Traffic Itself Is Simple – Just Analyzing It Is Not

Ralf Schleiffer
German Aerospace Center
Transport Research
51170 Cologne, Germany
E-mail: Ralf.Schleiffer@dlr.de

Abstract
Traffic itself is simple – just analyzing it is not. So why should we make our live difficult by trying to identify the underlying determinism of traffic by analyzing given time series with the usage of stochastic tests like regression or spectral analysis or with the usage of strange attractors as they are utilized in non-linear dynamics? And, moreover when applying such models for analysis we should be aware that we usually filter out all heterogeneous dissimilarities which can cause completely different explanations of our observation.

If the above hypotheses is correct as it will be discussed in this paper it is much more easy to produce traffic in our computer terrarium by generating artificial agents that request mobility in TrafficLand and employ simple rules, such as preferences for or against choosing a specific freeway, an individual travel speed, etc., that interact with each other under the given environmental conditions, and then we just examine the behavior of the whole population from a macroscopic point of view in order to compare it with real world observations. It will be illustrated in this paper that doing so we discover simple fundamental individual mechanisms that generate the highly complex and dynamic collective behavior of traffic.

1. Introduction

Notions of linear regression analysis, gravity models, logit models, and analytic explanations have dominated scientific thoughts in traffic research for a long time. These notions are so widely accepted that, even when no more than a misleading forecast can be established, scientists often feel confident in applying them.

Traffic in our days presents a picture of millions of people moving around each pursuing their own interests in a somehow limited area of the environment. The individual activities might in some sense be called coordinated – in many instances a type of order emerges. This order is often explained by some form of global authority, of some macroscopic regulation that regardless of conflicting interests of people turns self-interest into communal agreement. It is assumed that environmental characteristics endow the mechanisms guiding and organizing the behavior of single people.

But in the traffic modeling picture that we can piece together from past research, there is almost no need for such a global authority since typically the models look at homogeneous groups of perfectly informed individuals tending in their behavior towards static equilibrium states by maximizing given utility functions. So the behavior of a whole group of people is regarded as that of one representative – obviously a brave assumption. Just regard the aspect that traffic models are often applied to make strategic measure recommendations. Now, these measures affect individuals differently and thus the representative constructed before introducing the measure no more represents the related group of people after the change.

Surely there must have been some researchers who were concerned about these traditional models and asked themselves, whether the consequences of heterogeneity are unimportant to that extent that they may be filtered out, whether the state of a system like traffic does not depend on the individual’s expectations about the future, whether traffic can be explained independently from economic, cultural and demographic processes, whether an individual’s private preference information and its tastes can be neglected, whether global information is more realistic than information exchange via decentralized communication, whether an individual’s limited and erroneous decision making capabilities and the individual learning process can be ignored.

This paper presents a view that may point towards a direction that could be suitable in handling these concerns.

There are many motivations to consider our world and with it traffic as being deterministic, i.e. as a cause-and-effect relationship at the microscopic level. Nevertheless it usually exhibits a remarkable spectrum of dynamical exotic behavior that is often interpreted as chaotic or as random. In fact, when observing the real world or in our case traffic, extremely subtle tests are needed to detect the
hidden relationship in order to preserve describing it as stochastic (e.g. computing the Kolmogoroff entropy of a time series, performing a spectral analysis, etc.). It is well known, especially in the field of non-linear mathematics, that even simple deterministic processes can exhibit a particularly complex behavior (compare with [1], [2]). Now obviously this can not be overlooked and thus it has consequences for modeling.

Thus the purpose of this paper is somehow twofold. On the one hand it will point out that heterogeneity is an important aspect when modeling real world traffic behavior. On the other hand it will describe two examples on how a developed computer application can be utilized as a type of research laboratory in order to test which microscopic characteristics lead to observed macroscopic behavior.

The way we will take is to follow the path directed in socio-economic studies by Epstein and Axtell [3], by Gaylord and D’Andria [4] and by other researchers. Like they did when examining wealth development and distribution by simulating artificial societies, we will try to grow traffic with focusing on route choice and in the future also on mode choice examples, and particularly with drawing attention to learning behavior and to information distribution, from the bottom up.

Artificial autonomous agents, synonymous with autonomous agents (AA), were selected because they can be expected to uncover the underlying structure in traffic. They represent a type of computational intelligence and they operate similar to human populations - though on a highly simplified scale. But as we will see, already their simple determinism will be suitable to illustrate and to describe the dynamical structure of human behavior with reference to traffic.

There are several significant differences that distinguish AA from classical macroscopic modeling approaches of which some characteristics are listed above. Another feature of most of the established models is that the independent variables are combined in strictly linear fashion. And moreover the complexity in a model sometimes extends to such a high degree that the definition of additional variables whose relation to the real world is often not obvious becomes necessary.

In contrast to that our agents do not require the slightest macroscopic information. All they need is microscopic data described on the basis of single individuals. They will be equipped with data on where they live and where they have to go for work and also with some behavioral rules, e.g. how to move. Apart from that for any of these agents it is only important to know what he likes and what he avoids. Thus allowing him to select a specific alternative from a set of given alternatives. In order to support the decision making within the course of this paper our agents will be allowed to learn from past experiences and to exchange this knowledge with others.

Of course picking the right rules and characteristics is a critical development since even as we are involved in traffic activities every day, the knowledge about the rules we put into operation is for the most part unconscious. As we will see a good subset of all possible influences is enough to grow what we wish to view. This idea of excluding possible influences might be hard to accept since including more details of the reality should make the dynamics of the model be much more similar to reality. But there are credible purposes to do so: adding more characteristics of the reality does not necessarily result in a better understanding of the roots for the dynamics under investigation; and moreover limiting ourselves to a subset of them does substantially improve the computational performance of our model. For sure, the challenge is to find ways to pick the good features of the agents. And when this is done we just sit back and watch the traffic evolve.

The next parts of this paper are organized as follows. In chapter 2 we will have a look at TrafficLand, the world in which our agents act. And then in chapter 3 the agents’ preference modeling as well as their learning abilities will be explained. In the subsequent chapter we will have a look at our first example, examining the satisfaction about travel time in the agents community depending on the route choice process of agents who have to go to work over some distance and who can chose among different roads. This will be regarded under dissimilar types of information exchange. Chapter 5 will bring some strategic traffic flow measures such as speed limits on several roads, radar traps and also speed limits only for particular groups of agents (trucks) to our landscape. In this chapter we will examine the influence of these regulations on our agents’ satisfaction and on the occurrence of traffic jams. Finally the last chapter will give an outlook on future research.

2. A new landscape in our computer

TrafficLand is an artificial landscape in our computer that consists of a two-dimensional chessboard-like grid of predefined size. In our examples, as it is illustrated by Figure 1, is has 120 times 240 (North-South x East-West) alternative positions. These positions are designed such that they can occupy only one agent at a time. The grid is modeled as being surrounded by boarders except in the north and in the south, i.e. an agent who moves e.g. over the south side of the grid appears at the opposite column in the north. An agent can not move over the East or the West side of the grid.

The grid itself is partitioned in two separate spaces that are connected by openings within the barrier. At the
beginning of our examples all agents live on the landscape in the West. This is where they return after work and where they spend their leisure activities which might include additional travel in order to visit some friends. The East part of the grid is where our agents are employed, where they have to move to each day. (In Figure 1 the home positions are marked by the dots in the West and the work positions by the dots in the East of the grid.) But note that the agents are not restricted to these positions. In future examples the agents’ homes and works will be positioned based on different rules.

The openings in the barrier between the East and the West landscapes are initialized at random positions. Their number can be fixed in advance as well as it might be random. They typically differ in width and in length but these characteristics might also be pre-defined to fixed values. Through a wider break in the barrier more agents can pass at the same time than through a smaller one (compare with Figure 2 that zooms into the barrier shown in Figure 1). If such a break is blocked by some agents the following ones have to wait until space becomes available.

The underlying rule to build up the openings in the barrier is

\[ \text{IOP}[^{ζ, η}, {θ, 1}, {κ, λ}]: \text{initialize a random number between } ζ \text{ and } η \text{ of openings, each with a randomly determined width between } θ \text{ and } 1, \text{ and with a random length between } κ \text{ and } λ \]

These gaps in the barrier should be regarded as different roads, from one-lane ordinary roads to multi-lane freeways and expressways, leading from East to West and vice versa. Thus there are different lanes for East-West and for West-East travel.

Speed limits can be applied to all or to random roads and these might be controlled by radar traps (the light-colored dots above and below the roads in Figure 2) that can be initialized on roads with speed limit at hourly changing random positions. Ones a road has a speed limit this limit is not changed during a simulation. The explicit rules are

\[ \text{SL}[^{µ, ν, ο}]: \text{set the speed limit on } µ \text{ roads, each to a random value between } ν \text{ and } ο, \ µ \in \{ \text{all, random, no} \} \]

\[ \text{RT}[^{π}]: \text{set radar traps to random positions on } π \text{ roads with speed limit, } π \in \{ \text{all, random, no} \} \]

If an agent leaves the landscape in the West through such a gap he automatically enters the related road which he has to pass up to the end where he arrives at the East part of the grid at the gap’s opposite side.

Since each cell of the grid can only take one agent per time those that are already occupied are blocked for other agents. Additionally it is possible to block cells by agents’ homes and by agents’ work positions. In order to secure that an agent hiding home or to work is not blocked by the home and work positions of other agents, working and living positions are only initialized on the boarder of pre-defined open squares what is realized by allowing only positions with even horizontal and even vertical coordinate to become a home or a work cell.
3. Living in TrafficLand

Agents are the inhabitants of TrafficLand. They are distinguished in different groups with every agent belonging to a specific one. Agents of one group can be set apart from agents belonging to another group by different colors. They are equipped with a set of similar individual characteristics and they follow similar rules over the course of time. Some of the characteristics are static after initializing the agent, others vary. For every group these features can be initialized by fixing them to concrete values for all its agents or they can be individual random numbers within some distributional constraints. So although the model is fundamentally deterministic there are as well sources of randomness, primarily in the initial setting of preferences to an agent.

As soon as an agent is settled on the landscape a pair of destinations, namely his living position and his work position which both do not change during a simulation run, are randomly assigned to him. The possibilities to do are to randomly select a home position in the West and a work position in the East or vice versa, or to randomly choose these positions anywhere on the grid.

In the experiments of chapter 5 also trucks (slow speed agents) will be brought to TrafficLand. One of their characteristic is that they constantly travel from East to West and back again to destinations selected by chance on erratically selected roads. Thus there is the additional possibility that neither a home nor a work position is chosen, but instead destinations are picked out anywhere on the grid.

Each agent has an individual vision that specifies how far he can look around to find an empty cell where he might move to if his actual speed allows it. In every move the actual speed can only increase step by step. Typically it is limited to a speed individually preferred by the agent but if he is already late he might increase the speed up to its individual speed limit \( s_{\text{max}} \) that can not be broken. In the case the agent is travelling on a freeway his preferred speed \( s_{\text{freeway}} \) is different from the case when he travels in an urban area \( s_{\text{urban}} \) as it is represented by the grid cells.

As soon as an agent arrives at his home or at his work position he determines a time to leave and he waits until the time counter reaches this time. In the examples presented here the two rules to specify this time are

\[
\text{TLH}_g: \quad \text{wait until the actual time plus the expected travel time is } g \text{ then start moving to the work position}
\]

\[
\text{TLW}_h: \quad \text{wait until the time is } h \text{ then start back home}
\]

In order to determine the expected travel time an agent first has to select a particular freeway. One option to do so is to base the selection on a combination of his preferred travel speeds together with the single path length. The rule is

\[
\text{SF}_{\text{no}}: \quad \text{examine every freeway one after the other}
\]

\[
\text{• compute the travel time depending on preferred speed and path length to reach the final destination for the actual trip on the freeway in question}
\]

\[
\text{• rank the freeways according to the preference for short path length in contrast to short travel time}
\]

\[
\text{• select the best alternative (and store the expected travel time to decide when to leave)}
\]

An important feature of route choice is that the decision at a given time \( t \) depends in an essential way on the agent’s expectations about future travel times. The actual dynamics of the whole traffic flow on the single freeways is thus determined by the way agents forecast future travel times as a function of their information on the past, while possibly learning the structure of the travel times on the freeways. To describe this dynamical learning it is necessary to specify how an agent forms his forecast at time \( t \) as a function of his information on that time.

Every agent is equipped with a memory in which he can store an individual number of travel experiences for later access. The memory depth, i.e. the number of storable experiences is stationary over time. If it is different from zero the agent adds travel experience to his memory each time when he reaches his actual final destination and he erases the oldest experience from his memory if the memory depth is reached. On the first glance such a fixed bounded memory may appear to contradict learning since more and more experiences are available as time proceeds. Now, in reality it is difficult to believe that it should be possible to remember every travel in detail no matter how far in the past it happened. Typically only an individual number of the last experiences is available together with the travels taking minimum and maximum time. And this is exactly the information our agents have. The experiences concerning the shortest and the longest travel time on each alternative freeway are never erased from an agent’s memory. Of course the number of stored experiences can never be higher than the number of all past travels.

When an agent estimates a travel time for every freeway based on his past experiences, in those cases where they are available, he applies a specific individual principle to his past observations. The four possible principles are borrowed from the field of utility theory (compare with [9]). They are “take the minimum time (Minimum)”, “take a convex combination of the minimum and maximum time (Hurwicz)”, “take the average time (Bayes)” or “take a convex combination of the minimum time and the average time (Hodges-Lehmann)”. In those cases where no experience is available for a freeway the agent estimates the travel time following rule \( \text{SF}_{\text{no}} \).
The rule for including own experience is

\[ SF_{\text{own}}: \]
- examine every freeway one after the other
- if own experience for travelling on the regarded freeway is available compute an expected personal travel time for that freeway depending on past experience
- if own experience for travelling on the regarded freeway is not available estimate an expected travel time depending on path length and preferred speed
- rank the freeways according to the preference for short path length in contrast to short travel time
- select the best alternative (and store the expected travel time to decide when to leave)

If one is asked to list the most important influences underlying traffic phenomena social interaction would without question be one of the items at the top of the list. The influence of other people on individual behavior and decisions is some of the main factors behavioral modifications are based on. Thus a key feature of choosing a specific route in our model is that an estimated travel time is typically not only based on own experiences but also on the experiences of others. Accordingly every agent has an individual number of friends (other agents in the population; the equivalent in real world are co-workers, neighbors as well as other people living in the same area of the environment) with whom he can communicate so that information is dispersed among the agent population. But there are limits to communication since not every single travel experience is transferred to a requesting agent, i.e. the information is encoded into a limited set of signals that only includes the minimum, maximum and average travel time taken from the friend’s experience. In this way the communication could be called task-driven just like information exchange on the referring subject in real worlds takes place. In addition it should be noted that transmitting more detailed information would needlessly consume computation time.

Thus an agent’s private information as well as the experience of strangers is available for decision making. And therefore an agent has to elect if his decision depends more on his own experience or on the experience of other. To do this he is equipped with an individual optimism to make his decision rely on his own knowledge. Now the related rule to select a freeway can be stated as

\[ SF_{\text{other}}: \]
- examine every freeway one after the other
- if own experience for travelling on the regarded freeway is available compute an expected personal travel time for that freeway depending on past experience
- if own experience for travelling on the regarded freeway is not available estimate an expected travel time depending on path length and preferred speed
- if the experience of friends for travelling on the regarded freeway is available compute an expected friends’ travel time depending on their experience
- depending on the optimism to make a decision relying more on own experience than on the experience of friends compute an overall expected travel time for every freeway
- rank the freeways according to the preference for short path length in contrast to short travel time
- select the best alternative (and store the expected travel time for deciding when to leave)

Since one examination of this paper is the traffic flow (expressed in terms of agents’ satisfaction) under different information availability a central authority, that could be interpreted as a traffic jam information system, is introduced if “global information availability” is turned on for an agent. In this case all agents that are actually travelling on a freeway report their freeway identification and their actual speed to this authority that computes minimum, maximum and average speed values for the single freeways and that in turn presents these to the requesting agents. With this information the agent updates his route choice before every move according to the rule

\[ GI: \]
- examine every freeway one after the other
- if own experience for travelling on the regarded freeway is available compute an expected personal travel time for that freeway depending on past experience
- if own experience for travelling on the regarded freeway is not available estimate an expected travel time depending on path length and preferred speed
- get global information concerning minimum, maximum and average speed on single freeways
- compute the travel time depending on preferred speed in urban areas and path length to reach the regarded freeway and to leave it again to reach the final destination for the actual trip
- compute the expected travel time on the regarded freeway based on the minimum of “preferred speed on freeway” and “actual average speed on the freeway in question”
- add the computed travel times
- depending on the optimism to make a decision relying more on own experience than on the experience of others (in this case the global authority) compute an overall expected travel time for every freeway
- rank the freeways according to the preference for short path length in contrast to short travel time
- select the best alternative

The movement of an agent is different depending on whether he is in an urban area or on the freeway. Equal in both cases is the type of movement, i.e. if “reachable cells” are defined based on the neighborhood rules from von Neumann, Moore or Gaylord-Nishidate (see also [4]). Once more the selection is made individually. Typically the last option is chosen but also the other neighborhood definitions are applied by single agents. If an agent uses one these it can be interpreted as having a limitation to react on other agents movements.

First the case of travelling in an urban area will be described. Here a move is divided into several steps. The speed actually preferred by the agent (actually preferred) is set
equal to \( s_{urban} \). In cases where the arrival time is important an agent first checks if he is still in time and eventually he speeds up if he is not already driving at his individual speed limit. If he has the ability to receive global information and if he has not reached the freeway yet he requests global information about travel speed on the freeways and he updates his route choice. Then in a next step he looks around as far as the minimum of "vision", "actual speed plus one" and "preferred speed" (note that if the agent is already late the preferred speed is replaced by his maximum speed he can take) allows it to find a cell that is neither occupied by another agent nor is it a cell with a home or work destination on it (the blocking by home and work positions can also be disabled but this option will not be used in the examples presented here). Then he ranks the available new positions depending on their distance to the next destination that can either be the selected freeway or the actual final destination if the freeway is already passed. And finally if a reachable position that is closer to the destination than the actual one has been identified he moves onto this position and updates his actual speed. Thus the basic movement heuristic is

\( M_{urban} \):  
- if you are not driving at your preferred speed increase your speed 
- if you are late speed up (unless you are already driving at maximum speed) 
- if global information is available and the freeway is not reached yet update the route choice 
- go as far as your actual speed allows without crashing into another agent (or in a home or work position; if necessary adjust your speed) 

In the case that the agent is travelling along a freeway there are slightly different steps that complete a move. After the agent has set \( s_{actually preferred} = s_{freeway} \) he eventually replaces it by \( s_{max} \) if he is short of time. Next he checks if there is a speed limit on the freeway and if there is one he eventually adjusts his actually preferred speed to "allowed speed plus a positive random number" if it was previously higher. Then he looks into the direction of the freeway as far as his vision permits in order to search for possible radar traps. If one is detected and his actually preferred speed is higher than allowed he slows down to "allowed speed". Now he checks the cells in his travelling direction to find those which can be reached and which are not occupied by someone else. If he is already on a lane that is designed for overtaking others and if within vision there is someone slower on the lane right to him it depends on his preference for behaving when overtaking others if he immediately moves back to the lane right of him or if he stays on his lane and eventually moves one more lane left. Then he ranks the available positions in order to reach the one most far away from his actual one. And finally the movement to the new position is executed. Here the movement heuristic is

\( M_{freeway} \):  
- if you are not driving at your preferred speed increase your speed 
- if you are late speed up (unless you are already driving at maximum speed) 
- if there is a speed limit adjust your speed to drive only slightly above the limit (unless you are already driving at your preferred or maximum speed) 
- if you detect a radar trap slow down to the speed limit (if you are driving faster) 
- if someone slower is driving in front of you change to the lane to your left side in order to overtake him (if there is no more lane to the left, stay behind him) 
- if after overtaking someone there is another agent driving on the lane to your right decide depending on your characteristic if you stay on your actual lane or if you do not 
- go as far as your actual speed allows without crashing into another agent (if necessary adjust your speed)

\( \begin{array}{cccc}
\text{A} & \text{B} & \#2 & \#1 \\
\text{O} & \text{A} & \text{B} & \text{O} \\
\end{array} \)

Figure 3. Example for overtaking rules

An example is illustrated in Figure 3. Assume that agent A has a view of 5 (the white fields) that is not blocked by other agents, his movement and vision are based on the concept of Gaylord-Nishidate and its speed in the actual move is 5, too. Reachable cells are marked by a * for the case that 5 is the agent’s maximum speed. Furthermore assume that agent O is travelling at a slower speed than that of agent A who will overtake agent B. If A’s overtaking rule is “immediately move back” he moves to cell position 2, otherwise to cell position 1.

As a result an agent’s movement depends on global traffic rules given by the environment (e.g. speed limits, available routes), on local interaction with other agents (e.g. information exchange, blocking) as well as on his own heuristics (e.g. experience, preferences).

4. Driving to work

The overloads on freeways during top times of every workday’s commuter traffic are commonly known and their negative effects are sufficiently described. In this section the attempt to approach the reasons for overloads on some roads while others stay nearly empty will be carried out by letting commuters choose between optional freeways founded on their expected travel times on each alternative.

To illustrate the story that we start to grow in this chapter we will look at two exemplary agents A and B each following individual rules.
Every day in the morning at about the same time both awake - they have to go to work (in our first experiments they have to drive to the East side of TrafficLand where their employers are settled). A feels that he is still in time for enjoying breakfast for a while. If doing so takes him ten more minutes he will simply raise his speed to 100 miles per hour. And in the case he starts 15 minutes later then he will do 120. Of course he knows that this will not work when there is a traffic jam. But he remembers that there used to be a morning, maybe some month ago now, when he could drive that fast.

While enjoying his morning steak he is wondering which route should be the fastest one this morning - he does not care about the driving distance and the higher fuel consumption on a longer route, in his point of view driving is a type of leisure activity; the longer, the faster: the better.

Agent B is already on his way. On the last days he always took the same road to work and each day he started some minutes earlier. From these previous experiences he learned that he can take the shortest path within reasonable time if he starts without having breakfast, so that he avoids traffic peaks. Thus he prefers having his cup of coffee next to him on the front seat of the car and while he is trying not to spill the coffee he is listening to the radio. Suddenly there is a message calling his attention, saying that he is driving directly into a traffic jam that might cost him half an hour or even more. Unfortunately taking another route is no more a choice since all other roads towards the East are too far away from his actual position. Obviously B was not the only agent trying to avoid traffic peaks by starting early. For sure, next day he will take this into consideration when he decides when to leave home and which route to take, or maybe it would even be better to call some friends and to ask for their travel experiences.

In the meantime also agent A is on the road, driving as fast as the car’s engine allows it. Speed limits are there for the others, not for him; except for those specific position where radar traps are positioned alongside the road. But such a position is not reached yet. Instead he reaches a traffic jam. Maybe it was not the best choice to succeed as his neighbor suggested this morning when he met him in front of the house. But this is too late now there are already too many cars around him to leave the road anymore. So he starts becoming enraged about all the other agents blocking him and he decides to stay on the leftmost lane to secure that no other agent can limit his overtaking intention.

Finally our agents reach their destination and start their work. After work is over they commence a new decision making process in order to select a route to travel home.

In the following sections we specify the rules which guide the agents through their day and under which they determine what to do. These rules as well as the environment will be described for some experiments using the notions from chapter 2 and chapter 3.

We look at a grid of the size 120 times 240 different positions with the agents’ home in the West and the work positions in the East. The rules specifying the landscape are equal in all examples described in this chapter. They are set to \( FE \) \([9, 18]\), \( 0 \) \( IOPE \) \([7, 7]\), \([1000, 1500]\), \([1, 3]\), \( SL_{\text{random}} \) \([4, 5]\) and \( RT_{\text{random}} \).

In this part of the paper there are two groups of agents initialized on the landscape. Few of the agents’ characteristics are set to fixed values such as \( \text{importance of path length} = 0 \) percent (the importance of travel time is \( 100 - \text{importance of path length} \)), reachable positions are for all agents defined according to the concept of Gaylord-Nishidate and the vision as well as an agent’s movement are always blocked by home positions, by work positions and also by other agents.

To preserve heterogeneity in the agent population when performing a simulation run the agents’ characteristics are initialized depending on a Laplace distribution over the appropriate sets of choices for every characteristic. Note that ones a simulation is started no additional randomness is utilized. All other properties of the model are completely deterministic.

Every agent is initialized with applying one of the strategies given in the previous chapter to compute his travel time. The choice is made by throwing a roulette wheel. He has between 0 and 20 friends and also his other characteristics are initialized by chance with \( s_{\text{urban}} \in [1, 3] \), \( s_{\text{freeway}} \in [3, 8] \), \( s_{\text{max}} \in [5, 8] \) and \( \text{vision} \in [1, 12] \). Agents start traveling according to \( TLH_5 \) and \( TLW_{18} \). Of course the selection of all these values is arbitrary however it can be explained by equivalence between the model and the real world.

With these initializations six different experiments concerning information availability were executed a number of times. They are listed in Table 1.

<table>
<thead>
<tr>
<th>experiment</th>
<th>group 1 (size = 1000)</th>
<th>group 2 (size = 1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>information availability</td>
<td>memory depth</td>
</tr>
<tr>
<td>1</td>
<td>no</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>global</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>own</td>
<td>[0, 50]</td>
</tr>
<tr>
<td>4</td>
<td>own</td>
<td>[0, 50]</td>
</tr>
<tr>
<td>5</td>
<td>other</td>
<td>[0, 50]</td>
</tr>
<tr>
<td>6</td>
<td>global</td>
<td>[0, 50]</td>
</tr>
</tbody>
</table>

In the case when information of friends is available an agent’s own experience is initialized to be as important for decision making as the information received from friends. Each time he made his decision relying on the information
received from others he compares the realized travel time with his preferred one. And in the case that it is significantly higher he reduces the importance of his friends’ experiences for his decision making. And if his decision was relying on his own experience and the realized travel time is far above his preferred travel time he increases the influence of his friends’ experiences on his route choice. This procedure is the same if global information availability is introduced.

Information exchange among travelers was already inspected by utilizing a cellular automata in [8]. Due to our agents’ ability to adjust the influence of others on their decision making process the findings here differ from those discovered there. If the adjustment ability is turned off the outputs obtained in this place are similar.

The output variable that will be examined in order to compare the different information availability is the agents’ average satisfaction about their travel time. To be exact

\[
\sum_{s=\text{min}}^{\text{preferred travel time} - \text{realized travel time}} \frac{\text{completed travels}}{\text{number of completed travels}}
\]

is measured.

Since we are dealing with feedback processes the value of the single outputs depends considerably on the input in the sense that slight changes in the initial distribution of characteristics can lead to highly different results (as it is discussed in [7] in the context of feedback processes focusing on demand and supply interaction in travel mode choice) and thus the system behavior is not exactly the same in all runs. In particular it did never converge to a steady state. But nevertheless some qualitative results can be derived from the experiments listed in table 1 that were each simulated a number of times over a period of 150 days with all agents updating their positions every 30 (simulated) seconds in a random order.

In each simulation run the ways into the freeways served as a bottleneck with the agents getting stuck. (Of course traffic jams occurred only when the number of agents inhabiting TrafficLand exceeded a certain value that depended on the grid size as well as on the number of available freeway lanes. After some experimenting the relating numbers were fixed to those values given above.) After leaving the driveway there remained some space between an agent and the one travelling in front of him. But owing to different speed preferences the faster agents caught up to the slower ones and additional traffic jams occurred which could be observed to travel backwards as it was already illustrated in [5] and in [6]. In front of every radar trap the situation was the same.

The first day went equal in every experiment. Each agent looked out for the freeway offering the shortest travel time from origin to destination and since an agent’s expected travel time depends on a combination of path length and preferred speed, longer freeways remained nearly empty.

Executing experiment 1 this situation did not change. The agents constantly formed traffic jams on the shorter freeways. In this example the average satisfaction was the worst. But surprisingly it was not much lower than in experiment 2 when all agents received global information about actual speeds on freeways. In this example agents that were still far away from the openings in the barrier, while others had already entered the freeways, often changed their road selection and moved towards other freeways loosing time this way. And moreover since many agents did the same traffic jams occurred on their freeways too while the original jams on the freeways selected at first had already disappeared.

Experiment 3 improved the value of \( s \) after about 20 to 60 days travelling. The agents were distributed over all freeways but jams still became visible. Once there was a traffic jam on a specific freeway the situation on that road did not change very much within the next days. But then slowly from day to day the number of agents moved to other freeways that occupied fewer jams on the days before. This observation can be explained in that as soon as an agent gets stuck too often on a freeway he selects another one. Depending on the memory capacity “get stuck too often” is interpreted differently by all agents so that the changes did not occur at the same time.

In the following example the agents were partitioned in two groups of equal size with the agents of one group exchanging information with friends while the others could not receive information apart from their own experience. Average satisfaction significantly increased. Basically this was due to the agents communicating with others as they made their route choice more successfully. And those not communicating at all profited from the others efficient choice. Experiment number 5 now and then improved the average satisfaction to some extent but occasionally the value of \( s \) was somewhat lower. It seems that if a number of agents has the ability to make a route choice effectively increasing their number does not contribute to better results.

In example 6 all agents were initialized to use global up to date information. This example brought the best results but note that the distance from \( s \) to its value in the previous two examples was fairly low. Nevertheless it seems that global information does serve best. It was quite a surprise when the agents’ values for relying in their decision on own experience in contrast to the utilization of global information was examined after 100 days. In each run of the simulation over 60 percent of the whole agent population did not make their decision rely on global information to more than 5 percent. Their decision depended on their own experience only. The value of five
percent can be explained by the model since each time an agent is not satisfied with his route choice he adjusts his preference on which information should be considered by adding or subtracting five percent respectively.

Thus the main result of these experiments can be summarized in that the individual satisfaction concerning travel time can be achieved through decentralized communication more fruitfully than by global information at least if all individuals have the same informational options. In consequence any future traffic information system, e.g. publishing traffic jam information for holiday travel or broadcasting traffic jams on the radio, should be designed to support local self-organizing structures.

5. Traffic jams

Traffic flow itself is a rich domain for observing collective and dynamic group behavior (for an analysis of traffic flow on one-lane roads and on two-lane roads in a cellular automata environment compare with [5] and [6]). The question followed here is if strategic traffic flow regulating instruments can be identified that are able to increase the overall traffic throughput. Two strategies are examined: one is to introduce speed limits on freeways and the other one is to increase the speed for trucks. Both measures are designed to reduce the difference in speed of the single agents.

As on real freeways our agents are in most cases willing to accept a speed limit only in the sense that they travel not much faster than the limit allows. To catch those agents going above the speed limit radar traps are randomly initialized along those roads allowing travel at reduced speed only. In the example here the agents look out for radar traps and if within their vision there is one placed along the freeway and if they are going faster than allowed they immediately reduce their speed to the allowed value, so that at least sometimes the speed limit is not broken.

Radar traps change their position every hour so that learning their positions by the agents is not possible. All the agents can learn in a somehow roundabout way (they learn the travel times and as we will see these times increase when radar traps are at hand) is which freeways might have radar traps on them.

The initialization of the environment as well as that of the agents is presented in Table 2. Whenever one truck overtakes another one a jam soon appears behind him (at least on two lane freeways). But as soon as the truck finishes overtaking the agents following are released from the jam and once more spread out with at first equal distances. The situation gets worse if an agent of group 1 detects another truck within his view. Then he stays on the left lane slowing down the agents travelling behind him what causes additional traffic jams with long duration to vanish again. Caused by the agents’ large vision it is probable that another truck is detected and thus it often happens that the left lanes get jammed while the trucks on the right lane are still driving at their preferred speed – a situation quite usual on German expressways.

Table 2. Model examined in chapter 5

<table>
<thead>
<tr>
<th>variable</th>
<th>characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>grid size</td>
<td>120 x 240</td>
</tr>
<tr>
<td>work characteristics</td>
<td>FE[9, 18], 0</td>
</tr>
<tr>
<td>road characteristics</td>
<td>IOP[7, 7], [1000, 1500], [1, 3]</td>
</tr>
<tr>
<td>speed limit characteristic</td>
<td>SI_{min} (12, 12)*</td>
</tr>
<tr>
<td>radar trap characteristic</td>
<td>RT_{no}*</td>
</tr>
<tr>
<td>number of agents</td>
<td>agent group 1: 2500</td>
</tr>
<tr>
<td></td>
<td>agent group 2: 1000</td>
</tr>
<tr>
<td>home and work position</td>
<td>on opposite sides of</td>
</tr>
<tr>
<td></td>
<td>the barrier</td>
</tr>
<tr>
<td>time to leave home</td>
<td>TLH_0</td>
</tr>
<tr>
<td>time to leave work</td>
<td>TLW_{18}</td>
</tr>
<tr>
<td>concept for reachable</td>
<td>Gaylord-Nishidate</td>
</tr>
<tr>
<td>positions</td>
<td>von Neumann</td>
</tr>
<tr>
<td>movement blocked by</td>
<td>homes, work positions</td>
</tr>
<tr>
<td></td>
<td>and other agents</td>
</tr>
<tr>
<td>vision</td>
<td>10, 12</td>
</tr>
<tr>
<td>vision blocked by</td>
<td>home and work positions</td>
</tr>
<tr>
<td></td>
<td>home and work positions</td>
</tr>
<tr>
<td>#urban</td>
<td>[1, 3]</td>
</tr>
<tr>
<td>#freeway</td>
<td>[3, 8]</td>
</tr>
<tr>
<td>#max</td>
<td>[5, 8]</td>
</tr>
<tr>
<td>information availability</td>
<td>other</td>
</tr>
<tr>
<td>importance of own</td>
<td>0, 100</td>
</tr>
<tr>
<td>experience</td>
<td></td>
</tr>
<tr>
<td>number of friends</td>
<td>0, 20</td>
</tr>
<tr>
<td>importance of path length</td>
<td>0, 100</td>
</tr>
<tr>
<td>overtaking rule</td>
<td>stay on the overtaking</td>
</tr>
<tr>
<td></td>
<td>lane if someone</td>
</tr>
<tr>
<td></td>
<td>slower is in view*</td>
</tr>
<tr>
<td></td>
<td>immediately move</td>
</tr>
<tr>
<td></td>
<td>back right</td>
</tr>
</tbody>
</table>

(The characteristics noted with a * will be changed from experiment to experiment.)

Modifying the example in order to have all agents move immediately to the right lanes after overtaking...
others does significantly improve the average satisfaction since it reduces the occurrence of jams. Then in another simulation run the preferred speed for trucks was increased to be uniquely distributed in [3, 4]. This is similar to allow trucks driving at a higher speed level. And even since there are still trucks that can not drive faster than a speed of 3 the situation concerning the frequency of traffic jams becomes much better what might be explained by the aspect that the difference in speed between agents of group 1 and those of group 2 is reduced.

This lead to the idea to introduce speed limits on all roads and radar controls on some of them. Here radar controls did not bring any contribution to avoid traffic jams since they are detected by all agents who then slowed down right away forming a jam behind them. But introducing a speed limit that is individually broken appeared to be most profitable according to average satisfaction and the avoidance of jams. Probably once more because the differences in speed decreased.

Now the examples in this chapter are not thought of giving any direct advice how strategic measures should look like. They are described to illustrate how simple micro rules can be utilized to model a complex system behavior from which the rules that generate it could hardly be deducted if they were unknown.

6. The next steps

In this paper we focused our attention to the simulation of the complex system of traffic in which interactions of people at the micro level are accountable for situations detected at the macro level. An artificial simulation universe to study this system by executing experiments in a reduced environment was presented. These experiments, based on the simulation of the behavior of agents with heterogeneous characteristics, illustrate and in some sense explain the seemingly complicated performance of a whole community. They provide a way of looking at traffic phenomena by dealing with individuals only. Most ascertainable is that this uncomplicated type of traffic model leads to the evolution of quite complex dynamical behavior. Taken together the examples and the software application are descriptive, they are explanatory and they enable us to explore and to investigate sources for observations in the field of traffic.

It should be admitted that the examples described are very simple in the meaning that the observed group behavior does not adequately give a picture of real traffic situations. In future research the model will be widened by modifying the agents’ rules and by adding characteristics to the environment. As an example take the travel of agents on the freeways. Since the agents’ positions are actually updated in a random order to allow some kind of parallel agent action it was necessary to let an agent reduce his actual speed from any value to zero without any delay. Obviously this is too unrealistic and hence changing the updating strategy is necessary. Doing so should also enable us to let an agent’s overtaking behavior consider the agents travelling behind him as well as those in front of him. Other examples are the availability of different travel modes between which the agents can choose and which can be added and removed from the environment depending on demand, the introduction of tolls on freeways, the creation of a network of roads by connecting freeways. And also the influence of incentives like car pooling, alternative work arrangements such as different flexible working hours and compressed work weeks, as well as holiday travel depending on individual income will be examined in future experiments. According to the heuristics guiding an agent’s behavior and decision making process through the day also his level of wealth, his travel costs and his environmental concern will be included in future research.

7. References


