Traffic regime and 1/f noise for a specific approach to a city

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We examine the traffic lights regime to enable the fastest overall approach to a city for a specific case. The case involves a traffic light where one continues on the main road, into which additional cars are entering at the light. At this intersection an alternative route begins , which is longer but into which no additional cars are entering. To keep the total number of vehicles constant, we subtract on the main road,far from the intersection, the same number of cars as were added at the intersection. We calculate the Fourier transform of the average on each traffic light cycles of the velocity on the main road and bypass. We obtained different results for different cases. All the cases can be written as $1/f^{\alpha}$. We check by least squares the value of α. As changes in acceleration will also influence the noise, we check also the alpha for the change in acceleration.

1. INTRODUCTION

In a previous study,[3] , we examined a specific traffic problem. We wish in this study to change somewhat the previous assumptions and add the possibility of changing the duration of a certain traffic light. To make our exposition clearer we describe again the procedure given in our previous study. This traffic problem mimics to a certain degree a real situation. We did not try to obtain the actual values as we wish here just to show the feasibility of our approach. The real situation we encounter when entering the city of Beer Sheva, Israel, from the North-East. The specific light we are considering here is governed by the local council of the last suburb. The council decided not to let the through light to be longer than the one going to the suburb. Therefore the main question posed is whether by prolonging the period of going through the suburb(called here "the bypass") one may gain in the overall amount of cars entering the city, although those specific cars going on the bypass may lose time. The main purpose of this paper is to point out the method. We will use elementary cellular automata for our purpose.

Empirical observations of traffic show that at high enough densities the behaviour of traffic becomes quite complex. Therefore, Cellular automata is one of the most used methods for evaluating traffic and that is because of their speed and complex dynamic behaviour. Cellular automata were first studied by Ulam and von Neumann ([2]). An important contribution to the field was in the work of S. Wolfram [1] who introduced classifications, used in the present study. The elementary cellular automaton is a collection of cells arranged on a one dimensional array. Each cell can obtain just two possible numbers: one and zero. The "time" is discreet and at each time step all the cell values are updated synchronously. The value of each cell depends just on the values in the previous step of that cell and its two neighbours. Wolfram names each elementary cellular automaton with a binary numeral, which he calls: "rule". This value results from reading the output when the inputs are lexicongraphically ordered. This will become clearer when we will explain the rules which we use. The rules we used are taken from the cellular automata model as proposed by Gershenson and Rosenblueth[4] .

In addition to velocities and fluxes we are also interested in the power spectrum of the average velocities over a cycle. This value gives us the main contribution to the noise. All the cases can be written as $1/f^{\alpha}$. We obtain three regions for the value of α, before the jammed region, during the onset of the jam and for the denser region. We check by least squares the value of α. We will consider this expression in the section dedicated to calculating the noise.

TABLE I: Wolfram rules used in this model

$t-1$	t_{184}	t_{252}	t_{136}
000	0	0	0
001	0	0	0
010	0	1	0
011	1	1	1
100	1	1	0
101	1	1	0
110	0	1	0
111	1	1	1

2. THE MODEL

We will deal here only with the "microscopic " models were we consider each individual vehicle. Our highways are represented by an array of cells, each cell has the values zero or one. One represents a vehicle and zero an empty portion of the highway. We assume that the magnitude of a cell corresponds to the average length of a vehicle. In figure 1, we show the layout of our model. At a certain point we have a bifurcation where there are two different ways to proceed and at a later point where they merge again. This model represents in a simplistic way the posibility of using two alternative routes (the main route and the "bypass") when approaching a city from a certain direction of suburbs. We add the possibility that additional cars are coming into the main road and are removed when approaching the city. So that overall the number of vehicles is preserved. The rules, which are the same as used by Gershenson and Rosenblueth [4] , are given in Table 1. In figure 2 we give the rules at different locations along our array.

In our analysis we distinguish between four regions:

i. The "bypass region"(denoted by iq).

ii. The region on the main road between the entrance and exit of the "bypass"(denoted by ipe).

iii. The whole of the main road(denoted by ip).

iv. The part of the main road from the second traffic light and on(denoted by t).

2.1. Measures.

The density, ρ, is given by the number of 'ones' (i.e. vehicles) devided by the general number of cells. Initially we take this value to be the same for the three sections. We check how this value changes in the different regions. Here we are interested only in the equilibrium values. The velocities, v, denoted by vp, vq, vpe and vt, are given by the number of cells which change in one step from 0 to 1.

Another measure which interests us in this study is the ratio beween the average time it takes to traverse the "bypass" to the average time it takes on the main road between the two merging points. We will denote this value by 'qdpe'.

In our calculation, space and time are just abstract quantities. Still if concrete numbers are desired, one can quote[4] were one cell represents five meters, and a time step represents a third of a second, which gives us about 50 km/hour, roughly the speed limit within a city.

2.2. The grid

The schematic picture of our specific problem is given in fig 1. A general view of the grid is given in fig 2. The schematic car movement is given in fig 3. We denote the cells on the main route by ip and the cells on the bypass by iq. The cells between $ip = istop$ and $ip = istop1$ we denote by ipe. The cells after $ip = istop1$ we denote by ipt. At $ip = istop$ the vehicles move on the main road or on the bypass according to the 'lights', the time going on the bypass may be longer than the one going straight on the main road. We will check how this influences the overall speed of travel.

In fig3 we show schematically the movements of the vehicles. We have two stop lights (denoted by '1' and '2' on the diagram). When the movement is on the "main road" diagram 'a' gives us the movement. When we enter or exit the "by pass" then 'b' gives us the rules.

We have a parameter telling us the amount of

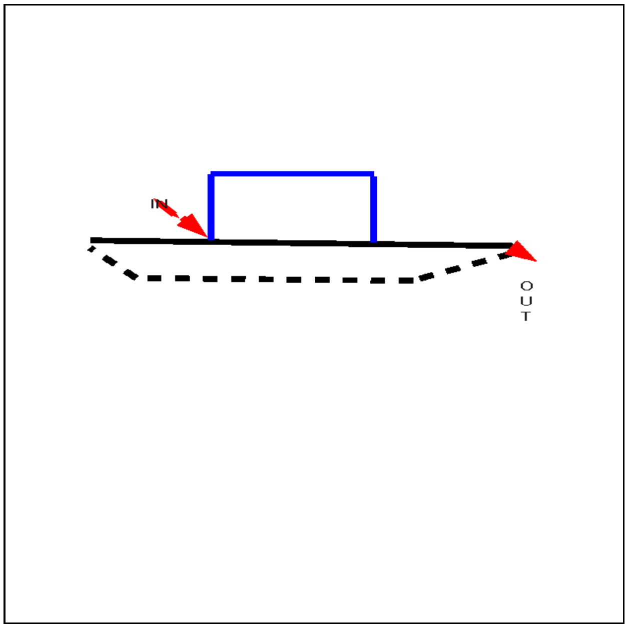

FIG. 1: The movement of vehicles

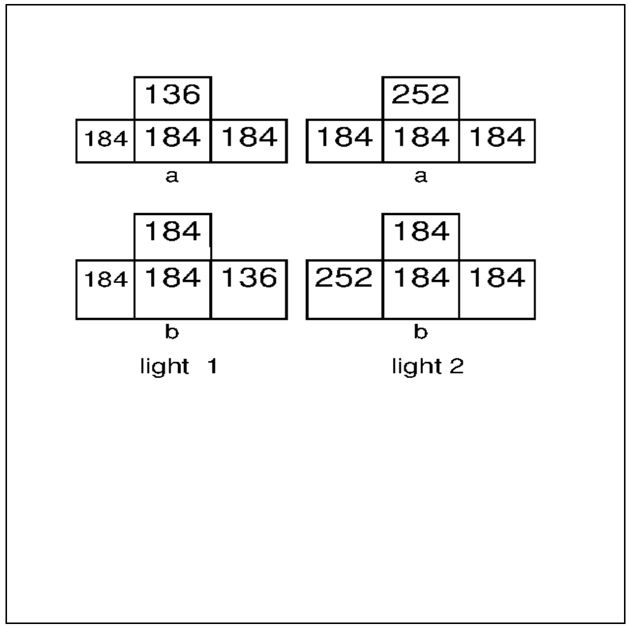

FIG. 3: The movement of vehicles

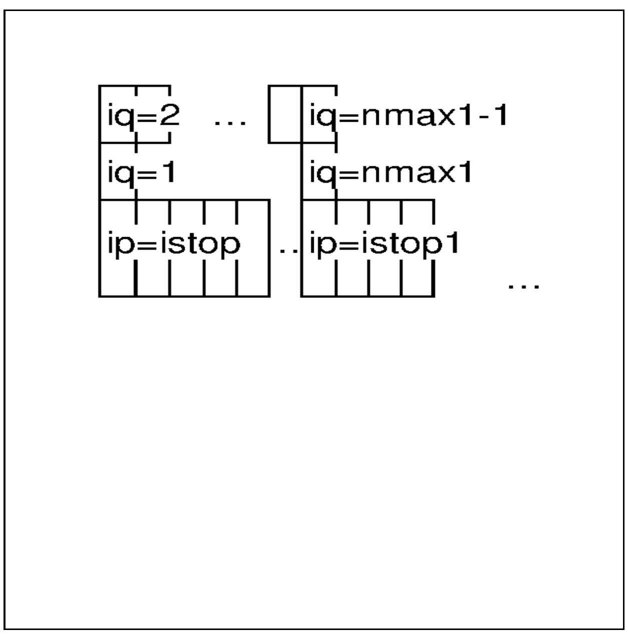

FIG. 2: The grid

"cars" added to the main road at the junction of the bypass. This same amount is deducted from the "main road" farther away and is done in order to preserve the total number of vehicles. The actual addition of cars is governed by a random number which depends on the parameter(i.e. the percentage of cycles when a car is added).

3. NOISE

Traffic noise is one of the most important souces of noise polution. It is well known that this is a health hazard. In this study we wish to check the frequency distribution of the noise. It was shown by Takayasu and Takayasu[7], that we obtain $1/f$ noise. Let us explain here this term: "$1/fnoise$" refers to the phenomenon of the spectral density, $S(f)$, of a stochastic process having the form:

$$S(f) = const./f^{\alpha}$$

When $\alpha = 0$ we say that we have white noise. If $\alpha = 1$ we say we have pink noise. If $\alpha = 2$ we say we have brown noise. To understand better this term see Procaccia and Schuster[5] and Erland et al.[6]. An Indian group[8] made measurements in a number of locations and obtained a mostly pink noise in a large range of frequencies. To obtain $S(f)$ we make the Fourier transform of the velocities. To perform our Fourier transform we take the averages over each light cicle and study the frequencies of these averages over all the cycles taken in our calculations. We compare the results to the $1/f^{\alpha}$ by a least square test.

4. RESULTS AND DISCUSSION

We used a fixed grid: The main road was comprised of 1200 cells, the "by pass" 300 cells and the distance between the two lights was 120 cells. We used the "green wave" regime. As we have just two lights it was shown by Gershenson and Rosenblueth [4] ,that in this case one does not get different results using the "self-organizing" regime.

We introduce a vehicle on the first intersection for 40% of the steps and we eliminate the same number of vehicles on the last point of our main route, again per unit time.

In Fig 4 we show the change in velocity of the main road, after the second traffic light (vt), as function of the car density. In this case we assume the same duration of the red and green lights at the first intersection.

We see in this figure that the average velocity changes from free flow to the jammed region at about $\rho = 0.6$. In the next figure (Fig5), we show the change of the appropriate flux as function of the density.

We denote by jw-1 the number of additional green light at the first intersection enabling cars to go by the bypass. That means that in Fig4 it is assumed that jw is 1. The maximum value for jw will be 12, as that is the cycle between green and red lights in our calculation. In the next three figures we wish to show the changes of different parameters as a function of jw for a specific density, which is at the beginning of the transition from free flow to the jammed region. We chose $\rho = 0.486$. The purpose is mainly ilustrative, but it is similar in other regions.

In figures 6 we show the change in velocities of the by pass(vq) and the velocity between the two traffic lights on the main road(vpe).

In all the cases, we see a strong change at jw=7. Quite clearly, the average velocity on the bypass increases as more cars are going that way and, at the same time, the average velocity on the main

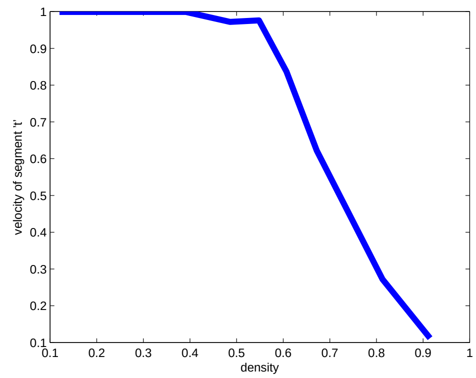

FIG. 4: The change in velocity as function of the density

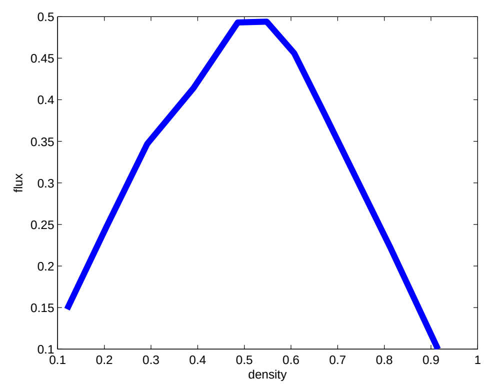

FIG. 5: The change in flux as function of the density

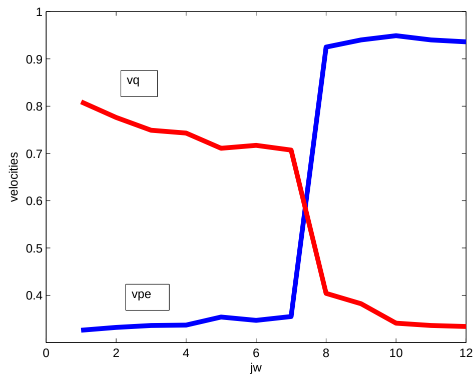

FIG. 6: The velocity on the bypass and betweenthe two traffic lights on main road

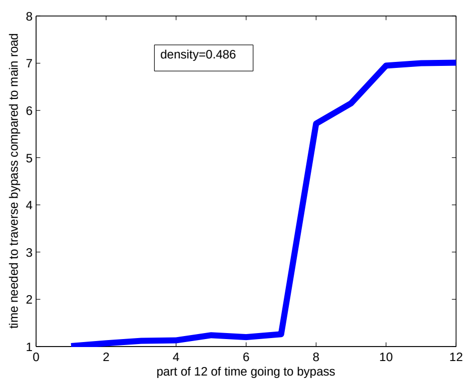

FIG. 7: The relation between the time needed to go by the two routes.

road decreses.

To get a better understanding of the traffic situation we have to check the relation between the times a car needs to arrive at the second traffic light on the bypass and on the main road. This relation is denoted by

$$qdpe = time(q)/time(pe)$$

. In Fig7 we show this relation, and we see again that at jw=7 we obtain a large change.

We averaged the velocities over a traffic light

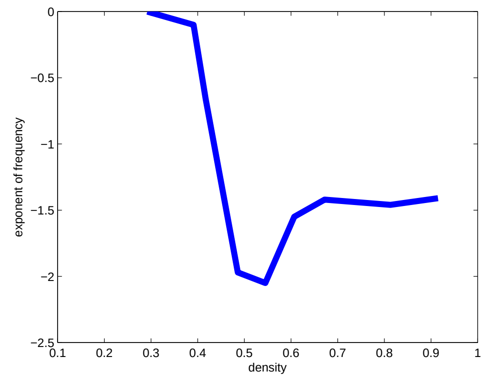

FIG. 8: The values of α as a function of density.

cycle and studied the power spectrum. The value we are interested in is α, in the expression $1/f^{\alpha}$. We give this value in Fig8.

This is an interesting result. When we increase the density so that we reach the transtion from free flow to the jammed region the noise shoots up from white noise to brown noise and then setles in the region of pink noise.

In conclusion, we can say that our calculations give us a wide range of information which can be applied for specific cases so that the traffic light regime can be chosen with much less trial and error than without such a guided approach.

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