Towards Fair and Efficient Traffic Flow Coordination Mechanisms for 2+1 Roadways

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Abstract. In 2013, 2+1 roadways have become mandatory for newly constructed rural roadways in Germany. The steady trend towards autonomous vehicles and vehicle-to-X (V2X) communication will enable new automated traffic coordination mechanisms. In our research, we study how traffic flow on 2+1 roadways can be improved by using such mechanisms for coordinating the usage of overtaking lanes. Conflicts between vehicles on 2+1 roadways arise due to (1) differing capabilities (e.g. maximum speed), and (2) conflicting preferences of drivers (e.g. desired speed). These conflicts can lead to poor use of resources, and ultimately in time loss both from an individual vehicle and aggregated system perspective. To foster acceptance of coordination mechanisms, it is important to not only consider the system perspective but also to ensure some level of driver satisfaction and fairness, e.g. if vehicles are denied access to the overtaking lane in favour of faster vehicles, this raises questions regarding the acceptance of external coordination. While there is some research studying microscopic optimisation of traffic flows on rural 2+1 roads and intersections, there has been only little research focusing on driver satisfaction and fairness of mechanisms. In this work, we present the results of a pre-study on simulated 2+1 manoeuvres conducted using the Simulation of Urban MObility (SUMO) suite to estimate optimisation potentials of coordination. Preliminary results indicate potentials to reduce driver dissatisfaction while maintaining fairness. We analyse optimisation potentials and propose a model which combines driver satisfaction and fairness of coordination, aiming at increasing acceptance of autonomous vehicle coordination.

1. Introduction

In order to increase traffic safety, especially during overtaking manoeuvres on one-lane roadways, one strategy is to extend the number of lanes on several sections to allow faster vehicles to safely pass. This leads to the concept of *2+1 systems* (see Fig. 1), alternating the exclusive availability of the third (i.e. middle) lane for each direction, to improve safety and comfort and reducing the individual travel time of faster (passenger) vehicles by avoiding slow platoons led by, e.g. trucks. Due to regulations in the *"Guidelines on the Construction of Rural Roads (RAL)"* by the *"Federal Highway Research Institute (BASt)"* [**ASe13**], *2+1 systems* are mandatory in Germany for newly constructed long distance and supra-regional roadways and existing roadways are expected to be extended during normal maintenance phases [**BAS13**].

Key words and phrases. fairness; satisfaction; rural roadways; 2+1 systems; coordination; microscopic simulation; preferences.

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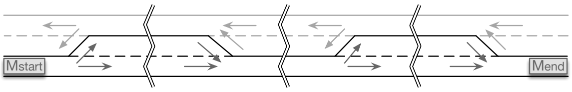

FIG. 1. Cross section of a *2+1 system* with two *measuring points* M_{start} and M_{end}.

From the traffic management perspective, the main optimisation factor is to minimise travel time of vehicles in the observed network by applying policies granting access to fast lanes, e.g. high-occupancy vehicle (HOV) or high-occupancy toll (HOT) lanes, for vehicles which meet the minimum requirements, e.g. capable speed, paid tolls, car pooling, etc. *Managed lanes (MLs)*, are a concept to grant access to fast lanes based on dynamic policies to reduce congestions and travel time. Access is usually granted by having drivers pay a toll, e.g. based on fixed or dynamic *congestion pricing* [**dPL11, Rou16**], or fulfil other requirements defined by the traffic management.

Assumptions. Current and planned advances in real-time traffic observation, roadside units, 4G and upcoming 5G/G5 networking technology open the possibility of fine-grained management of lanes on a microscopic level. Additionally to planning and driving the shortest route on a macroscopic level, as provided by turn-based navigation devices, drivers minimise the time loss by optimising their manoeuvres on an operational level.

We assume that vehicles equipped with Automated Driving Systems (ADS) will be commonly available in the near future. Vehicles classified as level 3 and above, according to [**SAE16**], would then be capable of overtaking and lane changing manoeuvres without human interaction. Similar to the scenario presented by [**DM16**] we envision that drivers, when entering such an autonomous vehicle, provide their individual preferences, e.g. what time loss would still be acceptable or the mode of driving (economic, time minimising, stress-free). We further assume that each driver has a *desired speed*, dependent on the time pressure or preferred driving mode. The maximum driving speed of an autonomous vehicle can therefore be expressed by the minimum of the driver's desired speed, the (technically) capable speed of the vehicle and speed limit on the roadway.

We further envision coordination service entities (CSEs), governing 2+1 roadway segments, to monitor vehicles and granting access to the overtaking lane based on policies to optimise for a high traffic flow, but also to ensure driver satisfaction and overall fairness of the employed coordination mechanism. We assume autonomous vehicles, cooperative and capable of sending requests for accessing the overtaking lane to automatically comply with the decisions of CSEs. [**HB06**] reported that on MLs with only a painted barrier, a high compliance with the employed policies could be observed. We argue that drivers can therefore be assumed to consent with their vehicles obeying the rules implemented by a CSE. To evaluate the outcome of a manoeuvre, each autonomous vehicle has a utility function to be maximised, based on the driver *satisfaction* threshold related to the *relative time loss* (compared to the estimated total travel time).

Research Questions and Hypotheses. The goal of our research for this paper was to identify potentials of optimising the *2+1 system* by means of coordination by a *service entity* on a microscopic level, by considering *fairness* of the system and *satisfaction* of drivers. For vehicles entering a 2+1 roadways we considered three cases: *Best-case* with an already optimal ordering of vehicles (i.e. entering with descending maximum driving speed), *random* ordering of vehicles by their maximum driving speed and *worst-case* with a ascending ordering of vehicles by their maximum driving speed. We suspected that for an best-case ordering of vehicles entering the 2+1 segment, the dimensions of fairness, satisfaction and efficiency are close to optimal after leaving the segment, whereas for a random to worst case ordering these dimensions are increasingly negative affected with rising traffic demand. Our hypotheses were that by analysing different service levels on 2+1 roadways, (1) optimisation potentials from traffic management and drivers' perspectives can be identified, i.e. at what traffic service levels it is sensible to apply optimisations, (2) an estimation can be given on how much improvement could theoretically be achieved and (3) the ordering of vehicles by their *maximum driving speed* plays an important role regarding room for optimisation. To answer our research questions, we developed a simulation framework using SUMO for analysing and identifying fairness and satisfaction by a scenario independent model on multi-lane roadways.

This paper identifies optimisation potentials on a microscopic, i.e. operational level for drivers on 2+1 roadways and is structured as follows: Section 2 gives an overview about recent work on coordination of autonomous vehicles on long distance roadway scenarios from a microscopic perspective, research on the safety of overtaking lanes in *2+1 systems* and coordination mechanisms currently employed. In Section 3 we present how we modelled *efficiency* and *fairness* from a system perspective and *satisfaction* of drivers in such systems. In Section 4 we explain our simulation setup and architecture and discuss our results. We conclude this paper and discuss further research topics in Section 5.

2. State of the Art and Related Work

2+1 Roadways. [**Irz10a, Irz10b**] studied 2+1 roadways regarding the safety of overtaking segment length for selected regional roadways in Germany and the typical demand which can be expected. [**HAS$^+$11b**] proposed a coordination mechanism to handling varying demand (e.g. commuter traffic) by employing a *dynamic lane reversal* to maximise throughput. The authors used a centralised optimisation approach with *Integer Linear Programs* to decide when to flip the direction of the middle lane, but only based on the vehicle demand, they did not consider individual driver preferences.

Coordination of vehicles on a microscopic level. With the Autonomous Intersection Management (AIM) platform, [**DS04**] proposed a reservation-based intersection control mechanism for autonomous vehicles. Extensions considering turning, acceleration, interaction and vehicle models were proposed in [**DS05, DS08**]. [**HAS11a**] studied policies for linked intersections. [**AZS15**] introduced a protocol called Semi-AIM and showed that a more efficient *intersection management* can be achieved by considering vehicle features like *Adaptive Cruise Control (ACC)*. The works of these authors focus mainly approaches not considering preferences of individual actors, like *user satisfaction*, or *fairness* of implemented mechanisms.

Driver preferences. [**RV17**] investigated driver preferences by studying route choices of drivers when confronted with alternatives routes which can increase or decrease the loss of travel time. In their study, the authors found that drivers would choose an alternative route if the increase in travel time exceeds 20 percent. Their findings can be interpreted as a time loss satisfaction threshold when drivers will be dissatisfied with the current traffic conditions.

3. Modelling Efficiency and Fairness in 2+1 Roadways

With the main motivation of reduced travel time (drivers) and higher traffic safety on 2+1 roadways, we designed a model to describe the objectives of drivers (*satisfaction* and *fairness*) and traffic management (*efficiency*) to investigate at what traffic demand it is sensible to implement policies to manage the access to a reserved lane. Indirectly, the traffic management also is motivated in maximising driver satisfaction and fairness as this increases the probability of compliance. In this section we propose our model of fairness and efficiency for multi-lane roadways. We model these objectives as optimisation functions to be minimised and refer to them as *dissatisfaction*, *unfairness* and *inefficiency* when comparing the outcome of a scenario.

Efficiency. An important goal of a managed 2+1 roadway is to decrease the travel times of vehicles in the network by providing overtaking segments on the roadway, allowing fast vehicles to overtake slower ones. From the traffic management perspective, system efficiency can be measured in terms of the vehicle flow, i.e. by the aggregated time loss vehicles suffer while passing through the 2+1 roadway. To compare vehicles with different capabilities (see Section 1) on a roadway, it is necessary to compare the *relative* time losses with the actual travel times, optimal travel times and maximum driving speeds. Let $a \in \mathcal{A}$ be a vehicle of a set of vehicles and r the underlying roadway segment with $length(r)$ denoting the total length of the observed segment. Further let $TT^{act}(a,r)$ be the actual time vehicle a needed to travel roadway r and respectively $TT^{opt}(a,r)$ the optimal travel time and $TL^{rel}(a,r)$ the relative time loss. We defined $v^{max}(a,r)$ to be the maximum driving speed, which is capped by the minimum of **(i)** the driver's desired speed $v^{des}(a)$, **(ii)** the vehicle's capable speed $v^{cap}(a)$ and **(iii)** the speed limit $v^{lim}(r)$ on the roadway r. As disturbance in the system adds to the time loss of vehicles with (theoretically) no upper limit, we modelled an objective function (Eq. (1)) to be minimised, describing the *inefficiency* of the system.

(1)

$$\begin{array}{rcll}
\text{inefficiency}(r) & = & \sum_{a \in \mathcal{A}} TL^{rel}(a,r) \rightarrow \text{min!} & \\
\text{s.t.} \quad TL^{rel}(a,r) & = & \frac{TT^{act}(a,r) - TT^{opt}(a,r)}{TT^{opt}(a,r)} & \blacktriangleright \text{ relative time loss of } a \text{ on roadway } r \\
TT^{act}(a,r) & \in & \mathbb{R}_0^+ & \blacktriangleright \text{ actual travel time of } a \text{ on roadway } r \\
TT^{opt}(a,r) & = & \frac{length(r)}{v^{max}(a)} \in \mathbb{R}^+ & \blacktriangleright \text{ optimal travel time of } a \text{ on roadway } r \\
v^{max}(a,r) & = & \min(v^{des}(a), v^{cap}(a), v^{lim}(r)) & \blacktriangleright \text{ maximum driving speed of } a \text{ on roadway } r
\end{array}$$

Driver satisfaction. Uncoordinated 2+1 roadways lead to executing manoeuvres by employing a *first come, first served* strategy when it comes to utilising the overtaking lane. But due to non-optimal ordering of vehicles regarding desired speeds, this can lead to a degradation of capacity, e.g. if a marginally faster vehicle tries to overtake and leaves trailing vehicles with considerably less overtaking lane to make a safe manoeuvre, this has a negative impact on the driver *satisfaction* of each trailing vehicle which can be measured in form of each vehicle's time loss. For reasons of consistency with our model in Eq. (1), we also modelled it as function to be minimised (Eq. (2)), i.e. we modelled dissatisfaction rather than satisfaction. We used a sigmoid function, due to its continuously differentiable properties to calculate whether a driver is dissatisfied regarding her current time loss considering the driver's (and subsequently vehicle a's) time loss threshold, relative time loss and optimal travel time (as defined in Eq. (1)) on the roadway r. We denoted the *time loss threshold* t for a given vehicle a of type $vtype \in \{passenger, truck, tractor\}$ as $t = TLT_{vtype}(a) \in \mathbb{R}^+$, i.e. $TLT_{vtype}(a) = t \ \forall a \in \mathcal{A} \wedge type(a) = vtype$ where $type(a)$ provides the vehicle type of a. Additionally, we added a smoothing factor $\rho \in \mathbb{R}^+$ to the sigmoid to control the sharpness, i.e. steepness of the curve.

$$
\begin{array}{llcl}
(2) & & & \\
\multicolumn{4}{l}{\text{dissatisfaction}(TL^{rel}(a,r), TT^{opt}(a,r), TLT(a))} \\
 & & = & \dfrac{1}{1+e^{(-TL^{rel}(a,r)+TLT_{vtype}(a)\cdot TT^{opt}(a,r))\cdot\rho}} \rightarrow \text{min!} \\
\text{s.t.} & \rho & = & 0.5 \\
 & vtype & \in & \{passenger, truck, tractor\} \\
 & TLT_{passenger}(a) & = & 0.2 \\
 & TLT_{truck}(a) & = & 0.1 \\
 & TLT_{tractor}(a) & = & 1.0 \qquad \blacktriangleright\, TL^{rel}(a,r) \text{ and } TT^{opt}(a,r) \text{ as in Eq. (1)}
\end{array}
$$

We set $\rho = 0.5$ for a more gradual change from satisfaction to dissatisfaction. For modelling the *time loss threshold* $TLT_{vtype}(a)$, i.e. the point at which satisfaction turns into dissatisfaction, for each passenger vehicle we applied the findings of [**RV17**] and set $TLT_{passenger}(a) = 0.2$ to fine-tune our model as depicted in Fig. 3. We further defined $TLT_{truck}(a) = 0.1$, as it can be assumed that truck drivers drive under high time pressure and $TLT_{tractor}(a) = 1.0$, as we assume that tractor drivers are aware that they are the slowest traffic participants and therefore have no reason to exhibit immediate time pressure behaviour. For our further studies the tractors served also as a *control group* of overtaking incapable drivers, perfectly fine with delays for testing our model for perfect road conditions.

System fairness. From the traffic management perspective, optimising *2+1 systems* has to ensure fairness regarding the drivers' time losses. We argue that policies should be put into effect to avoid that selfish drivers negatively affect the satisfaction of others more that their personal gain. Analogously to Eqs. (1) and (2) we modelled the system fairness as an expression of *unfairness* to be minimised. We used the interquartile range (IQR), also referred to as *H-Spread* (see [**Wei17a**]), i.e. the deviation from the median, as a general indicator of *unfairness* in the system. The h-spread HS is defined as the difference of the *Hinges* H_1 and H_2 (see [**Wei17b**]):

$$HS = H_2 - H_1 = N_{(3N+1)/4} - N_{(N+3)/4}$$

for an ascending sorted n-tupel N. For a given set A of vehicles $a \in \mathcal{A}$ on a roadway r, ascending ordered by their relative time losses and $TL^{rel}(A[i], r)$ being the relative time loss of i-th vehicle, we modelled unfairness as

$$
\begin{array}{rcl}
\multicolumn{3}{l}{(3)} \\
\text{unfairness}(A,r) & = & TL^{rel}(A[\frac{3N+1}{4}], r) - TL^{rel}(A[\frac{N+3}{4}], r) \rightarrow \text{min!} \\
\text{s.t. } TL^{rel}(A[i], r) & \leq & TL^{rel}(A[j], r)\ \forall i < j,\ i, j \in \mathbb{N} \\
N & = & |A| > 0 \qquad \blacktriangleright\, TL^{rel}(a,r) \text{ as in Eq. (1)}
\end{array}
$$

This approach allows us (1) to find the best and worst case in our data and (2) to determine the divergence of each data point from the statistical median. We defined unfairness as the *divergence of the median*, as then all vehicles can be considered equally treated. For example in the best case, i.e. a perfectly fair mechanism, applied to a roadway r

$$
\begin{array}{l}
\max(\{TL^{rel}(a,r) \mid a \in \mathcal{A}\}) = \min(\{TL^{rel}(a,r) \mid a \in \mathcal{A}\}) \\
\Rightarrow TL^{rel}(a,r) = TL^{rel}(b,r)\ \forall a, b \in \mathcal{A}.
\end{array}
$$

Analogously, an h-spread of zero indicates a perfectly fair overtaking policy, as each vehicle has the same time loss, whereas an h-spread greater than zero indicates that some vehicles are disadvantaged (higher time loss) or advantaged (lower time loss) compared to others. The benefits of this definition are that it can be applied independently from the underlying system, making it robust against inherently but unintended fair or unfair scenario configurations.

4. Evaluation

Simulation of 2+1 Roadways with SUMO. We chose a 2+1 roadway with realistic parameters as presented in [**Irz10b**, p. 167] for our case study, a driver dissatisfaction model consistent with [**RV17**] and a vehicle type distribution of 80% passenger vehicles, 15% trucks and 5% tractors. The roadway *B 210* satisfied our requirements as Irzik provided the *total length* (6800 m), *number of 2+1 switches* (4), *speed limit* (100 km/h) and typical *Annual Average Daily Traffic (AADT)* of 13000 vehicles/lane/day (= $514.\bar{6}$ vehicles/lane/hour).

CoLMTO Simulation Platform. The Cooperative Lane Management and Traffic flow Optimisation (CoLMTO) platform[1] [**Asc17**], developed to conduct our simulation studies, is structured as depicted in Fig. 2. CoLMTO is split in two parts: The simulation and pre-/post-processing components combined with a runtime system. The platform uses its own runtime which controls SUMO's time steps and exchanges vehicle states via Traffic Control Interface (TraCI). During preprocessing, the *Configuration Generator* creates for each run the SUMO specific `XML` files with individual vehicle parameters. From these configurations, an object structure is generated to represent the scenario, i.e. the environment with roadway and vehicles. The *Statistics* module aggregates the vehicle and roadway object structure, containing travel times, time losses and dissatisfaction for each vehicle as well as the overall fairness of the scenario and stores the collected data in a `HDF5` file format for post-hoc statistical analysis. The scenario configuration, e.g. 2+1 roadway parameters, demand, vehicle properties, and number of iterations are specified in a `YAML` formatted configuration.

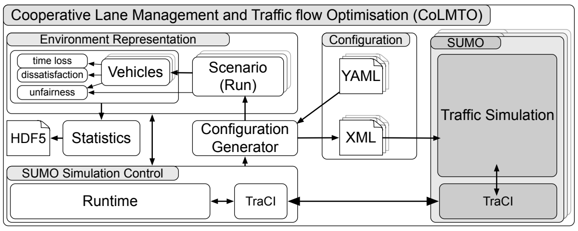

FIG. 2. The CoLMTO Simulation Platform.

Dissatisfaction thresholds and baseline time loss correction. We noticed that in version 0.28.0 of SUMO, which we used in our simulations, the vehicle following model exhibited – despite our best efforts to disable this by configuration – an imperfect driving behaviour, which had a negative impact on the drivers' satisfaction even in the optimal case. As such behaviour would not be expected for highly autonomous vehicles and would introduce a pessimistic bias into our model, we did 1000 runs of our scenario with an optimal ordering of vehicles with 10 seconds gap and measured the *relative travel time loss* for each vehicle (Fig. 3). We added the *medians* of each measurement (grouped by vehicle type) to every vehicle type's dissatisfaction threshold to compensate for this *noise of imperfection* in the SUMO model (correction in brackets): Passengers 0.2 (+0.026), trucks 0.1 (+0.014) and tractors 1.0 (+0.042).

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[1] Source code (and documentation) see: `https://github.com/SocialCars/colmto` (`https://git.io/vHPIU`)

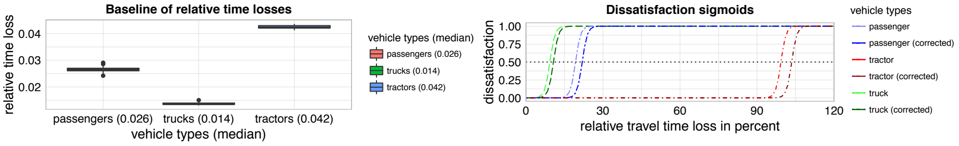

Fig. 3. Baseline dissatisfaction noise for optimal ordering of vehicles (left), corrected error in model (right).

Table 1. Results for random and worst case ordering of vehicles for lowest and highest tested demand (200 and 2000 vehicles/lane/hour).

vehicle type	random ordering *rel*	*dis*	*inef*	*unf*	worst case ordering *rel*	*dis*	*inef*	*unf*
passenger	0.125; 2.470	0.0; 1.0	16.751; 1781.809	0.291; 0.272	0.027; 1.062	0.0; 1.0	10.735; 809.495	0.172; 0.871
truck	0.042; 1.885	0.0; 1.0	2.422; 291.473	0.215; 0.199	0.219; 1.635	1.0; 1.0	3.985; 267.026	0.210; 0.238
tractor	0.042; 0.044	0.0; 0.0	0.084; 2.095	0.000; 0.002	0.042; 0.097	0.0; 0.0	0.085; 4.137	0.000; 0.043

Abbreviations: *rel*ative time loss; *dis*satisfaction $\in [0; 1]$; *inef*ficiency (seconds); *unf*airness (seconds)

Experimental procedure. We simplified the 2+1 roadways by removing curves and on/off-ramps as we focused our research on overtaking manoeuvres and did not consider ramp related lane merging operations. For our studies, we chose the demand (commonly referred to as AADT) as the independent variable, but converted to vehicles/lane/hour. The demand values tested in this work were 200 to 2000 vehicles/lane/hour in steps of 150 and the scenario typical 541.67 vehicles/lane/hour [**Irz10b**], covering the service level classification A to E of [**TDM17**] with a fine-grained resolution. For each service level, we considered best-case, random and worst-case orderings of vehicles entering the simulation scenario as described in Section 1. To achieve more realistic traffic flow, we applied *Poisson distributed* start times for the vehicles in each simulation run, depending on the demand. Applying our model (Section 3), we measured the *relative time loss*, *dissatisfaction*, *unfairness* and *inefficiency* with increasing demand. For a good statistical quality of our results, we repeated each run 500 times and *median* aggregated the results of each run. The results are presented in the following.

Results. For the best case ordering of passenger vehicles, the results for lowest (200) and highest demand (2000) were: relative time loss (0.027 to 0.042), dissatisfaction (0.0), inefficiency (2.134s to 33.06) and unfairness (0.001s to 0.004s). For trucks and tractors the best case results were lower: Trucks had a relative time loss of 0.014 to 0.035, dissatisfaction of 0.0 in both cases, inefficiency of 0.25s to 6.028 and unfairness ranging from 0.001s to 0.006s. Tractors: relative time loss (0.042 to 0.045), dissatisfaction (0.0), inefficiency (0.083s to 2.112s) and unfairness (0.0s to 0.001s). The values for the random and worst case are depicted in Table 1. As passengers contributed the most to our vehicle distribution (80%) and we assumed that drivers of passenger vehicles have more individual needs and preferences, we present their results detailed depicted in Figure 4. Noteworthy findings were, that for the random case the relative time loss saturated at about 2.47 times of the optimal travel time, whereas in the worst case it peaked for 1400 vehicles/lane/hour at 1.582 and declined from there to 1.062. Vehicle demand at which our metrics peaked can be seen in detail in Table 2.

Discussion. Our results support our hypothesis (see Section 1) that for an optimal sorting of vehicles the optimisation potentials are slim and not worthy of further consideration. Related to that we observed that regarding our model's

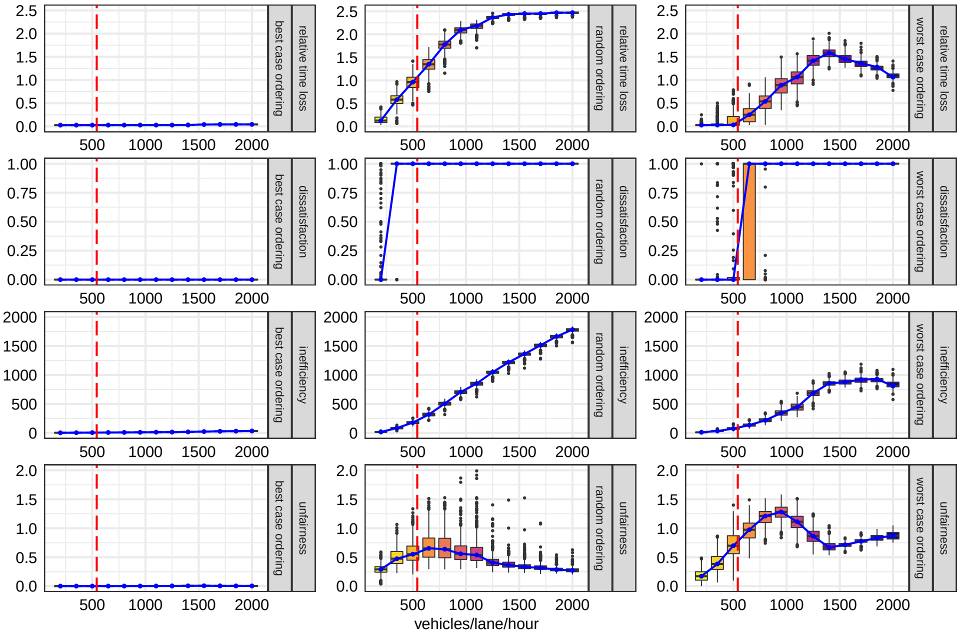

FIG. 4. Results for *passenger vehicles*, comparing *best*, *random* and *worst* case orderings with *relative time loss*, *dissatisfaction*, *inefficiency* and *unfairness*. Demand ranged from 200 to 2000 vehicles/lane/hour in steps of 150. The vertical dashed line (red) denotes the scenario typical demand of $541.\bar{6}$ vehicles/lane/hour. Blue line connects *medians* of each box. The raw dataset can be obtained at `https://zenodo.org/record/495742`.

TABLE 2. Peak, respectively earliest saturation of relative time loss, dissatisfaction, inefficiency and unfairness compared against levels of demand.

	best case ordering				random ordering				worst case ordering			
vehicle type	*rel*	*dis*	*inef*	*unf*	*rel*	*dis*	*inef*	*unf*	*rel*	*dis*	*inef*	*unf*
passenger	2000	200+	2000	1550	2000	350+	2000	650	1400	650	1850	950
truck	1550+	200+	2000	1550	2000	350+	2000	800	1400	300+	2000	800
tractor	1400+	200+	1850	950	1550+	200+	1850	1400	2000	200+	2000	1700

Abbreviations: *rel*ative time loss; *dis*satisfaction; *inef*ficiency; *unf*airness; + indicates maximum reached with no further decline.

dimensions (satisfaction, fairness, efficiency and time loss) tractors displayed no significant change in the random and worst case compared to an optimal ordering. This shows that our model yields correct results for altruistic vehicles as we modelled tractors not to have a need to use the overtaking lane (slowest vehicles) and with a sufficiently high dissatisfaction threshold. Regarding hypothesis (1) we observed that the driver-relevant factor of unfairness peaks after surpassing the typical traffic demand of the *B 210*. The dissatisfaction reaches 1 after the first increase of demand (200 → 350 v/l/h). We argue, that from a driver perspective, optimisation measures should be considered on the first signs of dissatisfaction and rising unfairness. But the unfairness indicator only gives an early sign for the traffic management to intervene, as it decreases for higher demand due to the fact that after an initial peak each vehicle gets treated equally bad which increases the overall fairness of the system. We observed that the relative time loss decreases after a tipping point for the worst case ordering. This effect can be attributed to SUMO's lane-changing and car-following models, leading vehicles to abandon plans on overtaking if there is no chance to overtake the leading platoon. The difference between the random and worst-case time loss can therefore be taken as a lower bound of optimisation gain (hypothesis 2) for mixed traffic as a lower travel time loss could be achieved by simply denying access to the overtaking lane without applying more complex policies. These findings also support our hypothesis (3) that the ordering of vehicles plays a significant role for optimisation strategies: For best-case ordering of vehicle groups any policy trivally yields an optimum result. For worst-case ordering of vehicles the demand and resulting length of the platoons becomes an issue as sufficiently long overtaking segments become scarce.

5. Conclusion & Outlook

In this paper we presented models for combining driver preferences and optimisation goals of managed lanes (MLs), governed by traffic management, aiming at increasing acceptance of autonomous vehicle coordination. We conducted a prestudy on simulated 2+1 manoeuvres by using our own framework CoLMTO with SUMO to estimate optimisation potentials of coordination. Preliminary results indicate that potentials to reduce driver dissatisfaction while maintaining fairness exist but a policy-based fine-tuning is necessary to avoid imbalances between these optimisation goals. We intend to use the findings of this work as a baseline for further studies to enhance the effectiveness of chosen policies especially in mixed traffic cases, where a more complex set of policies might be necessary. One aspect of future research will be to integrate a fine-grained control, comparable to [**AZS15**], for accessing managed lanes based on policies attractive to drivers and effective coordination mechanisms for a cooperative traffic management.

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