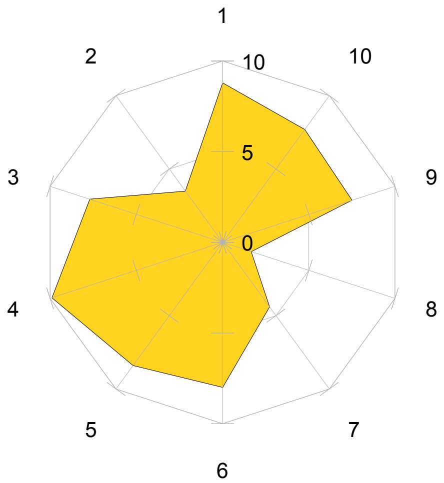
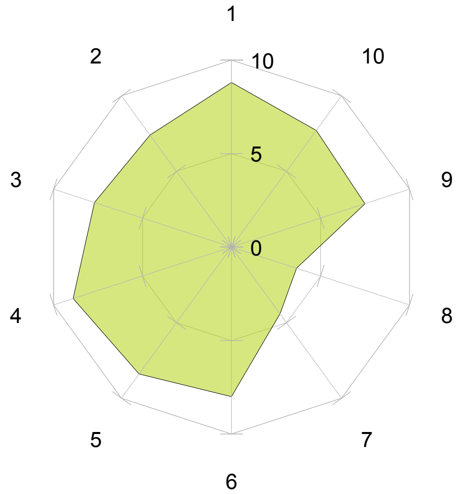
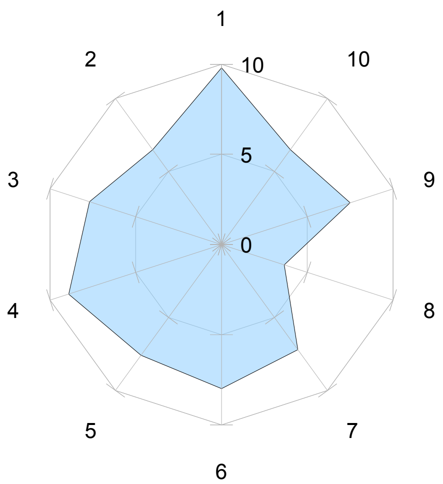
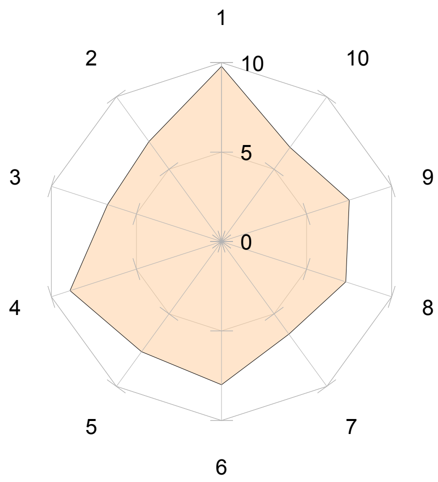




cong(s/m)-l*(2)*





Four diagrams showing graphic expansion and contraction of a vehicle cluster 746 (3 m :25 sec)

Composer:

Dimitri Voudouris

Composed:

[2013 – 2015]

Composition:

cong(s/m)-l$_{(2)}$

Dynamic sound analysis, computerized transcription of data from various single and multi-lane traffic congestions in a unidirectional system.

for

amplified grand piano and [C++] - granular synthesis **(or)**
[midi piano and [C++] - granular synthesis]

Duration:

20 min 38 sec

Index

multi-lane congestion
with overtaking

Composition of multi-lane model dynamics in traffic congestion

Location: From various interchanges – Johannesburg, Gauteng, South Africa.
Date: 23 recordings of data were captured between September / 2013 – May / 2014.
Time: Peak hour recordings: 7h00 -9h00 and 16h00 -18h00
Camera: Four cameras installed

Multi-lane vehicular traffic dynamics and behaviour in congestions with lane-change possibilities of a unidirectional system interpreted into a composition model. Using V.Shvetsov and D.Helbing analysis to simulate macroscopic dynamics of multi-lane traffic flow for linear and non-linear vehicle interactions. This includes the formation of traffic jams or stop-and-go waves of synchronized congested traffic. Many of these phenomena are simulated by multi-lane models that take into account overtaking manoeuvres and lane changes. Apart from lane-changing manoeuvres, traffic dynamics are considerably influenced by the composition of traffic and various types of vehicles with different desired velocity [acceleration / deceleration] capabilities. This even cause new kinds of phase transitions in mixed traffic, e.g. to a coherent, solid-like state of motion. The model is obtained from a generalized version of a gas-kinetic traffic model, from which is derived a one-dimensional model that is consistent with all known properties of traffic flow , including synchronized congested flow. Lane-changes and several vehicle types make the model quite complex, it is still possible to evaluate the Boltzmann-like interaction terms. Calculations take care of the fact that vehicles do not interact locally, but with the next vehicle in front, the interaction point is advanced by about the safe vehicle distance. We are able to study how the vehicle dynamics on a lane influences the others.
Inspecting kinetic stability or instability and disturbances in macroscopic dynamics of unidirectional multi-lane vehicle traffic, forming various clusters [Alternating: vehicle - density levels, speeds, cluster size and duration of congestion]. Analysis was conducted on macroscopic variables of interest such as the desired velocity (*Vo*), maximum density (*ρmax*), relaxation time (*τ*), safe time headway (*T*), anticipation factor (*γ*), coefficients for variance (*αo, Δα,ρc,δρ*), coefficient for overtaking probability (*ρo*), coefficient for spontaneous lane-changing (*gi,3-i*), of vehicles in lane at specific place and time, or defined as moments of the phase-space densities. Equations were programmed into Matlab, data obtained was converted into frequencies of notes for the piano and electronics for the composition model of cong(s/m)-l*(2)* . Calculated data was set according to speed, size and density of cluster formations, overtaking and lane-change possibilities, the final calculated data were graphically plotted of which 7488 fragments of information were compiled in the construction of multi-lane congestions. Application of probability theory consisting of permutations, combinatorial analysis were applied to areas of audible similarities [pitch and dynamics], within certain areas of fragmentation. In the midi program use of the *velocity function* to deal with various speeds, the *dynamic function* for adjusting higher to lower intensities deals with the variations of size, population and travelling velocities of clusters.
The pianist represents various rhythmical possibilities resulting from simulated formations of clusters, flow and flow closures. Granular synthesis was introduced to the model, representing lane changes and overtaking manoeuvres, as well as adding detail to accelerating and decelerating manoeuvres within clusters not able to be played on the grand piano alone. The vehicle/driver has an organo-mechanical relationship, similarly introducing a pianist/piano/granular synthesis have a similar relationship [the pianist is the driver of the process] also the midi piano / granular synthesis relationship the programmer is the driving force of the mechanical process.

Some equations used in the macroscopic multi-lane model:

One advantage of the kinetic equation is, that it allows the systematic derivation of equations for macroscopic variables. The macroscopic variables of interest are the densities, average velocities, and velocity variances of vehicles at place x and time t. They can be defined as moments of the phase-space densities:

$$\rho_i^a(x,t)=\int dv\, f_i^a(x,v,t)$$

$$V_i^a(x,t)=\rho_i^a(x,t)^{-1}\int dv\, v f_i^a(x,v,t)$$

$$\theta_i^a(x,t)=\rho_i^a(x,t)^{-1}\int dv\,(v-V_i^a)^2 f_i^a(x,v,t)$$

One can express the coefficients of B in terms of the moments of the distribution, namely the variances θ and the correlation coefficient k.

$$B(v,w)=\frac{1}{1-(k_i^{ab})^2}\left(\frac{(v-v_i^a)^2}{\theta_i^a}-2\mathrm{k}_i^{ab}\frac{(v-v_i^a)(w-v^{b}{}'_i)}{\sqrt{\theta_i^a\theta^{b}{}'_i}}+\frac{(w-V_i^b)^2}{\theta^{b}{}'_i}\right)$$

Density equation:

$$\frac{\partial}{\partial t}\rho_i^a+\frac{\partial}{\partial x}(\rho_i^a)(V_i^a)=\sum_{j\in(i-1,i+1)}\sum_{b=1}^{A}[\rho_{j}^a{},{}_iA_j^{ab}(\delta V_j^{ab})-\rho_i^a,{}_jA_i^{ab}-\rho_i^a,{}_jA_i^{ab}(\delta V_i^{ab})]$$

$$+\sum_{j\in(i-1,i+1)}\left(\frac{\rho_j^a}{T_j^a,i}-\frac{\rho_i^a}{T_i^a,j}\right),$$

Traffic flow equation:

$$\frac{\partial}{\partial t}(\rho_i^aV_i^a)+\frac{\partial}{\partial x}[\rho_i^a(V_i^{a2}+\theta_i^a)]=\frac{\rho_i^a}{\tau_i^a}(V_{0\mathrm{i}}^a-V_i^a)-(1-\rho_i^a)\sum_{b=1}^{A}B_i^{ab}(\delta V_i^{ab})$$

$$+\sum_{j\in i-1,i+1}\sum_{b=1}^{A}B_i^{ab}\left(\rho_j^a\frac{V_j^a}{T_{ji}^a}-\rho_i^a\frac{V_i^a}{T_{ij}^a}\right)$$

<u>The Boltzmann factors:</u>

A^ab_i determine thelane-changing flows due to interactions in the density equations

$$A(\delta V)=\chi(\rho)\rho\rho'\sqrt{S}[N(\delta V)+\delta V\,E(\delta V)],$$

B^ab_i the braking term,

$$B(\delta V)=\chi(\rho)\rho\rho' S[\delta V\,N(\delta V)+(1+\delta V^2)E(\delta V)],$$

C^ab_i the lane-changing terms due to interactions in the flow equations.

$$C(\delta V)=\chi(\rho)\rho\rho' S[\frac{V}{\sqrt{S}}N(\delta V)+(\theta-k\frac{\sqrt{\theta\theta'}}{S}+\frac{V}{\sqrt{S}}\delta V)E(\delta V)].$$

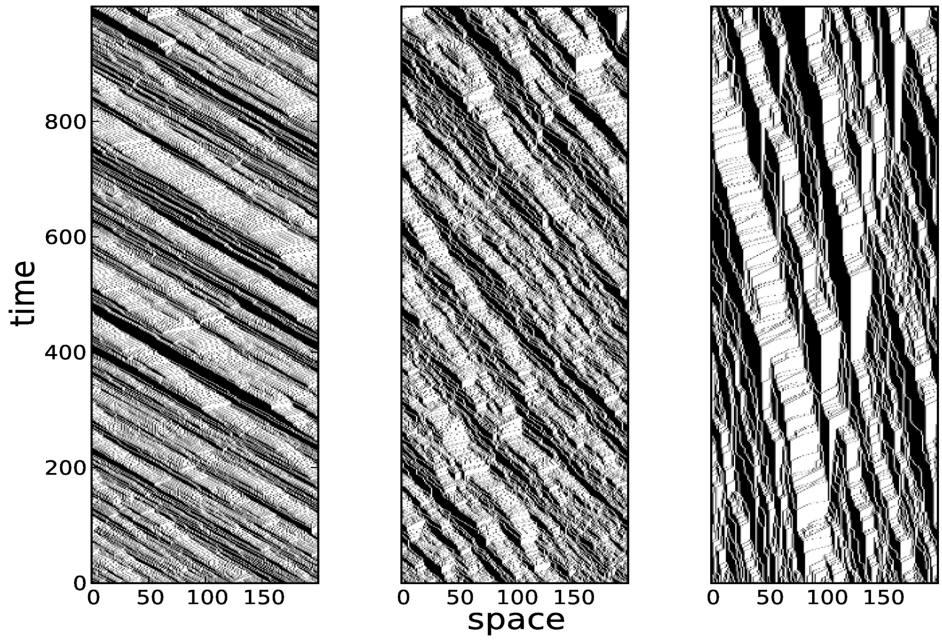


Fig 1

Spatiotemporal diagrams showing clusters (black regions) as well as larger unoccupied space (grey regions).

Interpreting data

Calibrating mode

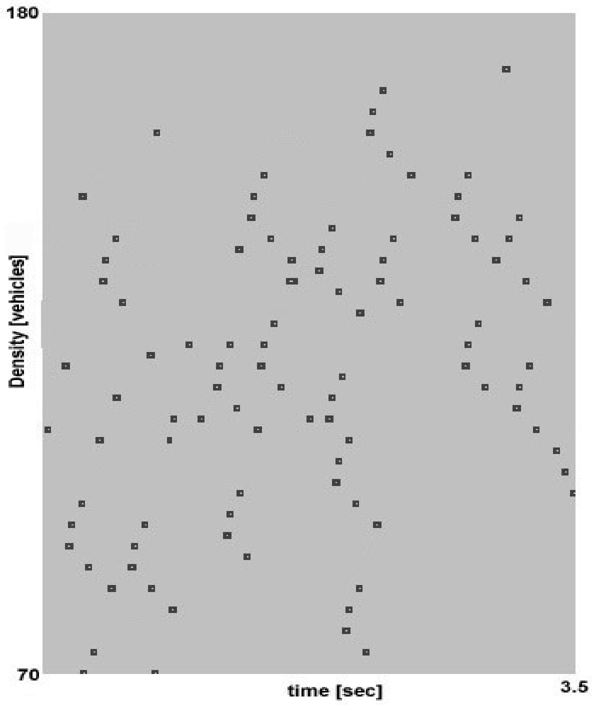


Fig 2a - Data representing non-linear multilane traffic congestions *[GDa-matlab:67/114]*

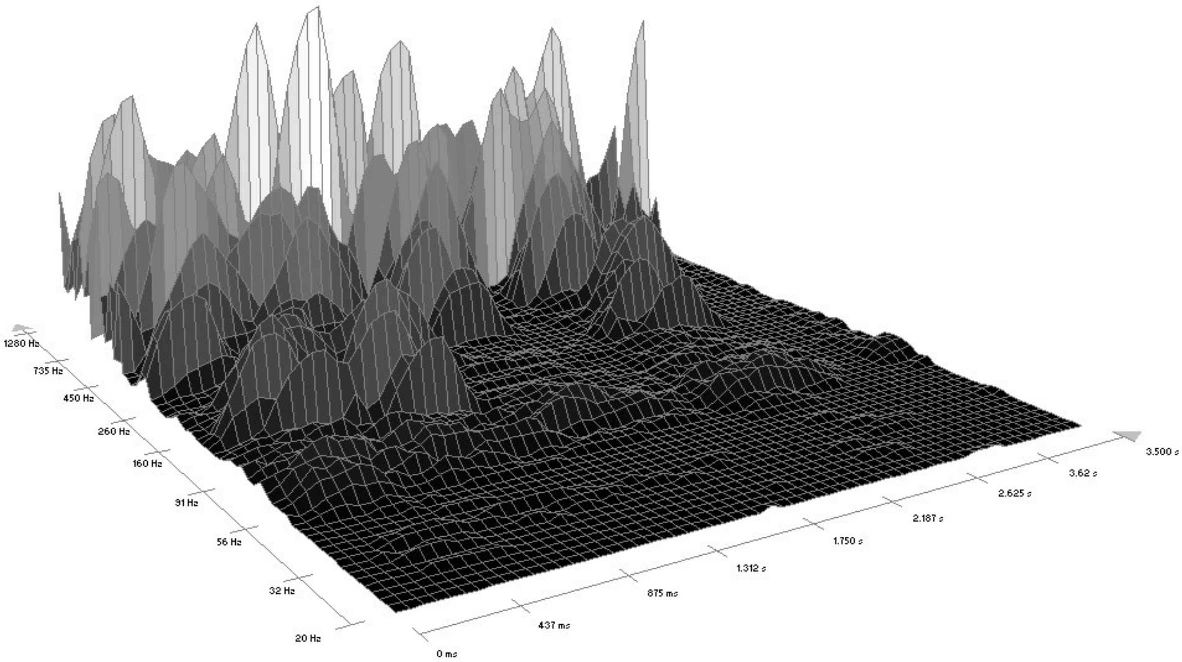


Fig 2b – Frequency vs time in an audio graph representing
[size and density of congestions] multi-lane congestion *[GDb-matlab:745/7]*

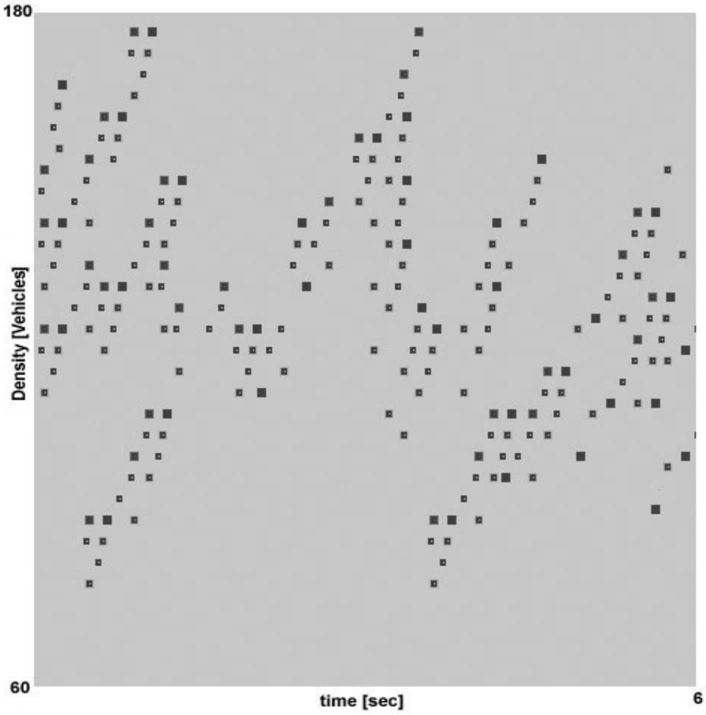


Fig 3a - Data representing non-linear multilane traffic congestions *[GDa-matlab: 674/92]*

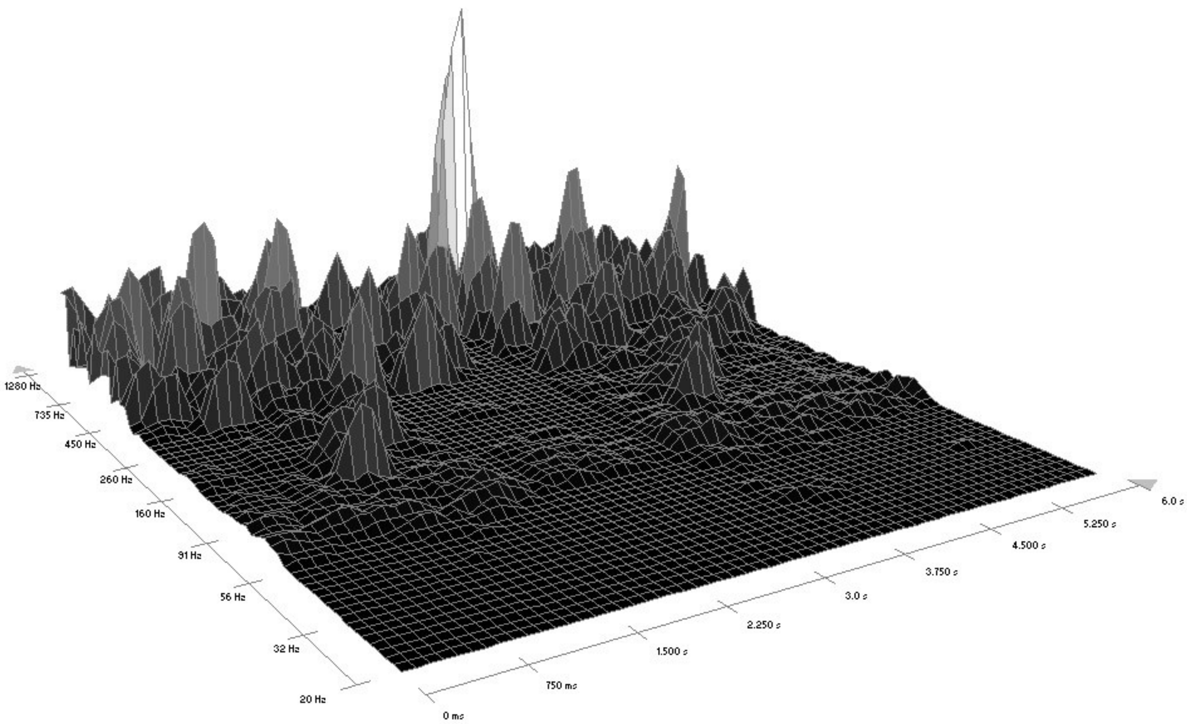


Fig 3b – Frequency vs time in an audio graph representing
[size and density of congestions] multi-lane congestion *[GDb-matlab:24/74]*

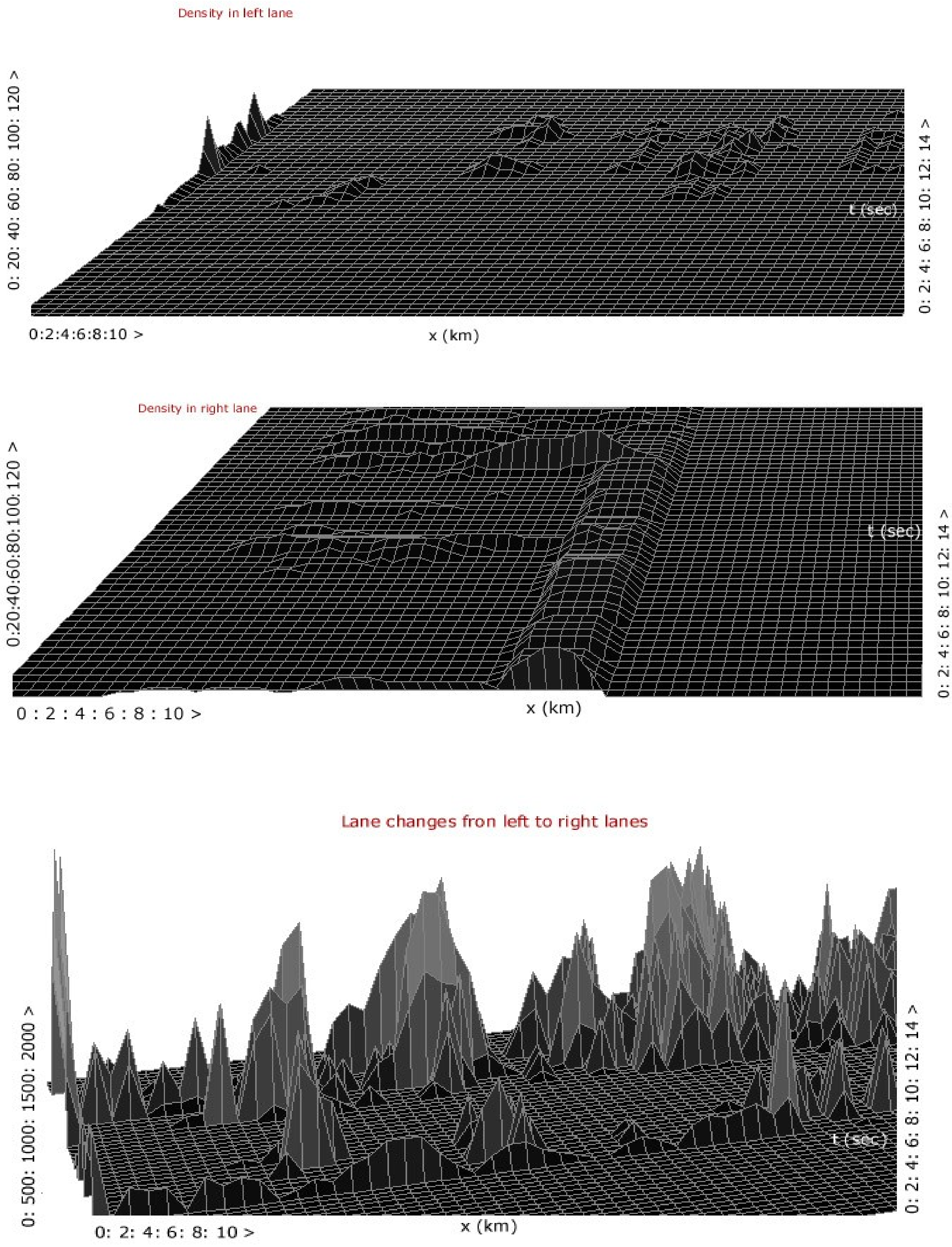


Fig 4 – Lane-changes *[GDu-matlab:84/76]*

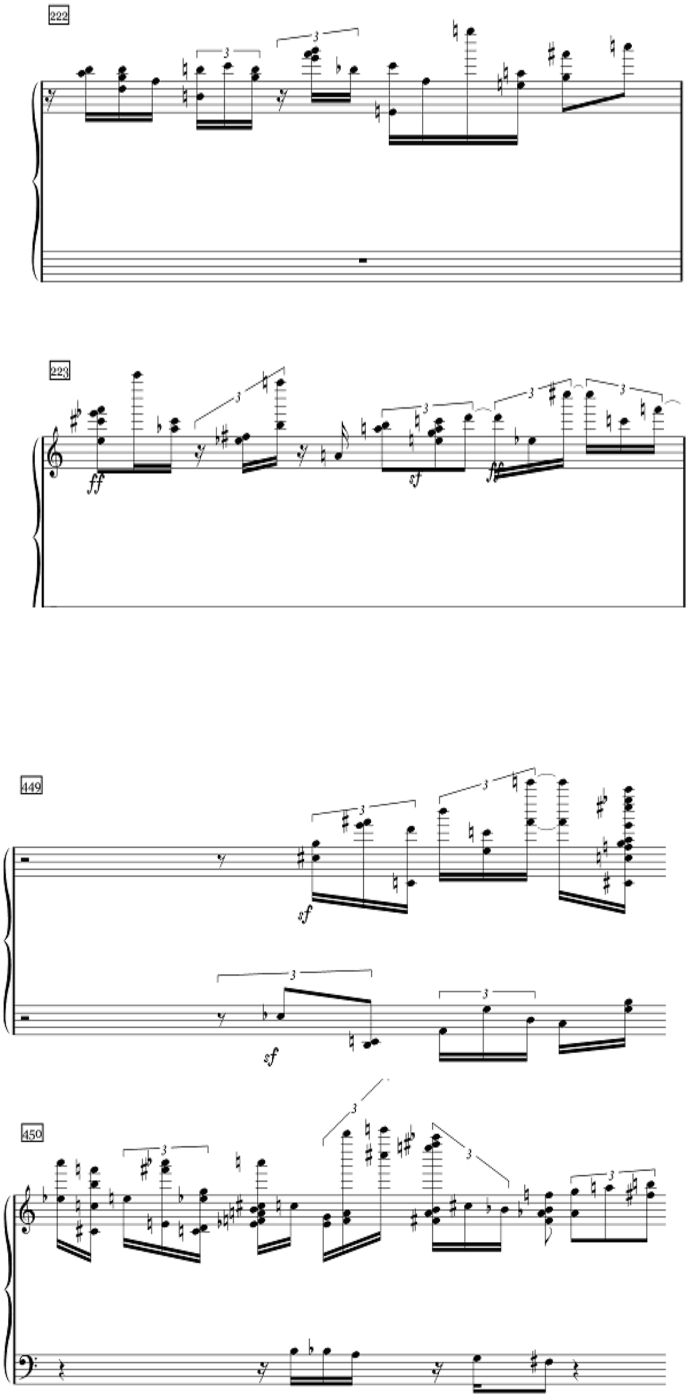


Fig: 5 - *bars (222-223)* showing vehicles exiting,
bars (449-450) showing vehicles overtaking and
entering - multi-lane congestion.

single-lane congestion
with no overtaking

Composition of single – lane model dynamics in traffic congestion

Location: From various interchanges – Johannesburg, Gauteng, South Africa.
Date: 17 recordings of data were captured between October / 2013 – February / 2014.
Time: Peak hour recordings: 7h00 -9h00 and 16h00 -18h00
Camera: Two cameras installed

The dynamics and behaviour of spontaneous transition from flow without congestion to that with congestion in a single-lane unidirectional system is interpreted into a music composition model. Using part of the analysis done by M. Bando, K.Hasebe, A. Nakayama, A. Shibata,Y. Sugiyama designed to demonstrate the dynamic behaviour of clusters, such as absorption or disappearance of clusters observed in the intermediate stage of forming the final stable structure of congestion. Equations exploring the dynamic evolution of congestion through small perturbations of instability to stability used in the single-lane model, were programmed into Matlab. The data was converted into frequencies of notes for the piano and granular synthesis for the composition model of cong(s/m)-l(2) .The composition model was designed around certain criteria, of time, density, vehicle velocity and headway velocity. The final calculated data were graphically plotted 2368 fragments of information were compiled in the construction of single-lane congestions. In the midi program use of the velocity function to deal with various speeds, the dynamic function for adjusting higher to lower intensities deals with the variations of size, population and travelling velocities of clusters. Flow closures within clusters is an intermediate stage consisting of several areas represented by granular synthesis, showing the dynamics of instability.

Demonstrative analysis of single- lane congestion

In order to see the process of the movement of each vehicle during the organization of congestion we need to plot the vehicle's movement in the phase space of the headway and velocity, (Δ*xn,* **xn*) with time development.

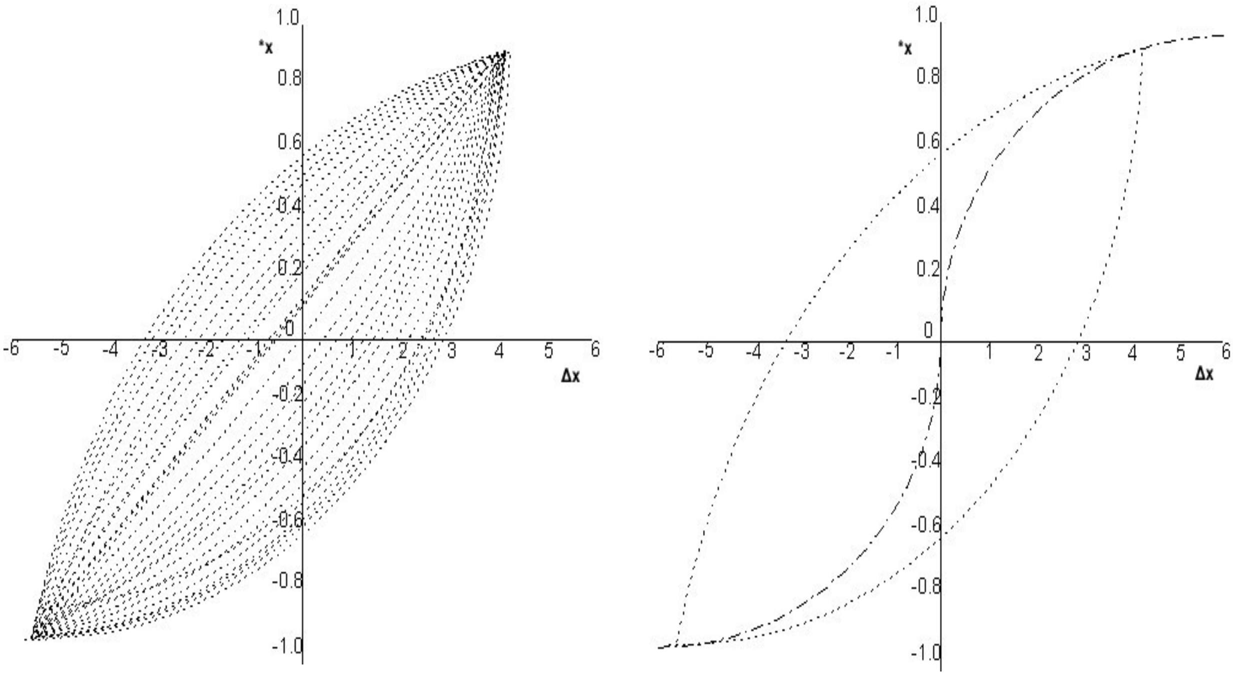


Fig: 6a / 5b

In **Fig: 6a/6b** each closed curve has two end points; one has large headway with large velocity (the upper point), and the other has small headway with small velocity (the lower point). The upper one corresponds to the region where vehicles are moving smoothly, and the lower one, to congestion. The upper point represents the region of low concentration in the circuit, where vehicles move and exist at one of these points. The upper curve shows the motion of vehicles entering into the congestion from the smoothly moving area, that is, vehicles moving at the largest velocity are made to slow down to the smallest one along this curve.The lower curve corresponds to the motion of vehicles leaving a congested region and going into the smoothly moving area. Vehicles with the smallest velocity are gradually accelerated to catch up to the largest one along this curve. The decelerating vehicle has a larger velocity than the corresponding legal velocity V (Δx). On the contrary, the accelerating vehicle has a smaller velocity than the legal one. This discrepancy indicates that the acceleration and deceleration are delayed. Even if a driver wants to change the velocity to the legal velocity for a given headway, the accelerating or braking force cannot affect the velocity quickly.

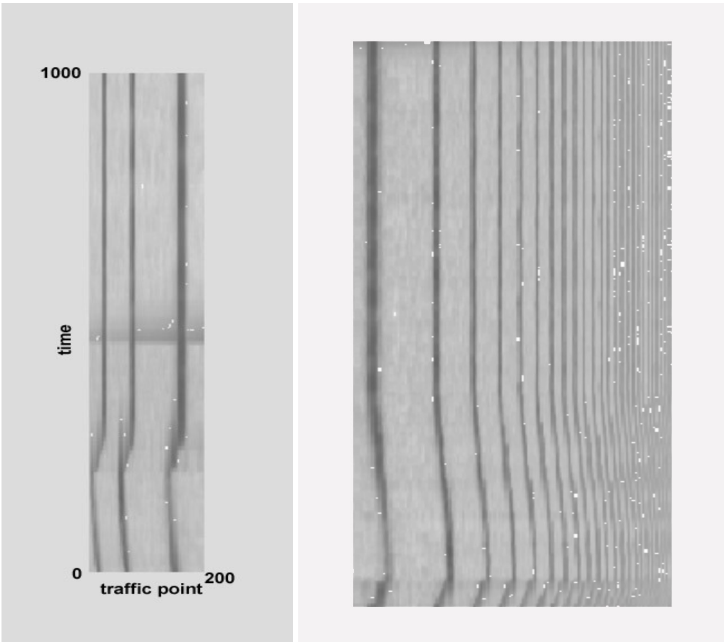


Fig: 7a / 6b

Fig: 7a/7b- *The organization of congestion by taking an initial clustering pattern scattered into several clusters. Clusters are designed to have 3, 2, 6, 7, 23, 5 and 4 numbers of vehicles with distances of 7, 7, 7, 9, 3, 10 and 7 successive vehicles.*

Investigating the instability of a cluster of vehicles and discussing some properties of dynamical behavior of clusters, such as combination, absorption or disappearance of clusters observed in the intermediate stage of forming the final stable structure of congestion. **Fig:7a/7b** is the result of a demonstrative simulation. Clusters are designed to have 2, 3, 4 and other numbers of vehicles with distances of 3 or 7 successive vehicles. Isolated cluster with the number of vehicles less than 3 is unstable, and that with more than 4 vehicles is stable. A cluster of fewer than 3 vehicles is not big enough for a vehicle moving into this cluster to reach the headway $\Delta xmin$ of stable congestion before the preceding vehicle accelerates and exits the cluster. Therefore, such small clusters cannot maintain the headway of stable congestion. As a result, the congestion becomes broader and disappears into the smoothly moving area.
Fig:7a, we observe the phenomena where two neighbor clusters (1^{st} and 2^{nd}, 3rd and 4^{th}, 5^{th} and 6^{th} ones) are combined as if there exists an attractive interaction. The length of the effective range of this interaction is the distance of 3 successive vehicles with the headway of $\Delta xmax$. This effective range does not depend on the size of the cluster. It is found that two clusters are stable and move independently outside this range. This 'attractive force' acts on the preceding cluster and pulls it backward. Therefore a cluster is always absorbed by the following cluster, independently of whether the cluster is larger or smaller than the following one. Actually, the 5^{th} cluster having 23 vehicles is absorbed by the 4th cluster of 7 vehicles. These phenomena are explained as follows. In the case where the distance between two clusters is too small, a vehicle moving out of the second cluster can not accelerate up to the velocity V ($\Delta xmax$) before reaching the first cluster. Therefore the hysteresis loop drawn by the motion of this vehicle becomes smaller than that of stable congestion, that is, the vehicle makes a congestion with a larger headway. Then, the density of the

first cluster reduces and as the result, the cluster is stretched backwards. The distance becomes shorter and shorter, and finally, the first cluster is absorbed into the second cluster. On the contrary, an unstable cluster disappears and is absorbed into a cluster ahead of it. We distinguish the disappearance of the cluster from the absorption of a cluster by the attractive interaction. These are two processes of the combination of two clusters in the intermediate stage of forming the stable clusters of congestion.

Some equations used in the macroscopic single-lane model:

Simple case:

L=1000, N=500

$$[b=\frac{L}{N}=2]: f=V^2(b)=1-\tanh^2(b),=0.077<\frac{a}{2}=\frac{1}{2}$$

In the stable case of the realistic model all amplitudes monotonically shrink with time.

Unstable case:

L=250 N=500

$$[b=\frac{L}{N}=0.5]: f=0.0786>\frac{a}{2}=\frac{1}{2}$$

Ustable case of the realistic model the amplitude of the positive mode increases while the others decrease.

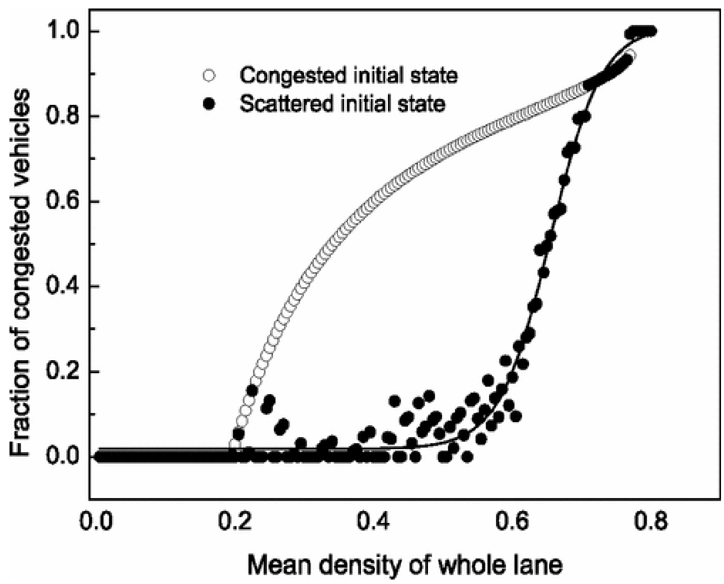


Fig:8 – Graphic analysis -
Vehicle density in congestion
repesented in bars (129-134)

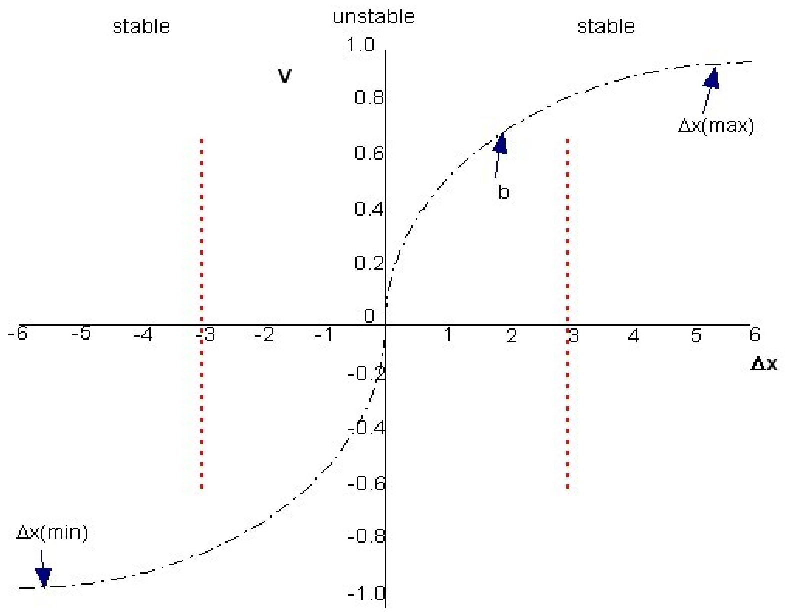


Fig: 9 - *In the realistic model the stable and unstable regions are sketched on the figure of the legal velocity V(Δx)=tanh(Δx -2)+tanh2. The initial vehicle spacing b , the headway Δxmin of high concentration, and that of low concentration Δxmax in the flow with congestion, are indicated by arrows.*

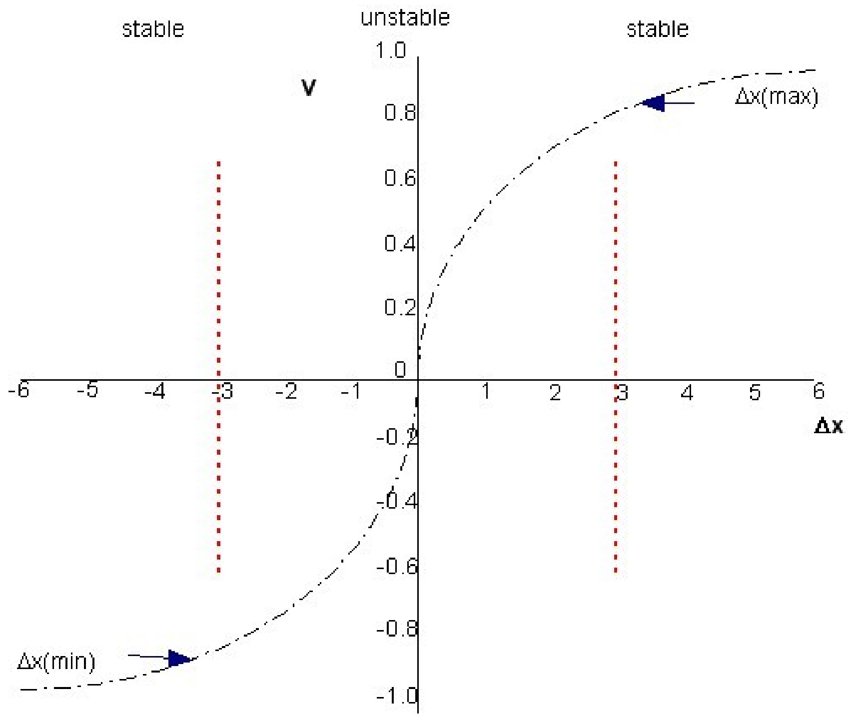


Fig: 10 - *In the simple model the stable and unstable regions are sketched on the figure of the legal velocity function: V(Δx)=tanh(Δx). In comparison with the realistic model, the corresponding headway Δxmin and Δxmax are indicated by arrows.*

a] The capacity of transportation can be defined as follows:

After the congestion formation has been completed, the flow is steady with high and low density regions on the circuit, and all vehicles behave in the same way; a vehicle moves with the constant velocity *V* **(***Δxmin***)** in a high density region, and *V* **(***Δxmax***)** in a low density region. Every vehicle moves at period *T* . The capacity of transportation is roughly estimated as *N/T*, where *N* is the total number of vehicles passing through a point of reference.

b] T is derived as follows:

The period *T* where a vehicle moves past a reference point and the period *T0* where a vehicle passes all clusters of congestion. The clusters move backward with the velocity *Vback*.

c] Using this velocity, T0 is expressed as:

$$T0 = \frac{\Delta xmax \cdot NF}{\Delta xmin \cdot NC} + \frac{V(\Delta xmax) + Vback}{V(\Delta xmin) + Vback}$$

d] The relation between T and T0 is given as:

$$T = \frac{(1 + Vback\ T)}{L}\ To$$

where the difference between *T* and *T0* is obtained by estimating the ratio of the area length to the path which clusters move in the period *T* with the velocity *Vback*. Then, we obtain the capacity of transportation *N/T*. In the typical case of *L*= 200

$$N/T - N \frac{- 0.263N + 200.99}{389.2N - 1478.8}$$

with *Δxmax* and *Δxmin* are read off from the data of hysterisis loop. Notice that the above equation is applicable for $59 \le N \le 606$ in case of circuit length $L = 200$. The minimum value bound means the critical value for at least one cluster of congestion to exist, which consists of more than 4 vehicles. $N = 606$ corresponds to the case where the whole circuit is occupied by clusters of congestion. On the other hand, in the flow with no congestion, which denotes the steady flow of uniform distribution of vehicles on circuit moving with the constant velocity *V* (*b*), where *b* is the identical headway $b = L/N$, the capacity of transportation is *N/T*, where $T = L/V$ (*b*). In the case of $L = 200$,The comparison of the capacity of transportation as variable *N* for two situations, equations (15) and (16) are shown in figure 14. The solid and dashed lines denote the transport of flow with and without congestion, respectively. The uniform solution is unstable in the range between vertical dotted lines, in which the transition from free to congested flow occurs. It this case, the existence of congestion reduces the capacity of transportation in the region $N \le 103$, and increases the capacity in the region $N \ge 104$.

Interpreting data

Calibrating mode:

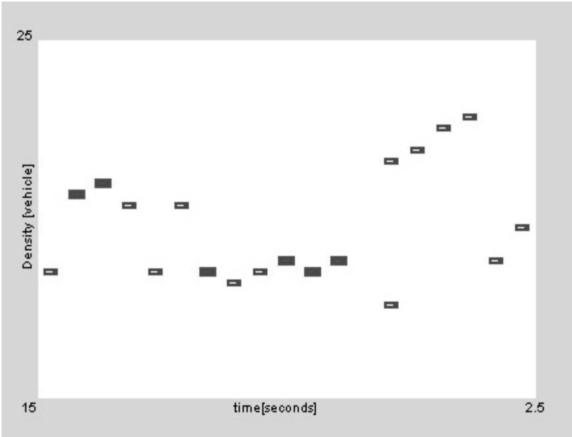


Fig: 11a - Data representing linear stable single-lane traffic congestion *[GDa-matlab:35/1]*

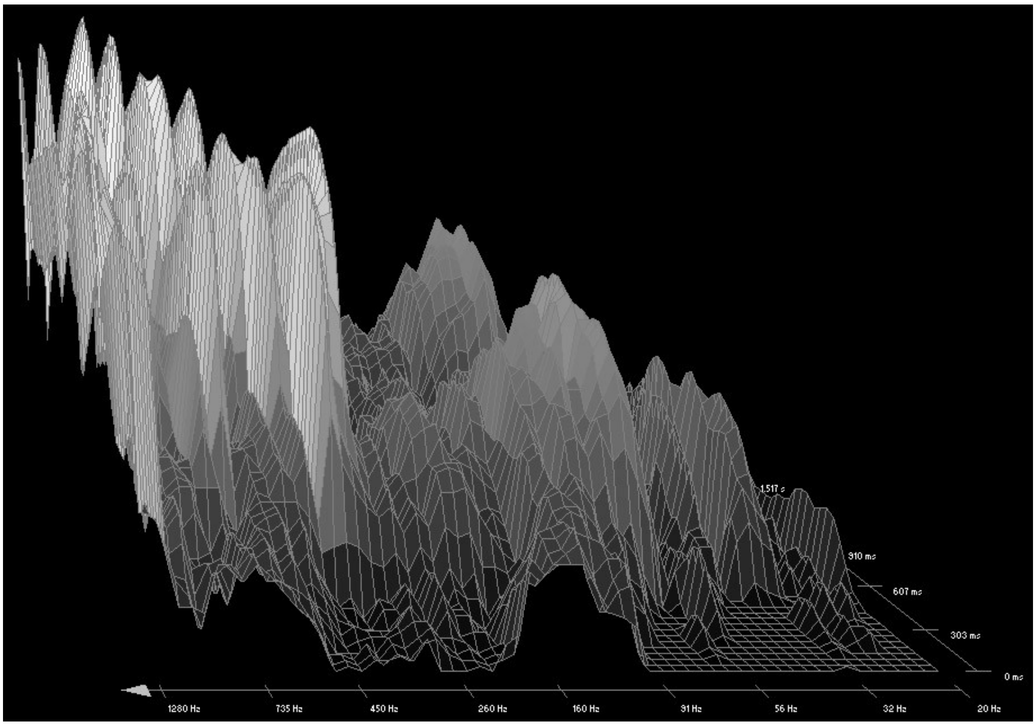


Fig: 11b – Frequency vs time in an audio graph representing
[Velocity and density of congestions] single-lane congestion *[GDb-matlab:92/10]*

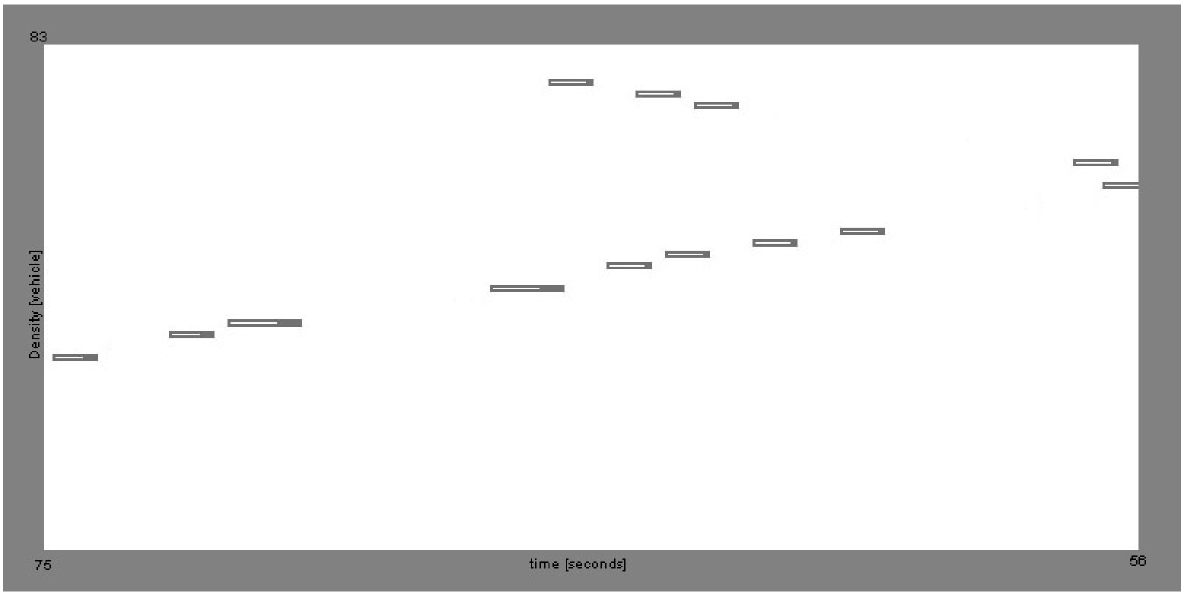


Fig:12a - Data representing linear unstable single-lane traffic congestion *[GDa-matlab:64/82]*

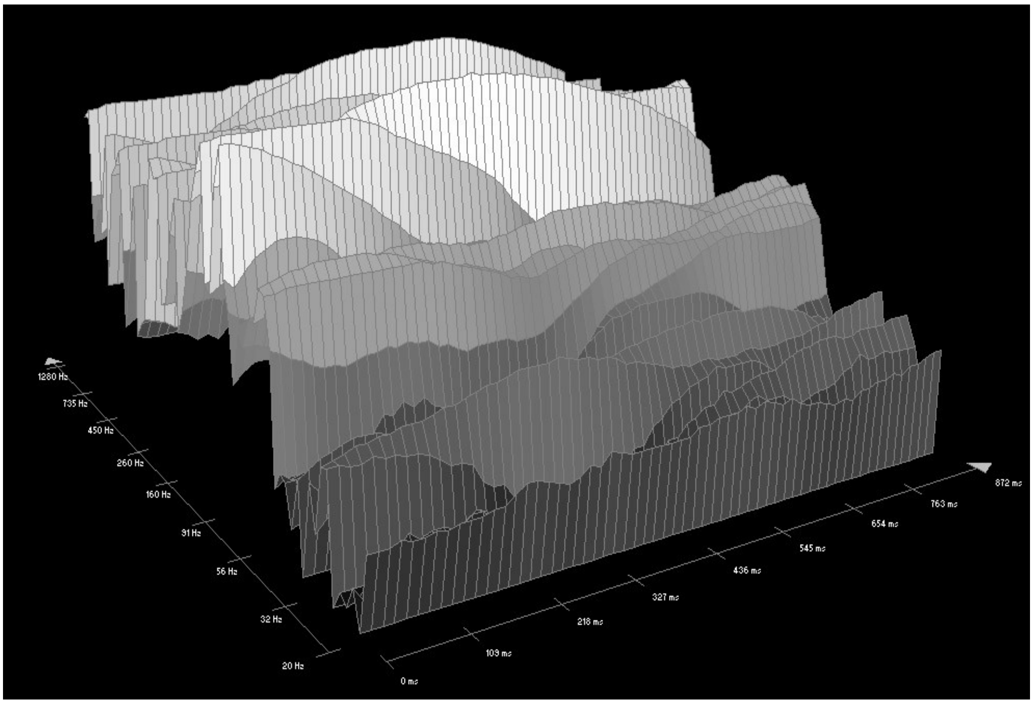


Fig:12b – Frequency vs time in an audio graph representing
[Velocity and density of congestions] single-lane congestion *[GDb-matlab:025/33]*

Fig:13 – *bars* (407-408) representing stable to unstable single-lane congestion

Fig:14 – *bars* (501-502) representing unstable to stable single-lane congestion

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