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USING TRAFFIC SIMULATION FOR LEVEL OF SERVICE TRAVELLER PERCEPTION STUDIES

ABSTRACT

Level of service (LOS) classifications of traffic operational conditions play a significant role in roadway-improvement funding decisions. Traveller perception of LOS should be consistent with traffic analysis values to avoid undermining the public confidence in the transportation agency decisions. Research methods to study traveller perceptions range from in-vehicle videos to focus groups and surveys. These methods have different advantages, but all suffer from time and/or cost inefficiencies for collecting data sets across a wide range of operating conditions. This paper describes a novel method to study this topic with increased time and cost efficiency. This new method combines traffic microsimulation and 3-D visualisation capabilities. The focus of this paper is to provide guidance on how to apply traffic microsimulation and computer 3-D visualisation to evaluate highway trip quality from a traveller's perspective. It discusses the creation of the simulation environment to produce a realistic view from the vehicle's cabin interior, including the network creation, landscaped area, dashboard speedometer, and rear-view mirror. The authors also propose an automated method for choosing an appropriate vehicle within the simulated traffic stream, such that the desired overall traffic stream conditions are conveyed to the traveller vehicle within the field of view.

KEYWORDS

computer 3-D visualisation; traffic level of service, traffic conditions perception; traffic microsimulation; automated vehicle selection method.

1. INTRODUCTION

The concept of level of service (LOS) was introduced in the second edition of the Highway Capacity Manual (HCM), in 1965 [1]. LOS refers to assigning a letter grade (from A, the best, to F, the worst) that corresponds to the general operational conditions, as measured by one or more performance measures, referred to as service measures. In the 1965 HCM, the selected service measures for freeways were operating speed and volume-to-capacity ratio [2]; in the third edition of the HCM, released in 1985 [3], basic freeway segments were assessed for the first time, with density chosen as the service measure [2], which was kept in the subsequent editions.

While the service measures and thresholds for LOS rankings have historically been chosen by transportation engineers involved in the development of the HCM, the intent is that these ranking thresholds would also be reasonably consistent with how the travelling public would perceive the quality of the operational conditions. Given the very large amount of funding typically involved in transportation infrastructure decisions, it is vitally important to transportation agencies that there be consistency between the quantitative changes to the operational conditions as a result of the investment and the perception of these changes by the users of the transportation system. However, until relatively recently, research on user perceptions of traffic operational conditions was lacking.

Some initial progress was made in this area in the HCM 2010 edition [4]. In that edition, LOS assessment based on user perception research was introduced for the bicycle, pedestrian, and transit modes on urban streets. Research on user perceptions of traffic operational conditions has gained momentum over the last 15 years, but is still a relatively immature area of research. Particularly challenging is developing a research approach to accurately measure user perceptions of traffic operational conditions that is also time and cost efficient.

This paper describes such an approach, which uses a combination of traffic microsimulation and three-dimensional (3-D) visualisation. Until relatively recently, computer visualisations within traffic microsimulation programmes have been in only two dimensions or of low visual quality if in three dimensions. On the other hand, dedicated computer visualisation programmes usually provided realistic representations of the roadway environment but the included traffic conditions were not grounded in traffic flow theory. Desktop computing performance has now reached a level where realistic-looking 3-D visualisations can be created directly within the traffic simulation environment. Given the novelty and nontrivial nature of this research approach, it is important to share the lessons learned in developing this approach so as to assist the research community in applying this promising approach to future efforts. Specifically, we address the topics of creating the simulation network, creating the roadway view from the vehicle's cabin interior, and developing an automated method for choosing a representative vehicle from the overall simulated traffic stream.

2. LITERATURE REVIEW

The literature shows two different approaches to understand how travellers perceive and are affected by the quality of trips. The first one is focused on the individual's subjective well-being, looking for elements that explain travel satisfaction [5] and tries to assess the individual benefits from travel improvements [6] through a psychological scale such as the satisfaction with travel scale [7].

The second approach tries to correlate engineering measures of effectiveness to users' perception of the quality of the trip aiming to somehow include the travelling public perception in the performance evaluation. Since the 2000s, several studies have been conducted to create a framework to understand the traveller's perception of the quality of service, across a variety of traffic facilities – e.g. freeways [8–10], two-lane highways, intersections [11, 12], roundabouts, sidewalks [13], and bicycle paths [14]. The study [15] that culminated with the introduction of user perception for multi-modal LOS in the HCM 2010 utilised a procedure for assessing LOS that consisted of having travellers view and rate video recordings of a variety of travel conditions. More specifically, a broad range of users were shown video clips recorded on typical urban street segments from the point-of-view of automobile drivers, pedestrians, and bicycle riders and were asked to rate the quality of service in each video clip. For this study, 26 to 35 videos were recorded for each travel mode. Multiple linear regression and cumulative logistic regression methods were used to fit models that could estimate the mean rating obtained for each video. The best model used three independent variables (stops per mile, presence of trees, and presence of an exclusive left-turn lane) and explained approximately 75% of the variation in mean observed LOS ratings. This model predictive performance was noticeably better than that of HCM LOS method (which explained only 46% of the variation in mean observed LOS ratings), clearly indicating the importance of including the users' perception in LOS evaluation.

For freeways and highways, other researchers have also used video clips to evaluate how drivers perceive the quality of service [8, 10, 16–19]. In all these cases, the video clips were recorded on real roadways, under the prevailing operational conditions at the time; consequently, the range of conditions were limited. Other techniques used include focus groups [20–23] and interviews with drivers after travelling on a highway [9, 24, 25]. These approaches generally share the same challenge: presenting to participants a sufficiently large set of driving conditions that would include the full range of operating conditions. A study using a convenience sample of 20 university students [26] investigated drivers' behaviour and perceived quality of travel using a driving simulator. Each participant drove through three different scenarios consisting of a 6-lane divided highway under traffic volumes and densities corresponding to the HCM LOS A, C, and E levels. The simulator software recorded speed, acceleration, and braking during each scenario. Participants answered a set of questions after driving in each scenario. Two of the questions asked drivers to rate the easiness of driving and of maintaining the desired speed, using a scale from 1 (hardest) to 4 (easiest). In the other two questions, drivers rated the trip quality with respect to traffic conditions (density and speed) and psychological comfort (stress level, etc.), by means of a 10-point scale, where 1 was the worst and 10 the best. The results showed a significant correlation between traffic density and the drivers' perception of trip quality. This study illustrates the major difficulties in trying to incorporate drivers' perception in LOS evaluation, namely obtaining a sample sufficiently large to be statistically significant and the need to use a limited number of scenarios, due to the complexity in generating a set of scenarios covering the full range of densities from LOS A to E.

These challenges can be overcome using computer generated video clips. Previous research has shown the strong potential of using 3-D animated clips generated from traffic simulation [27] and virtual reality [28] as tools in empirical research. Specifically for freeway facilities, several studies were based on animated video clips created using traffic simulators. Obelheiro, Cybis and Ribeiro [29] proposed a method to develop criteria for LOS at toll plazas. Video clips representing a variety of conditions (number of open booths, truck percent, flow rates, etc.) were created using microsimulation (Vissim), from a bird's eye viewpoint, and a website was used to reach a large survey sample with low costs. Thus, many users from different locations and with varying demographic characteristics were able to participate in the survey. Another study [30], also using animated videos generated by microsimulation software (Aimsun), proposed a method to estimate LOS thresholds based on the users' perception of the quality of the trip. The authors decided to use video clips recorded from the driver's viewpoint rather than an aerial viewpoint because the latter perspective does not represent the view automobile occupants experience when travelling on a highway. Study participants watched a set of animated videos and rated the quality of the trip positioning a cursor along a line between "very poor" to "excellent" – a visual analogue scale [31]. A convenience sample of university students was used to demonstrate the feasibility of the method.

The literature shows that, while there is a need to include users' perceptions in LOS evaluation, it would be extremely challenging, expensive, and time-consuming to record video clips covering the full range of operational conditions. The recruitment of a sufficiently large number of participants to watch video clips or to participate in a driving simulator-based experiment is in every way as challenging. The use of realistic 3-D animated video clips, generated by microsimulation software, is an appealing way to avoid these difficulties. Using microsimulation, one can easily generate a set of video clips covering the full range of operating conditions for any scenario. A website-based survey can be used to collect data on user ratings and to reach a large number of participants, avoiding the problems associated with small samples. In this paper, we discuss how to create realistic video clips using simulation and how to select a vehicle whose driver's view reflects the operational conditions associated with a certain traffic density.

3. MICROSIMULATION APPROACH

Traffic microsimulation has the potential to overcome one of the main challenges of field-based in-vehicle video recordings – obtaining a wide range of traffic conditions. Using traffic simulation software allows for the complete control of all factors that affect the traffic stream, making it possible to generate the full range of operating conditions, and requires only modest resources [27]. Furthermore, some modern microsimulation programmes are capable of generating realistic animated videos (i.e., computer-generated animations) from the driver's viewpoint, which is likely to elicit more accurate rankings from the study participants than an overhead view [30]. In this study, PTV Vissim Version 11 [32] was selected for the simulation platform: (1) because of its ability to render very realistic traffic animations from driver's field-of-view perspective, both forward and rearward looking; and (2) because of the authors' familiarity with the tool. Any other traffic microsimulation software with similar capabilities can also be used, provided that it has been previously calibrated to represent driving behaviour and heavy vehicle performance in a sufficiently realistic way [33, 34].

The following elements must be considered carefully for the development of realistic video clips: (1) creation of the simulated road environment, (2) the roadway view from the vehicle's cabin interior, and

(3) the choice of the vehicle within the traffic stream for creating the driver's view. These three aspects are discussed in the following sections. For brevity's sake, "videos" will be used in place of "animated videos" henceforth.

4. SIMULATED ROAD ENVIRONMENT

To reproduce the driving experience as realistically as possible, the simulation environment must contain elements that help the participant to view the roadway and traffic environment just as drivers would in a real car [27, 28]. Trees and plants placed beyond the shoulder and in the median help to convey the sense of travel speed. Horizontal and vertical curves must be represented by sufficiently small segments to ensure the feeling of a smooth ride. The perception of travelling on an upgrade requires the inclusion of suitable topographic scenery elements, such as hillsides, trees, plants, and grass.

The authors' experience suggests that including reverse horizontal curves connected by a short straight segment (as in the example shown in *Figure 1*) in the network works best to generate a realistic view of the landscape all the way to the horizon, while blocking the view of the parts of the network that are void of scenery elements. Other aspects of the network creation include a median and lanes in the opposite direction. To increase the realism of the video, a new graphic representation of the traffic lanes (with the proper lane width, realistic longitudinal pavement markings, left and right shoulders) replaced the default traffic lanes used by the simulator. Because Vissim creates the simulated roadway connecting (x, y, z) points by straight lines, horizontal and vertical curves along the road alignment were defined in the simulation using closely spaced points, corresponding to a 1-m increment on the x-axis. These short segments ensure that the vehicle movement along the road in the video clip is smooth and thus more realistic.

Figure 1 illustrates the network created for this study, showing the segment used for the video clip creation (between points A and B), surrounded by the landscaped area, and the section used for feeding vehicles into the network. Points A and B must be carefully chosen to ensure that the views from the driver's field of vision include only the

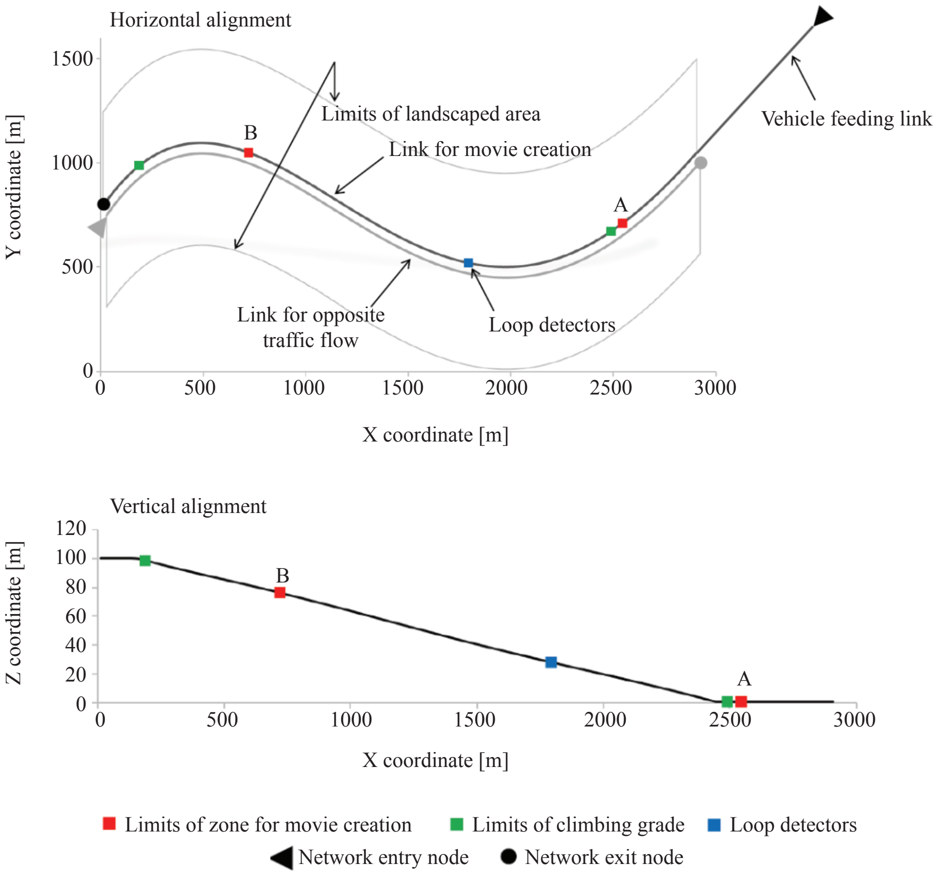

Figure 1 – Horizontal and vertical alignments of the simulation network, containing the links for traffic input and the landscaped area where the videos are created

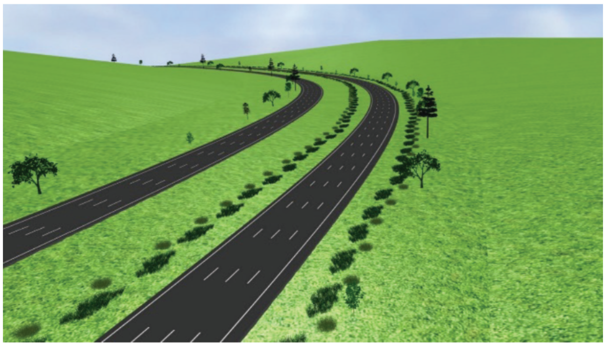

Figure 2 – Overview of the landscaped area

landscaped area. The section A–B used for the creation of the videos must be long enough for a 1-minute clip. If the study includes the study of the effect of steep inclines on the users' perception of the quality of service, the network should include an upgrade. The starting point for this upgrade should be such that it appears ahead of the car in the videos, so the respondent is able to notice that the car will climb a grade.

Figure 2 shows a general view of the landscape scenery elements along the roadway segment, such as grass, plants, and trees. In the figure, it is possible to observe both freeway directions, with pavement markings, shoulders, and the median.

5. ROADWAY VIEW FROM VEHICLE INTERIOR

It is also important that the generated driver's field-of-view from within the vehicle cabin be as realistic as possible [10]. The dashboard speedometer must be displayed because vehicle speed is frequently checked by a driver [26]. Drivers typically also want to know the posted speed limit of the roadway – this information is displayed in the recorded video (lower right corner) for 10 seconds at the beginning and 10 seconds at the end of the clip, rather than through occasional roadside speed limit signs that could be obscured by other vehicles. The windshield rear-view mirror should also be included since many drivers frequently check traffic approaching from behind. A separate video has to be created for the rear-view mirror and then overlaid with the front video, with time synchronisation. The combination of the two videos provides a realistic representation of overtaken and overtaking vehicles around the subject vehicle, as well as the intensity of the traffic flow.

Figure 3 shows the road from the driver's viewpoint, after the front-view and rear-view movies are combined and the instantaneous speed is placed over the dashboard. Both the forward- and the rearward-looking videos should be generated from a point-of-view corresponding to the typical eye height of a passenger car driver, 1.08 m above the pavement [35, p. 3–15].

Once the simulation network is properly set up and the desired level of realism for the animated videos is achieved, the next step is the selection of a representative vehicle within the traffic stream for the production of the video clips, as discussed next.

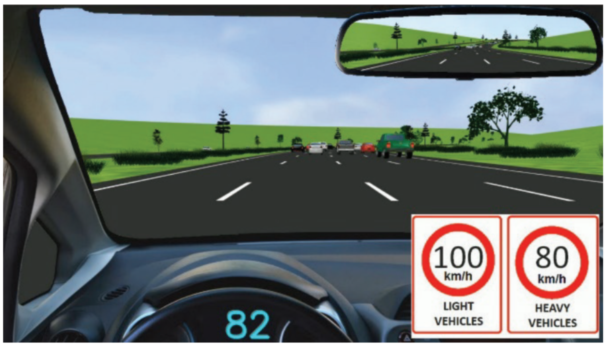

Figure 3 – Driver's view of the road and surrounding landscaped area through the windshield, with speed indication (in km/h) on the dashboard and a traffic stream presenting a density of 16.8 veh/km/lane

6. VEHICLE SELECTION IN TRAFFIC STREAM

The other significant issue is related to the variance of driver behaviour within the simulated traffic stream: which, among all the vehicles in the simulation, should be selected for the creation of the video clip? If the traffic stream is to be observed from overhead, this would not be a problem because the entire stream itself would be the object of interest. A video clip made from a driver's viewpoint, however, requires a careful choice of a vehicle that is really representative of the operational conditions that one wants to represent or, in other words, the density within the driver's field of view.

Previous studies have shown that density, speed variance, and percentage of free-flow speed are strongly correlated to the perceived quality of service [9, 17, 30]. Therefore, it is necessary to find a car whose speed and distance to the vehicle ahead vary as little as possible around the expected values for the operational conditions portrayed in the video clip.

Figure 4 illustrates the problem of randomly choosing any vehicle to create the video clip. It shows the variation of second-by-second speed of six vehicles over 60 seconds, for three simulation scenarios representing two different densities (6.0 and 16.8 veh/km/lane), with 0% trucks and 100 km/h speed limit. At a density of 6.0 veh/km/lane (near the threshold between LOS A and B), one would expect very little variation in speed, which should be close to the speed limit (100 km/h), as observed for vehicle 2, whose speed drops to 80 km/h and then goes back to its initial value. Vehicle 1 would not be a good choice: its speed varies considerably during this simulation interval and might not represent, for a person watching that clip, the traffic conditions expected for high levels of service.

At a density of 16.8 veh/km/lane (close to the boundary between LOS D and E), the average speed should be lower than for the 6.0 veh/km/lane scenario; however, this may not be the case for any individual vehicle, as is observed for vehicle 5, which travels very close to the speed limit for a large percentage of the time interval. Vehicle 6, also representing a heavy traffic scenario, started the simulation with instantaneous speed higher than the speed limit. A participant, watching these three 60-second video clips representing the heavy traffic, might not think that they represent trips within LOS D operational conditions.

To solve the problem of selecting a representative vehicle among all the vehicles in the simulation, we developed an approach based on the relationship between speed (u) and density (k). Initially, simulation output is used to fit a speed-density function, which is then used to choose a vehicle in the simulation that is travelling under the desired conditions.

6.1 Using the speed-flow relationship to select a representative vehicle

If the objective is to determine how drivers perceive the quality of service under a range of conditions, then each simulation scenario is a combination of factors (e.g. speed limit, truck percent, grade magnitude, number of lanes etc.) for a range of densities representing the LOS spectrum.

The developed approach uses a speed-density relationship fitted for each scenario to determine the flow rate and average speed that correspond to the desired density level. Since speed-density functions generated from simulation are very dependent on the employed car-following and lane-changing models and often do not match very closely empirical relationships, they have to be fitted to the output of simulation runs for each scenario, otherwise the selected vehicle might not be representative of the desired density conditions.

The data for fitting the speed-density function is obtained from loop detectors placed at a representative location in the network (e.g. at the location indicated as "Loop detectors" in *Figure 1*), where heavy vehicles would be travelling at their crawl speed on the upgrade, should a steep incline be part of the network. A series of simulations, starting with an input flow rate of 100 veh/h/ln, increased by 100 veh/h/ln every 15 minutes until reaching capacity, provides the data to fit the speed-density model.

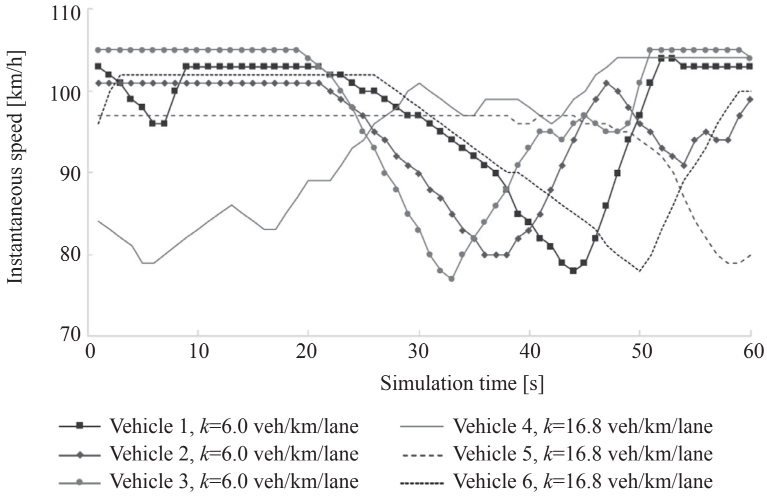

Figure 4 – Variation of instantaneous speeds of randomly selected vehicles during 60 s of simulation, for traffic streams with densities of 6 and 16.8 veh/km/lane

From the 5-min simulation reports, density is calculated using the relationship $k=q/u$ and the model is fitted using regression analysis. Any monotonically decreasing function that has a good fit to the simulation outputs can be used.

Figure 5 illustrates the proposed approach. In this example, a parabolic function was chosen to represent the speed-density function for a simulation scenario with 4% grade, 4 lanes, 100 km/h speed limit and only passenger-cars.

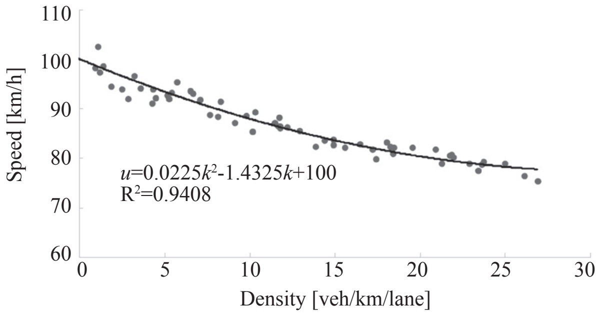

Figure 5 – Example of a speed-density function fitted using simulation results

The input flow rate for the simulation is calculated using the relationship $q=k \cdot u$, for the desired density level. For instance, considering the scenario presented in *Figure 5*, to record video clips that represent a density of 7.2 veh/km/ln, the required flow rate can be obtained using the fitted speed-density function:

$$u = 0.0255k^2 - 1.4325k + 100 \tag{1}$$

Setting k=7.2 veh/km/ln in *Equation 1* results in u=91.0 km/h; thus, the required traffic flow rate is q=7.2·91.0=655 veh/h/ln. At this flow rate, a representative vehicle would be travelling at an average of 91 km/h and the average spacing to a vehicle in front of it would be the inverse of the density, or approximately 140 m.

The search for a vehicle satisfying such conditions, among all vehicles in the simulation, would be very tedious and time-consuming to perform manually; thus, an automated search is the only reasonable way to facilitate this task.

6.2 Automated search for a representative vehicle for video clip creation

To ensure that the selected vehicle represents the target traffic conditions, the search for such vehicle requires checking a series of conditions, as illustrated in the flowchart in *Figure 6*.

The search for the suitable one-minute vehicle trip for the video clip creation starts by ranking every one-minute interval in the simulation according to traffic density and truck percentage. Using a sufficiently long simulation of the desired density scenario (i.e., using the input flow rate calculated as shown in the previous section), the loop detectors are used to collect 1-min interval data on the percentage of trucks, flow rate, average speed, and density (computed as $k=q/u$). These 1-min intervals are then ranked using the function:

$$\begin{aligned} F_{rank}(i) = & \left| k(i-1) - k_{des} \right| + 3 \cdot \left| k(i) - k_{des} \right| \\ & + \left| k(i+1) - k_{des} \right| + 10 \cdot \left| p(i) - p_{des} \right| \end{aligned} \tag{2}$$

where $F_{rank}(i)$ is the ranking function value for the i-th 1-min simulation interval; $k(i-1)$ is the density in the previous simulation minute; k_{des} is the desired traffic stream density; $k(i)$ is the density (veh/km/ln) in the i-th 1-min simulation period; $k(i+1)$ is the density in the next simulation minute; $p(i)$ is the proportion of trucks, in decimal, in the

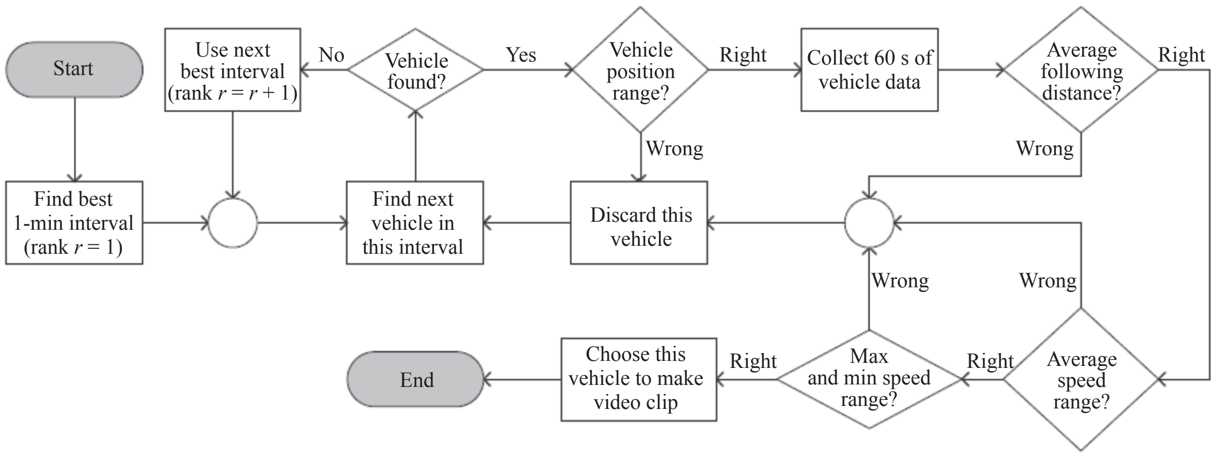

Figure 6 – Flowchart of method to search for a representative vehicle

i-th 1-min simulation period; and p_{des} is the desired proportion of trucks. The coefficients in the ranking function reflect the relative importance of each parameter: the density in the previous or in the next simulation minute is not as important as during the current (i-th) minute and the truck proportion is less important than the density.

To avoid selecting periods when density or percentage of trucks is too different from the desired levels, an arbitrarily large penalty (e.g.-1000) is added to the ranking function value obtained from *Equation 2* if $|k(i)-k_{des}| > 0.5\ k_{step}$ or $|p(i)-p_{des}|>0.5p_{step}$. These two checks ensure that traffic density and proportion of trucks during that minute is sufficiently close to the desired levels, assuming that k_{step} is the density step and p_{step} is the truck percentage used to produce the videos.

After this, the 1-minute interval $F_{rank}(i)$ values for the simulation are ranked, from the smallest (best) to the largest (worst). The notation used to represent the sorted order is r, where r=1 is the rank for the best ranked 1-minute interval, which is the one with the lowest $F_{rank}(i)$ value.

The next step in the procedure consists of finding a vehicle in the best-ranked minute that satisfies all criteria in the flowchart shown in *Figure 6*, with regard to its initial position in the network, its speed and average distance to the vehicle travelling ahead during the 60-s simulation interval. The initial position is relevant because, depending on the initial or final position of the vehicle on the segment, the video might include undesirable views of empty space beyond the landscaped region.

The procedure uses second-by-second data for each simulated vehicle, as shown in *Table 1*, with outputs of simulation second, vehicle number, position from the beginning of the link used for the video creation, speed at the end of the time step, and distance behind its leader vehicle (following distance).

The procedure starts by finding the best ranked 1-min interval. The next step consists of searching the data shown in *Table 1* to find the first vehicle whose simulation time (first column in *Table 1*) is within that 1-min interval. Upon finding a vehicle that satisfies this condition, the programme checks the position of that car in the link. In the network used by the authors, only cars whose position is between 500 m and 530 m from the start of the link are desired, because the rear view mirror image must only show the landscaped area and the video must show the beginning of the slope. If the vehicle's position is within this range, then the average speed, maximum speed, minimum speed, and the average following distance are collected for the vehicle for the next 60 simulation seconds; otherwise, this vehicle is discarded and the programme looks for the next vehicle in this 1-min interval.

Table 1 – Example of the vehicle tracking data exported by simulation tool

Simulation time [s]	Vehicle number	Position [m]	Speed [km/h]	Following distance [m]
300.05	77	1083.17	80.17	250.00
300.05	79	1436.12	87.80	250.00
300.05	90	562.56	77.72	250.00
300.05	97	736.23	88.87	250.00
301.05	77	1105.44	80.17	250.00
301.05	79	1460.51	87.80	250.00
301.05	90	584.15	77.72	250.00
301.05	97	760.92	88.87	250.00
302.05	77	1127.71	80.17	250.00
…	…	…	…	…

The next restriction to be checked is the average following distance, s, which must be within the interval:

$$\frac{1000}{k_{des}+k_{step}} \leq s \leq \frac{1000}{k_{des}-k_{step}} \tag{3}$$

where s is the average following distance (m) for this vehicle during the 60 s of collected data. This check guarantees that the average spacing will be within the predefined density level during the video clip; if not, this vehicle is discarded and another one is tested.

The last two checks verify that the vehicle's speed is compatible with the desired density range and does not vary too much during the 60-s period of interest. The first condition checks if the average speed is within the speed calculated per the developed speed-density function (as illustrated in *Figure 5* and *Equation 1*), using the desired density, plus or minus a small tolerance (e.g. 1 km/h). Thus, it guarantees that the average speed of the vehicle is always lower than the average speed of a vehicle chosen for lower densities. Also, the maximum and minimum instantaneous speeds must not differ by more than a reasonably small range (e.g. 10 km/h) from the average speed during the 60 seconds that the video clip lasts. Failing either of these two checks, the vehicle is discarded and the programme searches for the next one within that 1-min interval.

This procedure can be automated using, for instance, Visual Basic for Applications (VBA) in an Excel spreadsheet or Python. Once the search procedure finds a vehicle that passes the four checks, a video clip of these 60 seconds is recorded from the driver's point of view, facing forward (to show the windshield view) and facing backwards to create the image in the rear-view mirror.

We used a Python programme to place the speedometer, a speed limit sign at the beginning and end of the video, the forward-looking video and the rearward-looking video in the proper places on an image of a car interior. The final result is shown in *Figure 3*. The speedometer shows the speed second-by-second, using data from the simulation output (*Table 1*). The procedure is then repeated until video clips for all scenarios are recorded.

7. RESULTS

The best way of demonstrating the effectiveness of the proposed approach is to show two vehicle trajectories, one created from a vehicle selected using this procedure and another one created from a randomly chosen vehicle. *Figure 7* shows the instantaneous speed of six vehicles selected using the proposed approach (three in each density level) during a 60-s video clip. For low density (6 veh/km/ln, speeds were constant for almost the whole duration of the video and near the speed limit (100 km/h), as one would expect. Vehicle 1 experiences some interference from other vehicles but the speed drop is within what has been defined as acceptable. Higher density traffic conditions (k=16.8 veh/km/lane) produce lower vehicle speeds. There is also interference from slower vehicles causing a reduction in speed, as in the first 17 seconds of the video clip of vehicle 4. All vehicles' maximum instantaneous speeds are lower than the speed limit and consistent with the traffic stream density: vehicle speeds are different for different density levels and similar for vehicles travelling within the same density level. Comparing the vehicle trajectories in *Figure 7* to those previously shown in *Figure 4* makes evident the improvement brought by the proposed approach.

Table 2 compares information gathered from individual vehicle tracking data (shown in *Table 1*) and traffic stream data (from loop detectors) to show that the operational conditions during the 60-second trips are similar to the point measures. Note that the average density experienced by the selected vehicles in the scenario with density of 16.8 veh/km/ln are higher than those for the 6 veh/km/ln scenario, as expected. The average speeds of vehicles in the scenario with density 6 veh/km/ln are higher than those for the selected vehicles in the 16.8 veh/km/ln density scenario. The density derived from detector data is very close to the desired density, for both scenarios.

A sample video [36], available for download, demonstrates the comparison of trips by randomly selected vehicles and vehicles chosen using the developed procedure. The data shown in *Table 2* and *Figure 7* were obtained from the simulations used to create the sample video.

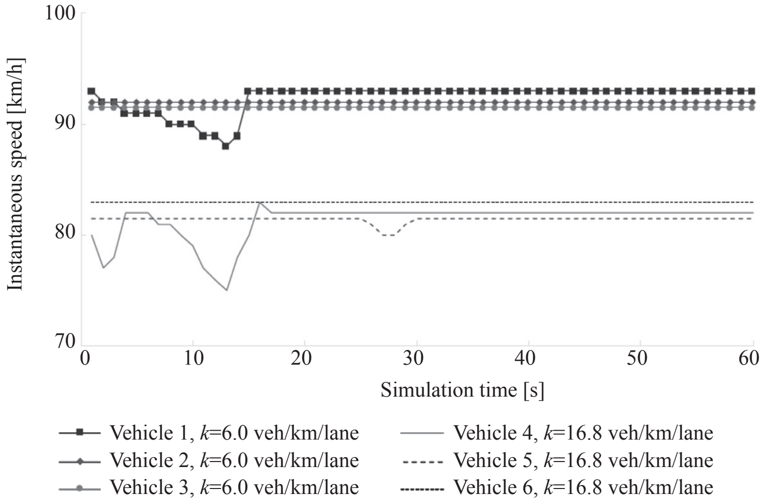

Figure 7 – Instantaneous speeds for six vehicles selected using the proposed approach. Simulation conditions for density of 6 veh/km/ln are +1% grade, 4 lanes, 100 km/h and 0% trucks and the same for 16.8 veh/km/ln, except for grade (+4%).

Table 2 – Data for six vehicles selected by the developed procedure: vehicle data are obtained from tracking individual vehicles over the 60-s trip; traffic stream data are obtained from the loop sensors over the same 60 s time interval

	Vehicle data		Traffic stream data		
Id	Speed [km/h]	Density[1] [veh/km/ln]	Speed [km/h]	Density[2] [veh/km/ln]	Target density [veh/km/ln]
1	92	5.1	85	6.0	6.0
2	92	6.2	94	5.9	6.0
3	92	6.2	95	6.0	6.0
4	82	17.2	81	16.9	16.8
5	82	17.5	84	16.9	16.8
6	82	16.4	83	16.9	16.8

¹ Density = (Average vehicle spacing)$^{-1}$
² Density = Flow rate / Average speed during the 60-s interval

We used the proposed approach to create 417 one-minute video clips covering 128 traffic stream scenarios for a follow-on study to collect LOS ratings from a large audience. Study participants visited a website where they watched and rated a subset of these video clips (total of 12) depicting a wide range of traffic densities, from very light traffic flow to capacity flow. The website-video clip strategy allowed for reaching a large number of participants (977 persons) at a very low cost over a short time. The results of the analysis of the obtained 10,228 ratings will be reported in a subsequent paper.

8. CONCLUDING REMARKS

This paper describes guidelines and processes that can be used to facilitate the application of traffic microsimulation software to the study of user perception of traffic operational conditions. The topics covered included network creation, field-of-view setup from the vehicle cabin interior, and development of an automated procedure to select representative vehicles in the traffic stream. The end result is animated videos that realistically portray a 60-s vehicle trip under the desired traffic characteristics. The proposed vehicle-selection procedure was developed and tested using a programme coded in VBA, but any programming language can be used. The programme was used to select vehicles to create 60-s video clips for different combinations of traffic stream density, truck percentage, grade magnitude, number of lanes and speed limit. The proposed approach was found to generate video clips that represent the operating conditions of the traffic stream with greater fidelity than those created using randomly chosen vehicles. Researchers interested in obtaining the VBA and Python source code are encouraged to contact the corresponding author.

The flow rate and speed for any given scenario are set to yield a specific density for the overall simulated traffic stream. However, one limitation of the proposed method for selecting the vehicle in the simulated stream is that it only uses information about the car ahead of the candidate vehicle and does not include information about vehicles travelling behind the candidate vehicle or on adjacent lanes. This limitation could be overcome by means of second-by-second evaluation of a “local” density, based on the number of vehicles within the driver's field of view, to the front, side, and behind the candidate vehicle (through front windshield and rear- and side-view mirrors). Furthermore, additional checks on the selection of the representative vehicle could, for instance, include measures of how many seconds the vehicle is travelling outside the upper and lower limits for instantaneous speed and spacing.

DATA AVAILABILITY

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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USO DE MICROSSIMULADORES DE TRÁFEGO EM ESTUDOS DO NÍVEL DE SERVIÇO BASEADOS NA PERCEPÇÃO DOS USUÁRIOS

RESUMO

As classificações de nível de serviço (NS) das condições operacionais de tráfego desempenham um papel importante nas decisões de financiamento de melhorias em rodovias. A percepção do NS do viajante deve ser consistente com os valores produzidos em análises de tráfego para que os contribuintes tenham confiança nas decisões das agências de transporte. Os métodos de pesquisa para estudar as percepções dos usuários variam de vídeos gravados em veículos a grupos focais e pesquisas com os usuários. Esses métodos têm vantagens diversas, mas são pouco eficientes com relação ao tempo e/ou custo para coletar dados de ampla gama de condições operacionais. Este artigo descreve um novo método para estudar este tópico com maior eficiência de tempo e custo, combinando microssimulação de tráfego e visualização 3D. O foco do artigo é fornecer orientações sobre como aplicar a microssimulação de tráfego e visualização 3D por computador para avaliar a qualidade da viagem na rodovia a partir da perspectiva de um motorista. São discutidas a criação do ambiente de simulação para produzir uma visualização realista do interior da cabine do veículo, incluindo a rede, o ambiente no entorno da rodovia, o velocímetro e o espelho retrovisor. Propõe-se também um método automatizado para escolher um veículo apropriado dentro do fluxo de tráfego simulado, de modo que as condições gerais desejadas da corrente de de tráfego sejam visualizadas dentro do campo de visão do motorista.

PALAVRAS-CHAVE

visualização 3-D por computador; nível de serviço do tráfego, percepção das condições de tráfego; microssimulação de tráfego; método de seleção automática de veículos.

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