{\Omega}$. A condition, binding the objective function to ensure that $\boldsymbol{\omega}^*$ exists must be met (Henderson *et al.*, 2006). Figure 1 shows the pseudocode of SA:

```
Pick a beginning solution $w \in \pi$
Identify the counter for temperature change $k = 0$
Pick a schedule for temperature cooling, $t_k$
Identify a starting temperature $T = t_0 \geq 0$
Identify a schedule for repetition, $M_k$defining the iterations number processed at each temperature, $t_k$
Repeat
    Set counter for repetition,$m = 0$
    Repeat
        Function generates a new solution $w^1 \in N(w)$
        Calculation of $\Delta w.w^1$= $f(w^1) - f(w)$
        If $\Delta w.w^1 \leq 0$  $w \leftarrow w^1$
        If $\Delta w.w^1 > 0$  $then\ w \leftarrow w^1$ with probability $exp\left(\frac{-\Delta w.w^1}{t_k}\right)$
        $m \leftarrow m + 1$
    $Until\ m = M_k$
    $k \leftarrow k + 1$
Until criterion to stop is achieved
```

Fig. 1: Simulated Annealing Pseudocode (Henderson *et al*., 2006)

## 3 METHODOLOGY

Representing the problem mathematically was the first step, thereafter, implementing the algorithm implemented using MATLAB 2018a, while it was run on an HP 630 laptop having 2.20GHz, Intel(R) Pentium(R), dual core, 2 Logical Processors and 4 Gigabytes (GB) of Random Access Memory (RAM). Those who read this article could do repetition of the results on any laptop with the MATLAB program.

### 3.1 SYSTEM DESIGN

In designing the coordinated traffic intersection, the following assumptions were made: Traffic lights were solar-powered, widths of lanes were equal and double lanes were considered. Fitness or objective values were generated by SA using equation 3.1 below. The interface of the traffic model (coordinated intersection) as shown in figure 2 was developed using the Graphical User Interface of MATLAB. For the crossroad, the vehicles had three possible directions of movement, while the vehicles in the adjoining T-junction had two directions of movement (as in figure 2). Two cases were involved ($d_1 \geq 500$m and $d_2 \leq 100$m) for cases 1 and 2 respectively, although the same interface was used for both. Equally assumed were possession of equal settings in dynamic properties: rates of change of displacement, velocity and negative acceleration. We adopted the design constraints chosen by Akinola *et al.* (2016) after updating their assumptions. However, we adopted the Single-Lane Queue Length Model (Ding *et al*., 2021) for distributing signals across the lanes from the system: the total number of vehicles in the final queue entrance is equal to both the number of vehicles now held and the total number of vehicles held in the previous cycle (as illustrated in figure 2).

## 3.2 MATHEMATICAL MODEL

The number of lanes participating must be six (6) maximum iteration number = 100

$$f = inline(20C_1^4 + 16C_2^2) \text{ where c = cycle} \quad (1)$$

$$T_i = \left(\frac{K}{K_{max}}\right)^q \quad (2)$$

where q=cooling/quenching factor

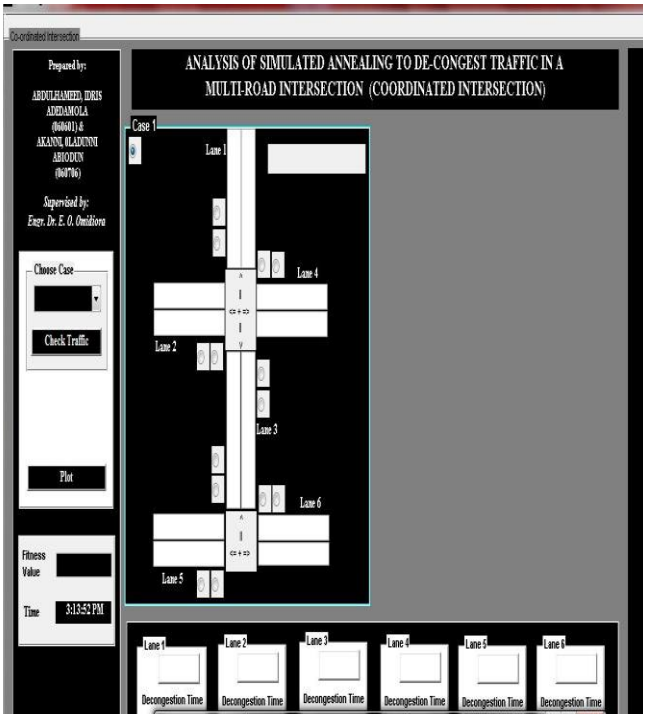
```
Set the number of cycles, Cy =  0 (initialising);
Pseudorandom function to checks for the busiest lanes;
The busiest lanes are checked by the system;
Traffic signal activated (GREEN or RED) on the lane with busiest value
While N>= Cy Do
Fitness value and decongestion time for the active lane are generated;
REPETITION process
New set of numbers are randomised;

For kk = 1 to (kkmax+1) DO

Temperature = tt

$tt = \left(\frac{K}{K_{max}}\right)^{qq}$

mu = 10^(Ti*100);
kkmax = 100; qq=1; fx1=feval (f,x1); df = fx1-fx;
UNTIL the lower boundary is achiever;
 stop;
```



ANALYSIS OF SIMULATED ANNEALING TO DE-CONGEST TRAFFIC IN A MULTI-ROAD INTERSECTION (COORDINATED INTERSECTION)

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Time 3:13:52 PM

Fig. 2: Designed coordinated intersection

## 3.3 SIMULATED ANNEALING

### 3.3.1 Flow Chart

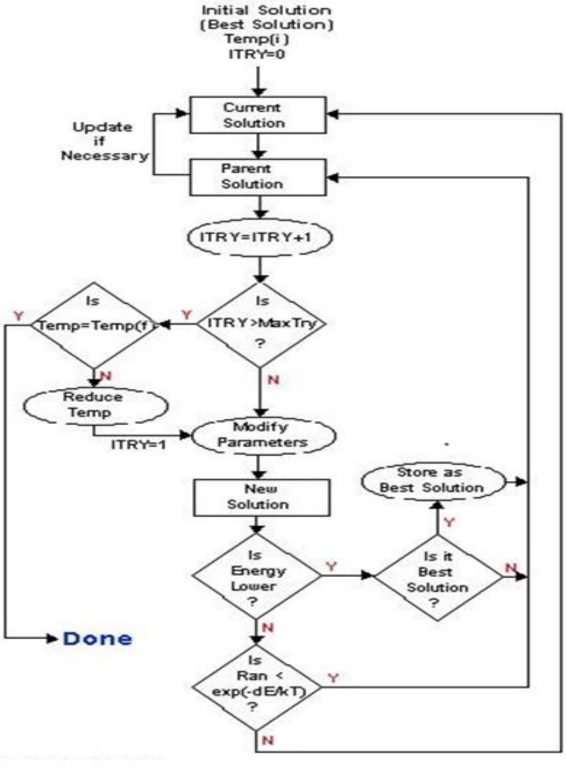

Fig. 3: Standard Simulated Annealing Flow Chart (Luke, 2002)

Figure 3 depicts the standard SA flow chart. This shows the variables and constant: iteration, Botzman constant, conditionals, best solution and reduced temperature methods. This original concept was adapted in our work as shown in the code snippet below:

```
dyy = mv_inv(2*rand(size(CARS))-
1,mupperb).*(upperb - lowerb); %upperb = upper
boundary %lowerb = lower boundary
x11 = CARS + dxx; %next guess
x11= (x11 < lowerb).*lowerb +(lowerb<=
xlowerb).*(xlowerb <= upperb).*xlowerb+(upperb<
xlowerb).*upperb;
fxx1 = feval(f,xlowerb); dff = fxlowerb- fxx;
if dff < 0 | rand < exp(-Ti*dff/(abs(fx) + eps)/TolFun)
CARS = xlowerb; fxx = fxlowerb;
end
if fo>fx, xo = CARS; fx1=fo; end % xo is the initial
guess
end
```

Following the above snippet, guessing was done using a function called x11, and a randomised number of vehicles were inputted on the lanes (1-6) when the user clicked "check traffic" on the interface. Equally, the boundary conditions were set using the "lowerb" and "upperb" because this is how the annealing can be achieved. The initial temperature and cooling factor were set too.

### 3.3.2 The Objective (Fitness) Function

A vector with a length equal to the entire number of independent variables should be provided as the function's input, and it should return a scalar as its result. For vectorized solvers, the function should accept a matrix (where each row corresponds to one input vector) and output a vector of values as the objective function (MathWorks, 2011).

The equation (1) above outputs the fitness value on the completion of the cycle following the standard SA flowchart. On completion of the traffic decongestion process, the duration covered is recorded and that is referred to as decongestion time (seconds). Each lane has its decongestion time which is stated after traffic decongestion completion.

## 4 RESULTS AND DISCUSSION

The details of the simulation are captured in tables 1 and 2, and graphically as shown in Figure 4.

Table 1. Fitness Value vs. Time to Decongest (Case 1)

| Fitness value | Time to Decongest (s) |
|---|---|
| 0.9146 | 41 |
| 0.007200 | 9 |
| 0.1412 | 11 |
| 0.1001 | 10 |
| 0.7569 | 41 |
| 0.3711 | 11 |

Table 1 showed the relationship between the fitness value (four significant figures) and decongestion time generated by the model in the first case. The fitness values fell within the range of 0 and 1, meaning probability was confirmed. However, there were repetitive values in the decongestion time 41s and 11s.

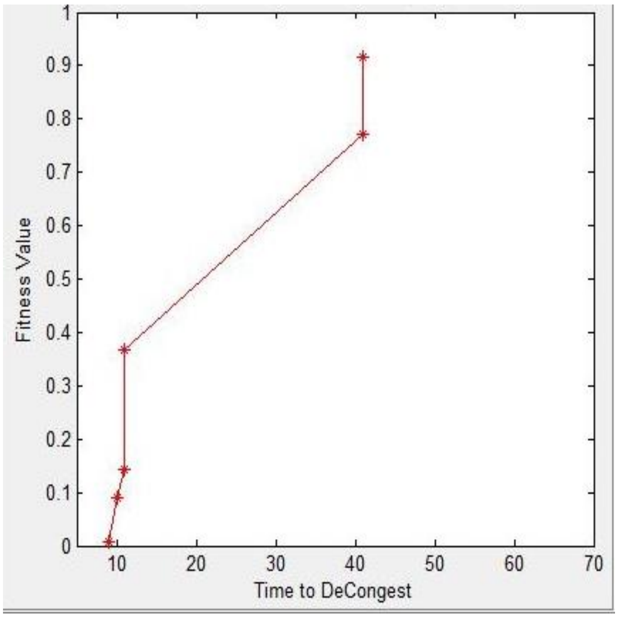

Fig. 4: Plot of Fitness values against Time to Decongest (case 1)

Figure 4 showed a sharp increase in decongestion time was observed from 9s to 41s; hence, a haphazard graph was seen.

Table 2. Fitness Value vs. Time to Decongest (Case 2)

| Fitness value | Time to Decongest (s) |
|---|---|
| 0.1423 | 2 |
| 0.4372 | 18 |
| 0.5789 | 30 |
| 0.2501 | 15 |
| 0.7750 | 58 |
| 0.6458 | 44 |

Table 2 also conformed to the probabilistic technique in the fitness values. Accordingly, figure 5 showed a direct proportionality between the fitness values and decongestion times. The fitness values obtained were between 0 and 1 in all and decongestion time between 0 and 70 in all. By calculating the average, the results were (20.5seconds, 0.3816) and (27.8seconds, 0.4733) for cases 1 and 2 respectively. This showed that case 2 had a better result because of the average fitness value to case 1 though with slightly higher decongestion time.

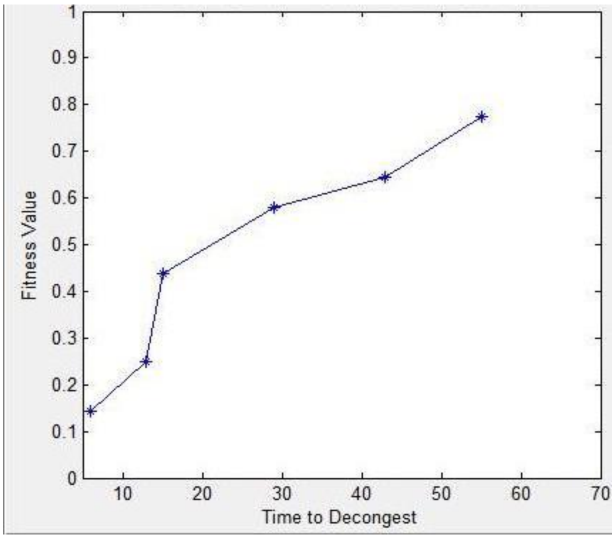

Fig. 5: Plot of Fitness values against Time to Decongest (case 2)

Furthermore, table 3 showed the output of decongestion time, phases and cycles for the first case. It was shown that data generated at this stage was much because it focused on achieving a cycle. According to table 3, six cycles were involved to complete the traffic decongestion, however, it took the system eight cycles for the second case; different phases had different decongestion times.

Table 3. Description of decongestion time, phases and cycles (Case 1)

| S/N | Decongestion Time (s) | Phases Involved (Lanes) | Cycles |
|---|---|---|---|
| 1 | 41,09,37,07,35,04 | 2,4,3,5,1,2 | 1 |
| 2 | 09,38,06,35,04,32 | 6,2,5,1,2,4 | |
| 3 | 33,02,31,59,28,57 | 3,6,2,1,4,1 | 2 |
| 4 | 52,21,50,18,47,15 | 2,1,4,3,5,6 | |
| 5 | 25,48,13,41,10,39 | 4,1,2,6,3,5 | 3 |
| 6 | 11,41,14,31,18,50 | 3,1,5,4,6,2 | 4 |
| 7 | 28,56,13,20,05,23 | 1,3,2,2,5,4 | 5 |
| 8 | 39,10,41,13,23,26 | 1,2,5,6,3,3 | |
| 9 | 33,09,57,22,51,29 | 3,1,6,5,5,5 | 6 |
| 10 | 26,55,23,48,13,41 | 3,2,4,1,6,2 | |

Table 4 Description of decongestion time, phases and cycles (Case 2)

| S/N | Decongestion Time (s) | Phases Involved (Lanes) | Cycles |
|---|---|---|---|
| 1 | 38,06,12,43,44,09 | 2,4,3,5,1,6 | 1 |
| 2 | 70,30,15,24,20,50 | 4,3,2,1,5,6 | 2 |
| 3 | 43,32,12,23,30,62 | 1,2,3,6,4,5 | 3 |
| 4 | 39,24,29,15,23,38 | 6,6,5,4,3,1 | 4 |
| 5 | 16,25,36,19,42,17 | 2,3,2,5,6,1 | |
| 6 | 19,37,62,44,50,36 | 1,2,6,5,4,3 | 5 |
| 7 | 33,42,38,61,15,22 | 5,4,3,2,1,6 | 6 |
| 8 | 35,65,20,34,05,23 | 1,2,3,5,4,6 | 7 |
| 9 | 37,25,39,21,27,36 | 3,4,4,1,2,6 | 8 |
| 10 | 19,42,15,24,32,16 | 2,5,1,6,4,5 | |

Table 4 proved that if the whole lanes were not touched in the first cycle, then they must all be touched in the second one. For example, "2,4,3,5,1,6" showed all the lanes were touched in cycle "1", while "6,6,5,4,3,1" and "2,3,2,5,6,1" showed the lanes were touched in cycle 4.

## 5 CONCLUSION

In this work, the vehicles on the lanes were randomly generated following the adoption of the standard simulated annealing algorithm. Also, there was generation of objective values and decongestion times were generated and plotted against one another for the two cases considered.

It was found out that the second case (with shorter distance) had more decongestion time against the first one because of the imminent congestion experienced there. On the other hand, the fitness values in the first case (with longer distance) were more compared to the other.

Future studies should compare the theoretical values to real-life cases, the scheduling algorithm should cater for emergency conditions and researchers should consider the amber signal in the simulated traffic control system. The anomalies being referred to in the conclusion could be resolved if hybridisation of other algorithms such as Particle Swarm Optimisation, A* algorithm, Genetic Algorithm with real-time signalised control.

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