Smoothing Speed Variability in Age-Friendly Urban Traffic Management

José Monreal Bailey[1][0000−0003−0080−6779], Hadi Tabatabaee Malazi[1][0000−0002−2960−6896], and Siobhán Clarke[1][0000−0001−5721−9976]

University of Dublin Trinity College, Dublin, Ireland
{monrealj,tabatabh}@tcd.ie
Siobhan.Clarke@scss.tcd.ie

Abstract. Traffic congestion has a negative impact on vehicular mobility, especially for senior drivers. Current approaches to urban traffic management focus on adaptive routing for the reduction of fuel consumption and travel time. Most of these approaches do not consider age-friendliness, in particular that speed variability is difficult for senior drivers. Frequent stop and go situations around congested areas are tiresome for senior drivers and make them prone to accidents. Moreover, senior drivers' mobility is affected by factors such as travel time, surrounding vehicles' speed, and hectic traffic. Age-friendly traffic management needs to consider speed variability in addition to drivers' waiting time (which impacts fuel consumption and travel time). This paper introduces a multi-agent pheromone-based vehicle routing algorithm that smooths speed variability while also considering senior drivers during traffic light control. Simulation results demonstrate 17.6% improvement in speed variability as well as reducing travel time and fuel consumption by 11.6% and 19.8% respectively compared to the state of the art.

Keywords: Age-friendly cities · Vehicle routing · Adaptive signal control · Collaborative signal control · Collaborative vehicle routing · Multi-agent systems · Smart city.

1 Introduction

The reality of ageing populations requires significant transformations to twenty-first-century living. There are implications for many sectors, including urban services and transportation [1]. Senior drivers feel uncomfortable in hectic traffic, and the risk of being in a car accident has a direct impact on their decision to quit driving [21]. They usually drive slowly and have a high reaction time to traffic events [5, 12, 16]. An age-friendly smart traffic management system could make senior drivers more confident in traffic, which is important for their well-being.

Smart traffic management systems (STMS) improve traffic flow, minimise traffic congestion and crash rate by applying strategies for vehicle routing and adaptive signal control. While drivers aged over 75 have the highest crash rate of all age groups [6], speed variability is positively correlated with crash frequency

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1

[19, 20]. Therefore, one of the key factors in improving traffic flow for senior drivers is to decrease speed variability. We define the speed variability of a road as the standard deviation of the speed of the vehicles driving on that road at a particular time. A high level of speed variability shows frequent acceleration and deceleration, which leads to an increase in accident risks, especially for senior drivers. Additionally, a vehicle's fuel consumption increases in a *stop and go* mode, with a consequent increase in CO2 emissions, compared to smooth movement at a constant speed. Moreover, a smooth driving speed is a more pleasant mobility experience even on heavy traffic roads. While much of the related research on STMS focuses on reducing waiting time, the main objective of this work is to reduce speed variability without affecting waiting time.

Researchers have applied a wide range of techniques to mitigate vehicular traffic congestion, such as bee colonies [14], integer linear programming [3], pheromones [4, 9, 18], collaborative multi-agents [2], and reinforcement learning [22]. Some are centralised and prone to a single point of failure, while others require drivers to share their final destination as well as their planned route. In general, research has concentrated on shortening travel and wait time, reducing fuel consumption and greenhouse emissions [15, 18]. There has been limited focus on considering the special needs of senior drivers. In our previous work, we devised a collaborative multi-agent adaptive signal control model to reduce wait time and fuel consumption for senior drivers [2]. However, this was insufficient, as speed variability is also a key factor for such drivers.

In this paper, we propose CoMAAPRAS, which is an age-friendly traffic control system. It adapts to environment changes using a pheromone-based and collaborative multi-agent model. It is based on CoMASig [2], which improves senior drivers' waiting time by extending green light times. CoMAAPRAS extends this model by enabling vehicles to take routes that contribute to reducing speed variability and the accumulative waiting time of senior drivers. Our method uses bio-inspired concepts to reduce speed variability and provide an age-friendly smart traffic light planning system. The model is adaptive, using decentralised, real-time decision-making, without requiring route information from drivers.

2 Related Work

An urban traffic management system can be defined as a large scale, dynamic and decentralised multi-agent system, where vehicles and infrastructure are represented by agents. The interaction among agents can be: (i) homogeneous, where only agents of the same type communicate and make decisions based on the information shared; (ii) heterogeneous, where only agents of different type communicate and take actions; (iii) both, where agents interact with every agent type, share information and make decisions based on that information.

In this section, we review work that addresses different traffic problems, in particular, traffic congestion, and vehicles' fuel consumption and their waiting time. In general, current approaches use vehicle re-routing [3, 7, 14, 18] and urban traffic light control [2, 11, 22] strategies to address traffic problems. For example,

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1

Cao et al. studied a combination of arrival and total travel times with a semi-decentralised multi-agent based method [3]. Infrastructure agents are responsible for route guidance at each junction by solving a route assignment problem. The method reformulated route assignment as a Mixed-Integer Linear Programming (*MILP*) problem to achieve computation efficiency. A weighted quadratic term is used to minimise the expected travel time according to the potential route assignment. *Arriving on time* is formulated as a probability tail model to maximise the probability of arriving before the deadline. In other words, they incorporate a quadratic term into the objective function of the original arriving on-time problem. *Ng* et al. introduced two Multiple Colonies Artificial Bee Colony (*MC-ABC*) algorithms for online vehicular routing [14]. They provided a flexible re-routing strategy for scheduled logistics to reduce the risk of late delivery. Their methods balance the exploitation and exploration of the original bee colony, and simulation results show that this approach outperforms other artificial bee colony algorithms by avoiding getting trapped in local optima. *Soon* et al. introduced the Eco-friendly Pheromone-based Green Vehicle Routing (*E-PGVR*) strategy [18]. The main focus is on reducing fuel consumption and greenhouse gas emissions by providing green waves to vehicles based on the pheromone intensity of each road. This work assumes fixed traffic light timing and fully connected vehicles. Communication between traffic light agents and intelligent vehicle agents is made through road supervisor agents. The authors argue that similar pheromone-based methods tried to alleviate traffic congestion by rerouting vehicles to routes with lower intensity of pheromone, but the vehicles may still suffer from multiple red signalised junctions. To tackle this problem, the chances for paths with multiple green signalised junctions was increased. To address scalability, the authors also devised a decentralised Hierarchical Multi-Agent Pheromone-based System (*HMAPS*), which uses local dynamic traffic information of m-hops downstream. They also introduced a modified dynamic k-shortest path for path assignment that reduces the computation load. It is worth pointing out that a fixed traffic light program can generate unnecessary waiting times for vehicles at the junctions.

We previously introduced a Collaborative Multi-Agent Signal control algorithm to support senior drivers, called (*CoMASig*) [2]. We focused on senior drivers' special needs and characteristics to improve their driving experiences. Vehicles communicate with traffic signals enabling them to autonomously adjust the phase timing based on the road demand and the proportion of senior drivers. However, our findings were that speed variability was exacerbated in the presence of senior drivers. *Zhou* et al. described an Edge-based Reinforcement Learning algorithm (*ERL*) that optimises traffic lights in real-time by employing edge servers [22]. The low latency edge servers provide a fast computation means for deep neural network training and control feedback. The servers collect local traffic data and aggregate it with the received data from neighbouring edge servers. The approach partitions urban traffic into hierarchical levels of junctions, neighbours, and districts. The modular approach facilitates fine-grained optimisation, with the optimisation processing performed at the three levels in parallel. The

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1

extra communication with edge servers and also the cloud may add overhead to the network and affect its performance. Their work limits vehicles' lane-change capability and focuses on the average speeds, which may hide extreme values.

Current research in vehicle traffic re-routing focuses on the reduction of travel time, waiting time, fuel consumption, and greenhouse gas emissions. Different types of drivers (e.g., senior drivers, young drivers) are generally not considered. The current work shows that traffic policies are used to improve traffic congestion, travel times, fuel consumption and greenhouse gas emissions. However, speed variability has not been evaluated as a required feature for an age-friendly urban traffic management system.

3 System Model

We model a traffic network as a grid of 4 by 4 junctions and 16 traffic lights (Fig. 1a). The roads are two way, have 3 lanes each way, and have the same length l. Each *traffic light* ($\mathrm{tl}_{(i,j)}$) controls the incoming traffic flow of the roads to the junction. We refer to these roads as the controlled roads of traffic light $tl_{(i,j)}$. Each traffic light uses the standard NEMA dual-ring, eight-phase structure. There are eight movements at each junction. Fig. 1b shows the four phases per ring in a traffic light. The barrier exists to avoid conflicting movements between groups, which means that all phases in one group must end before the next group starts. Each traffic light establishes a neighbourhood composed of all traffic lights at one junction distance. Fig. 1a shows an example of neighbourhoods in which a blue dotted circle and a red dotted circle depicts the neighbourhood of TL7 and TL6 traffic lights respectively. Eq. 1 shows the set of neighbourhood traffic lights for $tl_{(i,j)}$ which is denoted as $N(tl_{i,j})$. A traffic light is modelled as a collaborative agent, which can send/receive messages to/from other traffic lights within its neighbourhood set, and vehicles within the communication range.

$$N(tl_{i,j}) = \{tl_{(k,l)} | (k = i \wedge (l = j - 1 \vee l = j + 1)) \vee (l = j \wedge (k = i - 1 \vee k = i + 1))\} \quad (1)$$

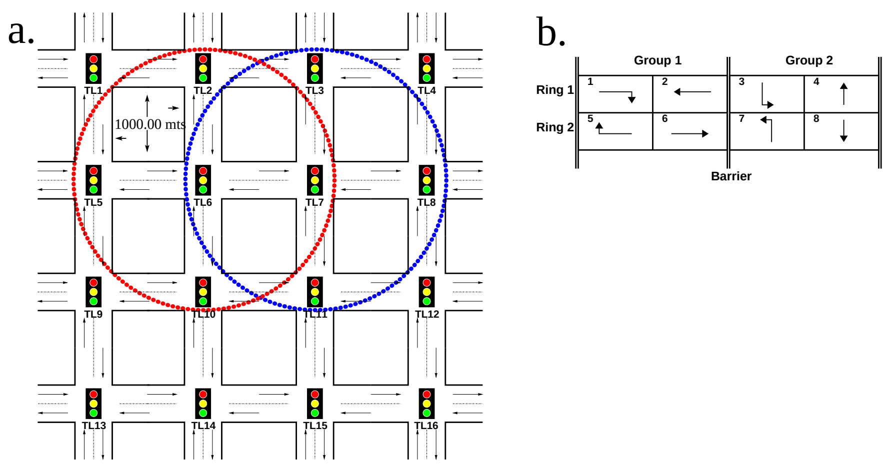

Fig. 1: a. Layout of 4 by 4 grid road network. b. Dual ring, 8 phase controller.

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1

A vehicle is denoted by v_x where x is its identifier. A v_x starts its trip at time t_{start} and reaches its destination at t_{end}. The speed of a vehicle is s_x^t where t is the time epoch. Similarly, the location of a vehicle v at time t is denoted by $l(v, t)$, and it is part of a controlled road. A vehicle is also modelled as an agent, and each vehicle agent (v_x) communicates only with the traffic light ($\mathrm{tl}_{(i,j)}$) that controls the road on which it is travelling. This process is performed periodically (i.e., every $10s$) to get a significant value while, at the same time, maintaining a good performance. Every v_x communicates with its relevant traffic light through message transfer. Each v_x subscribes to the $\mathrm{tl}_{(i,j)}$ that controls the road on which the vehicle is currently driving, and it unsubscribes when it leaves that road.

There are two types of drivers in the system: d_{yd} *young drivers* and d_{sd} *senior drivers*. $d(v_x)$ denotes the driver type of vehicle v_x. Each driver type has a maximum speed. SMax_{yd} and SMax_{sd} are the maximum speed for driver type d_{yd} and d_{sd} respectively. Similarly, each driver type has a reaction time (rt_{yd} and rt_{sd}) defined as the decision-making time of a driver.

The speed variability of a controlled road at time t is defined as the standard deviation of the speed of all vehicles moving on that road at time t. Eq.2 shows the formal definition of speed variability, where N and $\overline{s_{cr}}$ are the number and average speed (Eq.3) of the vehicles on the controlled road cr at time t.

$$SV_{cr}^t = \sqrt{\frac{1}{N-1} \sum (s_i^t - \overline{s_{cr}})^2} \quad (\forall v_i : l(i,t) \in cr) \tag{2}$$

$$\overline{s_{cr}} = \frac{1}{N} \sum_{\forall i : l(i,t) \in cr} s_i^t \tag{3}$$

The *current waiting time* of vehicle x is defined as the accumulative time that a driver moves below $0.1m/s$ from the moment it started its trip to the current time, and voluntary stops (i.e., stops not caused by congestion) are not considered. The current waiting time is denoted by $\mathrm{t}_{(tw,x)}$ where x is the vehicle ID (Eq.4). Similarly, *total waiting time* ($\mathrm{T}_{(tw,x)}$) is the accumulative waiting time of vehicle x on the whole trip.

$$t_{(tw,x)} = \sum_{s_x^m < 0.1} |t_m| \qquad (\forall t_m : t_{start} \leq t_m \leq now) \tag{4}$$

The *travel time* of a vehicle x is the amount of time the vehicle needed to reach its destination. The *fuel consumption* of a vehicle x corresponds to the total amount of fuel spent by the vehicle on the whole trip.

The objectives of the age-friendly traffic light system are to minimise speed variability (Eq.5) while reducing total waiting time (Eq.6) for senior drivers.

$$\mathcal{M}in \sum_{\forall cr} SV_{cr}^t \tag{5}$$

$$\mathcal{M}in \sum_{\forall x : d(v_x) = d_{sd}} T_{(tw,x)} \tag{6}$$

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1

4 CoMAAPRAS

The CoMAAPRAS system works with two types of agents: vehicle agents v_x and traffic light agents $\mathrm{tl}_{(i,j)}$. This section describes how the system uses pheromones to calculate both the speed variance in a controlled road and waiting time for senior drivers. It also describes the traffic policies that are implemented based on these two values - for example, when to change the lights, or re-route vehicles.

CoMAAPRAS is based on ant-colony optimisation, using the pheromone idea of ants going through different paths to find the shortest one. Vehicle agents communicate their speed and waiting time to traffic light agents, which are in control of the decrease or increase of the pheromones in the road. These pheromones help vehicle agents to find roads with slower speed variance and traffic lights to extend the green light when needed. Traffic lights manage two types of pheromones: a speed variance pheromone ($\mathrm{P}_{\hat{v}}$) and a waiting time pheromone (P_{tw}). Each of its controlled roads has a separate value for each pheromone type. For both pheromones, a high value raises a concern about the suitability of a road for senior drivers, while a low value is positive. The values for both pheromones evaporate (i.e., decrease) periodically, to adapt the system to time-related traffic conditions. Pheromone deposits (i.e., increases based on penalties) relating to negative traffic conditions are described in this section.

Speed variance: Each traffic light updates the speed variance pheromone values for each of its controlled roads from a calculation of each vehicle's speed experience, as communicated when the vehicle is within the communication range. Each v_x records its speed periodically for each control road. When it enters the communication range with the traffic light controlling that road, it sends the full vector containing these measurements and then continues to do so at each recording period. Regardless of any communication from vehicles, every t seconds, each $\mathrm{tl}_{(i,j)}$ evaporates (decreases) the values of the speed variance pheromones for all its controlled roads, at a fixed rate (e.g., 10%). This handles the case where there may be no vehicles on the road, which would be positive for senior drivers. The process then assesses whether penalties should be applied to the speed variability pheromone by examining the vehicles' submissions on their periodic speed. Each $\mathrm{tl}_{(i,j)}$ increases the $\mathrm{P}_{\hat{v}}$ by the speed variance in the controlled road (Eq. 7).

$$\mathrm{P}_{\hat{v}} = \mathrm{P}_{\hat{v}} + SV_{cr}^{t} \tag{7}$$

Waiting time: When each vehicle agent with a senior driver (v_{sd}) enters communication range with the traffic light controlling the road on which it is travelling, it, like all vehicles, sends the full vector containing the measurements of each speed recording period, and also sends a calculation of the time driving below $0.1m/s$. Each vehicle continues to send these values periodically until it leaves the controlled road. Each traffic light updates its waiting time pheromone values for each of its controlled roads from the reported waiting times. Again, to handle the situation where there are no vehicles on the road, regardless of any communication from senior driver vehicles, every t seconds each $\mathrm{tl}_{(i,j)}$ evaporates (decreases) the values of the waiting time pheromones for all its controlled roads,

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1

at a fixed rate (e.g., 10%). The process then assesses whether penalties should be applied to the waiting time pheromone, depending on the current waiting time of senior drivers on the road. Each $\text{tl}_{(i,j)}$ increases the P_{tw} proportional to $\text{t}_{(tw,x)}$ (Eq. 8).

$$\text{P}_{tw} = \text{P}_{tw}\left(1 + \frac{\text{t}_{(tw,x)}}{100}\right) \tag{8}$$

Traffic Policies: Traffic light agents use the pheromones and a set of rules to decide which traffic policy (e.g., light change or rerouting) to apply. Each $\text{tl}_{(i,j)}$ communicates with its neighbourhood as shown in Figure 1, and shares the pheromone information about its controlled roads to its neighbourhood. All neighbourhood traffic lights' information is utilised to decide as to which traffic policy to apply: (i) green light extension, (ii) vehicle re-route, (iii) green light extension and vehicle re-route, or (iv) none, as follows:

i **Green light extension:** Every traffic light compares the pheromone levels in its controlled roads. The waiting time pheromone is increased only by senior drivers. If the controlled roads in green phase have higher waiting time pheromone by a certain percentage (e.g., 10%) than in conflicting phases, then the phase is extended. Otherwise, the traffic light does not extend the green phase and switches to the next phase.

ii **Routing:** Every traffic light compares the speed variance pheromone level on all possible roads that a vehicle may enter after exiting the current road. We refer to these roads as destination roads. If the speed variance pheromone level from any of the possible destination roads differ in more than a certain percentage (e.g., 10%) then the traffic light sends a reroute message to the vehicles in the communication range. The vehicle searches for a new route with the lowest speed variance.

CoMAAPRAS has two steps: *Update Road Pheromone* and *Collaborative Decision Making*, which are explained next.

4.1 Update Road Pheromone

Vehicles send their current speed and waiting time messages periodically to their controlling traffic light when within the communication range. Each traffic light stores all incoming messages and processes them at the end of each time epoch (Algorithm 1). The traffic light processes the information depending on the message type: speed variance or waiting time. Each message contains the vehicle identifier, road identifier, and the set of values stored during its journey until the communication is established. If the message type is speed variance, then the traffic light takes the speed values from the vehicle to calculate its speed variance. Then, the traffic light updates the speed variance pheromone value given the old speed variance and the current one using Eq. 7. The traffic light also updates the speed variance for the road with the speed values from the vehicle. If the message type is waiting time, then the traffic light retrieves the

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1

Algorithm 1 Update Pheromone

```
procedure updateRoadPheromone(message)
  if message.type is speed then
    speeds ← message.vehicleSpeeds
    roadId ← message.vehicleRoadId
    newSpeedVar ← speedVariance(speeds)
    pv ← getPvFromRoad(roadId)
    pv ← pv + newSpeedVar
    setPvFromRoad(pv, roadId)
    updateSpeedVar(speeds, roadId)
  if message.type is time and message.from is sd then
    waitingTime ← message.vehicleWaitingTime
    roadId ← message.vehicleRoadId
    ptw ← getPtwFromRoad(roadId)
    ptw ← ptw * (1 + (waitingTime/100))
    setPtwFromRoad(ptw, roadId)
```

accumulative waiting time and road id from the vehicles' message. The traffic light computes the new waiting time pheromone using Eq. 8 and updates its value in the road where the vehicle is driving.

4.2 Collaborative Decision Making

Algorithm 2 Collaborative Decision Making

```
procedure applyTrafficPolicy
  greenLightExtension ← TRUE
  routing ← FALSE
  currentPtw ← getPtwFromRoad(currentRoadId)
  for each roadId ∈ tl_(i,j) do
    if roadId belongs to a conflicting phase AND greenLightExtension then
      nextRoadPtw ← getPtwFromRoad(roadId)
      if nextRoadPtw > 1.1 * currentPtw then
        greenLightExtension ← FALSE
  dRoads ← sort(destinationRoads_tl(i,j))
  if 1.1 * dRoads[first] <= dRoads[last] then
    routing ← TRUE
  if greenLightExtension then
    tl_(i,j) extend green light
    for each tl_(k,l) ∈ neighbours_tl(i,j) do
      if can tl_(k,l) collaborate? then
        tl_(k,l) applies green light extension
  if routing then
    tl_(i,j) send re-route message to vehicle
```

Each Traffic light assesses which traffic policy needs to apply from the moment vehicles come into the communication range (Algorithm 2). If a vehicle's current road waiting time pheromone is lower (e.g., by 10%) than in conflicting phases, then the green light extension is disabled. Then, the traffic light evaluates the speed variance pheromones from all possible destination roads for the vehicle. The routing policy is enabled if the speed variances on destination roads differ by a certain percentage (e.g., 10%). If the green light extension traffic policy is enabled, the traffic light will ask the neighbouring traffic lights to collaborate for a green wave, if possible. If the routing policy is enabled the traffic light will send a re-route message to the subscribed vehicle.

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1

5 Experiment Design

In this section, we introduce our evaluation scenario, the baseline methods used for comparison, and the performance metrics.

In our simulation scenario, the signal control plan sequence is fixed and we assume all vehicles can communicate with the infrastructure through a VANET. The evaluation scenario includes three congestion levels for different ratios of senior drivers. Table 1 shows the hourly traffic density in our network for low, medium, and high levels of congestion used in [8] where N, S, W, and E are the cardinal directions of the incoming and outgoing traffic flows. We used two types of driver profiles (younger drivers and senior drivers) and we do not consider any pedestrians in our simulation. The response time (rt_1) for younger drivers is set to the same value as the simulation step (1 second). Senior drivers move at a slower speed ($SMax_2 = 0.6 \times SMax_1$) and their reaction time is 40% slower than young drivers ($rt_2 = 0.6 \times rt_1$) [10]. We consider different ratios of senior drivers ($\text{ratio}_{sd} \in [0, 100]$) increasing by 20% each round per execution.

		W to E	W to S	W to N	E to W	E to N	E to S	N to S	N to W	N to E	S to N	S to E	S to W	Total
Traffic Levels	Low	1668	224	288	1848	144	448	76	560	672	72	912	320	7232
	Medium	4008	704	512	4440	352	1088	184	1488	1632	176	2208	768	17560
	High	6680	1184	864	7396	592	1824	304	2496	2720	292	3680	1296	29328

Table 1: Vehicles per hour

The model is developed using Simonstrator, SUMO v1.5, and JDK 8. Simonstrator is a network simulator that facilitates communication between agents [17]. SUMO is an urban traffic simulator that simulates different driver profiles, network layouts and traffic density. Vehicles are distributed using SUMO [13], which generates a normal distribution of the traffic flow. JDK 8 is the Java development kit version 8, which is compatible with both simulators.

The experiments are executed on a Kelvin system, a high performance compute cluster hosted and managed by the Trinity Centre for High-Performance Computing (TCHPC). Each simulation runs on a cluster node that has GNU/Linux, 2.66 GHz Intel processor, and 24 GB of RAM [1]. We execute each of our simulation configurations 11 times which gives a confidence interval of 95%.

We have compared our proposed method against three baselines that aimed at enhancing traffic performance and show improvements in traffic congestion.

Fixed signal control (FSC) is widely used today in urban areas and has a fixed time duration of the lights. The duration has been calculated in advance to improve traffic flow at each junction [8].

Eco-friendly Pheromone-based Green Vehicle Routing (E-PGVR) is a pheromone-based routing algorithm that prioritises paths with green waves to reduce fuel consumption, mean travel time, and road congestion [18]. Its performance shows it can improve vehicles journey times.

Collaborative Multi-Agent Signal Control (CoMASig) minimises the waiting time for senior drivers, while it increases the throughput at each junction [2].

[1] Kelvin details - https://www.tchpc.tcd.ie/resources/clusters/kelvin

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1

The evaluation metrics are speed variability, waiting time, time travel, and fuel consumption defined in Section 3.

6 Results

We evaluate the performance of our approach and compare it with the three baselines in 3 traffic level scenarios. We use different percentages of senior drivers (0%, 20%, 40%, 60%, 80%, and 100%) for each of the previous combinations, and present the results from our experiments with different traffic levels and driver types. We present the results for speed variability, waiting time, fuel consumption and travel time in subsections 6.1, 6.2, 6.3 and 6.4 respectively.

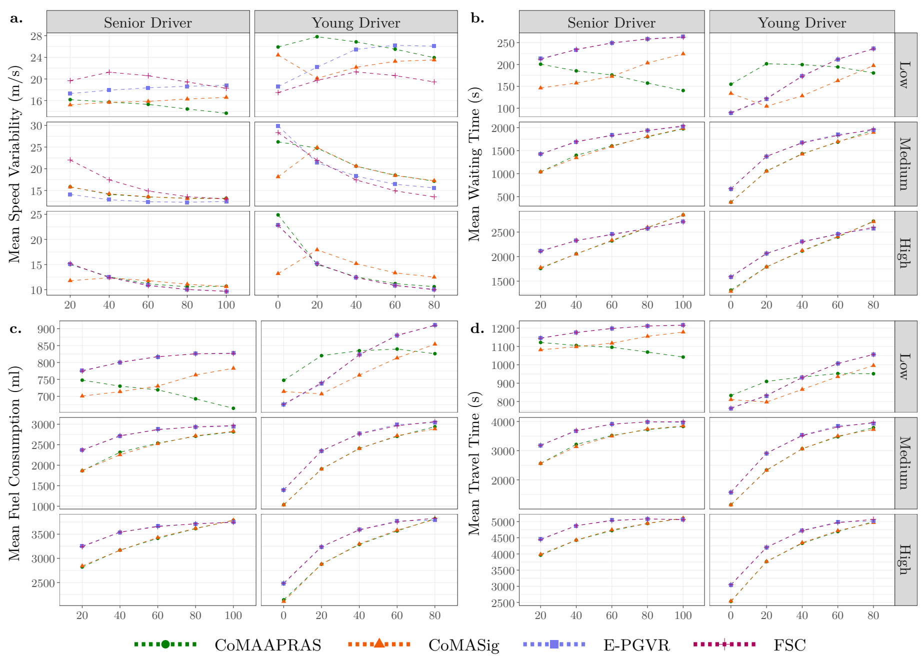

Fig. 2: Plots of performance: a.Speed variability, b.Waiting time, c.Fuel consumption and d.Travel Time, under different traffic levels. For each plot the X-axis corresponds to the percentage of senior drivers, while the Y-axis corresponds to a. the mean speed variability expressed in m/s, b. the mean waiting time in s, the mean fuel consumption expressed in ml and d. the mean travel time in s. Results are separated by driver type (Senior driver, Young driver), and traffic level (Low, Medium and High).

6.1 Speed Variability

In the low-level traffic scenario, the simulation results show that CoMAAPRAS and CoMASig perform better for senior drivers under low traffic volume (Figure 2a) since these methods explicitly consider senior drivers in the decision

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1

making of their traffic policies. CoMAAPRAS starts to diverge from CoMASig as the percentage of senior drivers in the scenario increases to over 40%. This behaviour is explained as both traffic policies in signal control extension and re-route take place more frequently. The improvements in speed variability are 3.5%, 11.4% and 17.6% for 60%, 80% and 100% of senior drivers respectively.

For the younger drivers in low-level traffic volume, FSC demonstrates the lowest speed variability since the vehicles take advantage of both optimised traffic light timing and the percentage of senior drivers. This approach does not focus on driver types but traffic flow. The results show that the speed variability in FSC starts to improve for every vehicle when the percentage of senior drivers is greater than 40%. In our proposed method, the speed variability of young drivers starts improving when the percentage of senior drivers increases from 40%. Vehicles in CoMAAPRAS are benefited from the number of senior drivers on the road plus the pheromones strategy to re-route and adapt the traffic lights timing. In E-PGVR and CoMASig methods, the speed variability for both young and senior drivers increase as the percentage of seniors drivers rises. In CoMASig, the speed variability decreases by 17.6% between 0% and 20% of senior drivers. This approach considers the overall demand on the road and minimal change in senior drivers' waiting time.

The speed variability for medium and high levels of traffic is completely different from the low-level scenario. Speed variability is not improved in CoMAAPRAS, while E-PGVR shows better performance given the optimised traffic light timing and the pheromones strategy from the ant-colony optimisation algorithm.

6.2 Waiting Time

CoMAAPRAS is the only approach that reduces the waiting time for senior drivers in the low-level traffic scenario, as the percentage of seniors increases (Figure 2b). The waiting times are improved by 22.6% and 31% when there are 80% and 100% of senior drivers in the scenario. However, CoMAAPRAS does not improve the waiting time in the medium and high-level traffic scenarios, and again, behaves almost the same as CoMASig. Waiting time is directly connected with traffic jams, as it corresponds to the time vehicles driving below $0.1m/s$. The roads controlled by each traffic light have similar speed variability pheromone levels because of the traffic jams. For this reason, CoMAAPRAS only enables the green light extension policy, which is similar to how CoMASig works. E-PGVR and FSC have similar behaviour for the different traffic levels. The reason for this is the optimised traffic light timing in conjunction with the volume of vehicles per hour entering the roads. The pheromones levels in the roads do not change much to generate a new route, in the case of E-PGVR. The majority of vehicles will drive their predetermined route just like in FSC.

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1

6.3 Fuel Consumption

The simulation results reveal that the fuel consumption in CoMAAPRAS reduces as the number of senior drivers increases for the low-level traffic scenario (Figure 2c). The reduction in fuel consumption starts from the beginning but improves from approximately 60% of senior drivers. In this case, vehicles drive more smoothly and faster which helps to considerably reduce fuel consumption. The fuel consumption decreases by 1.5%, 9.3% and 19.8% when there are 60%, 80% and 100% of senior drivers. However, CoMAAPRAS does not improve fuel consumption in medium and high-level traffic scenarios. In fact, it behaves almost the same as CoMASig. The reason for this is the traffic congestion generated by the volume of vehicles travelling on the roads. The roads controlled by each traffic light have similar speed variability pheromone levels for which CoMAAPRAS only enables the green light extension policy, which is similar to CoMASig. Likewise, FSC and E-PGVR have similar behaviour, because of the volume of vehicles per hour on the roads and the traffic light optimised timing. In the case of E-PGVR, the pheromone levels do not change vehicles route that often. Most vehicles will drive their predetermined route just like in FSC. Young drivers' fuel consumption with our proposed method does not improve between 20% and 60% of senior drivers, compared to all other approaches.

Despite that, fuel consumption is almost constant between 20% and 80% of senior drivers with CoMAAPRAS. The fuel consumption increases as the number of senior drivers increases in all other approaches. In fact, the fuel consumption improves when there are approximately 80% of senior drivers in the scenario with CoMAAPRAS. In this case, 20% of young drivers benefit from re-routed actions and traffic light time extensions.

6.4 Travel Time

CoMAAPRAS performs promising in reducing the travel time for senior drivers in the low-level traffic scenario, as their number increases (Figure 2d). This reduction starts from the beginning but it begins to improve when there are approximately 60% of senior drivers in the scenario. The travel time is improved by 2.0%, 7.4%, and 11.6% when there are 60%, 80% and 100% of senior drivers in the scenario. However, CoMAAPRAS does not improve the travel time at all in the medium and high-level traffic scenarios, and again, behaves almost the same as CoMASig. The roads controlled by each traffic light have similar speed variability pheromone levels because of the traffic jams. For this reason, CoMAAPRAS only enables the green light extension policy, which is similar to how CoMASig works. E-PGVR and FSC have similar behaviour for the different traffic levels. The reason for this is the traffic light optimised timing in conjunction with the volume of vehicles per hour entering the roads. In the case of E-PGVR, the pheromones levels in the roads do not change much to generate a new route. The majority of vehicles will drive their predetermined route just like in FSC.

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1

7 Conclusions

The growing number of senior drivers introduces new challenges for an urban traffic management system to meet their needs such as smoothing speed variability. In this paper, we addressed this challenge by devising a collaborative multi-agent age-friendly pheromone-based intelligent traffic signal control that autonomously reroutes vehicles and adapts the signal timings of the traffic controller. We evaluated the performance of our approach in speed variability, waiting time, fuel consumption, and travel time. The results reveal improvements in all of these metrics as the number of senior drivers increases in a low-level traffic scenario, while in the medium and high-level scenarios, similar performance is achieved compared to the state of the art baseline.

We assume connected vehicles in our work, but the mixture of connected and non-connected vehicles can be a topic of future work. Another limitation of our work is the fixed threshold for decision making. An adaptive hyper-parameter setting can be addressed in future work to improve the performance in other traffic levels. Finally, we assume only vehicles in our scenario. A mixture of vehicles and pedestrians can be of interest in future work.

References

1. Peace, dignity and equality on a healthy planet. https://www.un.org/en/sections/issues-depth/ageing/, accessed: 2019-09-19
2. Bailey, J.M., Golpayegani, F., Clarke, S.: Comasig: A collaborative multi-agent signal control to support senior drivers. In: 2019 IEEE Intelligent Transportation Systems Conf. (ITSC). pp. 1239–1244 (2019)
3. Cao, Z., Guo, H., Zhang, J.: A multiagent-based approach for vehicle routing by considering both arriving on time and total travel time. ACM Trans. Intell. Syst. Technol. **9**(3), 25:1–25:21 (2017)
4. Cao, Z., Jiang, S., Zhang, J., Guo, H.: A Unified Framework for Vehicle Rerouting and Traffic Light Control to Reduce Traffic Congestion. IEEE Transactions on Intelligent Transportation Systems **18**(7), 1958–1973 (2017)
5. Doroudgar, S., Chuang, H.M., Perry, P.J., Thomas, K., Bohnert, K., Canedo, J.: Driving performance comparing older versus younger drivers. Traffic Injury Prevention **18**(1), 41–46 (2017)
6. Ebnali, M., Ahmadnezhad, P., Shateri, A., Mazloumi, A., Heidari, M.E., Nazeri, A.R.: The effects of cognitively demanding dual-task driving condition on elderly people's driving performance; real driving monitoring. Accident Analysis & Prevention **94**, 198–206 (2016)
7. Hamidi, H., Kamankesh, A.: An Approach to Intelligent Traffic Management System Using a Multi-agent System. International Journal of Intelligent Transportation Systems Research **16**(2), 112–124 (may 2018), http://link.springer.com/10.1007/s13177-017-0142-6
8. He, Q., Head, K.L., Ding, J.: Multi-modal traffic signal control with priority, signal actuation and coordination. Transportation Research Part C: Emerging Technologies **46**, 65–82 (2014)

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1

9. Ho, M.C., Lim, J.M.Y., Soon, K.L., Chong, C.Y.: An improved pheromone-based vehicle rerouting system to reduce traffic congestion. Applied Soft Computing **84**, 105702 (2019)
10. Hultsch, D.F., MacDonald, S.W.S., Dixon, R.A.: Variability in Reaction Time Performance of Younger and Older Adults. The Journals of Gerontology: Series B **57**(2), 101–115 (2002)
11. Jin, J., Ma, X.: Hierarchical multi-agent control of traffic lights based on collective learning. Engineering Applications of Artificial Intelligence **68**, 236–248 (feb 2018), https://www.sciencedirect.com/science/article/pii/S0952197617302658
12. Koppel, S., Stephens, A., Charlton, J., Di Stefano, M., Darzins, P., Odell, M., Marshall, S.: The Driver Behaviour Questionnaire for older drivers: Do errors, violations and lapses change over time? Accident Analysis & Prevention **113**, 171–178 (2018)
13. Krajzewicz, D., Hertkorn, G., Feld, C., Wagner, P.: Sumo (simulation of urban mobility); an open-source traffic simulation. pp. 183–187 (2002)
14. Ng, K., Lee, C., Zhang, S., Wu, K., Ho, W.: A multiple colonies artificial bee colony algorithm for a capacitated vehicle routing problem and re-routing strategies under time-dependent traffic congestion. Computers & Industrial Engineering **109**, 151–168 (2017)
15. Pan, J., Popa, I.S., Zeitouni, K., Borcea, C.: Proactive Vehicular Traffic Rerouting for Lower Travel Time. IEEE Trans. on Vehicular Technology **62**(8), 3551–3568 (2013)
16. Raitanen, T., Törmäkangas, T., Mollenkopf, H., Marcellini, F.: Why do older drivers reduce driving? Findings from three European countries. Transportation Research Part F: Traffic Psychology and Behaviour **6**(2), 81–95 (2003)
17. Richerzhagen, B., Stingl, D., Rückert, J., Steinmetz, R.: Simonstrator: Simulation and prototyping platform for distributed mobile applications. In: Proceedings of the 8th Intl. Conf. on Simulation Tools and Techniques. p. 99–108. SIMUTools '15, ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), Brussels, BEL (2015)
18. Soon, K.L., Lim, J.M.Y., Parthiban, R., Ho, M.C.: Proactive eco-friendly pheromone-based green vehicle routing for multi-agent systems. Expert Systems with Applications **121**, 324–337 (2019)
19. Stipancic, J., Miranda-Moreno, L., Saunier, N., Labbe, A.: Surrogate safety and network screening: Modelling crash frequency using gps travel data and latent gaussian spatial models. Accident Analysis & Prevention **120**, 174–187 (2018)
20. Stipancic, J., Miranda-Moreno, L., Saunier, N., Labbe, A.: Network screening for large urban road networks: Using gps data and surrogate measures to model crash frequency and severity. Accident Analysis & Prevention **125**, 290–301 (2019)
21. Sullivan, K.A., Smith, S.S., Horswill, M.S., Lurie-Beck, J.K.: Older adults' safety perceptions of driving situations: Towards a new driving self-regulation scale. Accident Analysis & Prevention **43**(3), 1003–1009 (2011)
22. Zhou, P., Braud, T., Alhilal, A., Hui, P., Kangasharju, J.: Erl: Edge based reinforcement learning for optimized urban traffic light control. In: 2019 IEEE Intl. Conf. on Pervasive Computing and Communications Workshops. pp. 849–854 (2019)

ICCS Camera Ready Version 2021
To cite this paper please use the final published version:
DOI: 10.1007/978-3-030-77961-0_1