

Traffic Deadlock Caused By Two Intersections

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Problem Structuring

The behavior of the vehicle drivers depends usually on the traffic conditions and some external factors such as the traffic lights. Normally it is assumed that traffic flow is a linear process that is feedback effect of some driving behavior to itself is assumed to be negligible. The usual simulation models of the traffic flow are based on spatial automata modeling, queuing theory or other modeling technique that doesn't consider or focus on the feedback dynamics.

Our work focuses on an important feedback problem in the traffic flow. The problem is observed in Etiler – a neighborhood in Istanbul. But the structure lying under this problem is very general. The problem is triggered by the congestion in Oven Road. The cars coming from the Torito Road pass the Torito Junction, when the light is green to them. But there remains no sufficient place to allow all the cars flowing into the Oven Road. So some cars stay on the Torito Junction. These cars prevent the outflow of the Kodak Road through the junction. Therefore the congestion of cars in the Kodak Road increases more. This causes the cars flowing into the Kodak Road from the Akmerkez Road to go slower or to stay in the Akmerkez Junction, when the

light is green to them. When the traffic lights in Akmerkez Junction turn green to Oven Road, the halting cars in the Akmerkez Junction prevent the outflow from this road. Therefore the congestion in Oven Road increases as well. This results in a higher halting period for the cars in Torito Junction and therefore for the cars in Akmerkez Junction. In ideal conditions, if there were no any other outflow road from Oven and Kodak Roads, then this dynamics would lead to an absolute jam, which would never allow the cars to move any further.

This problem resembles to a snake trying to eat its own tail. As the snake tries more to reach to its tail, its tail goes further away. It is a vicious cycle and the snake never reaches its goal. In our problem, the cars in the Oven Road try to move faster. As they try more, the traffic gets more congested and their conditions get worse. So in order to simplify the referral to the dynamic problem, we call it “snake tail” problem.

Problem Definition

In this work we focus on a unique problem that helps us understand snake tail problem better. We focus on the load of the traffic. We will answer the problem, how much loading does start the snake tail problem?

Time Horizon and Perspective

The time horizon relevant to this work is the period, when the people go home from their work. This is the time period, when the congestion in the roads exceed a certain level, which results the flow in the junctions be stopped up. The variables are measured in time units of minutes, which is relevant for a time horizon of a few hours.

Behavior over Time Graphs

There is no detailed observed data available. But the hypothetical dynamics of number of cars in the Oven and Kodak Roads and the outflows from these roads are shown in Figure 1 and Figure 2, respectively.

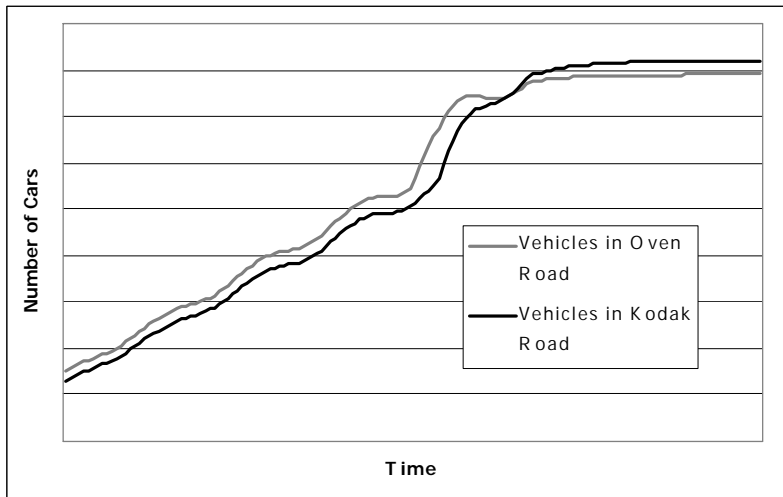


Figure 1 Hypothetical Dynamic Behaviour of the Number of Cars in the Roads

The cars accumulate in the road firstly in a linear manner, assuming that there is enough space for the new coming cars and inflow rate is higher than the outflow rate at the beginning. These assumptions are valid for the concerned period. The inflow rate into the road is very high due to the people going to their home at evening. The outflow rate is lower than the inflow rate due to the already congested roads which the Oven and Kodak Roads are connected to.

The linear accumulation of the cars occurs until a certain point, when the remaining capacity in the Oven and Kodak Roads constrain the inflow rate. Until this point, the inflow rate was constrained by the duration of the traffic lights. But from this point on, the new coming cars cannot flow through the junction into the Kodak or Oven Road as rapid as they want, because of the short distance to the next car.

From then on, the accumulation of the cars occurs in an s-shaped manner. The cars flow into the Kodak and Oven Road, until their capacity is fully utilized. The capacity of a road is fully utilised, when there is no more space left for the newcomers.

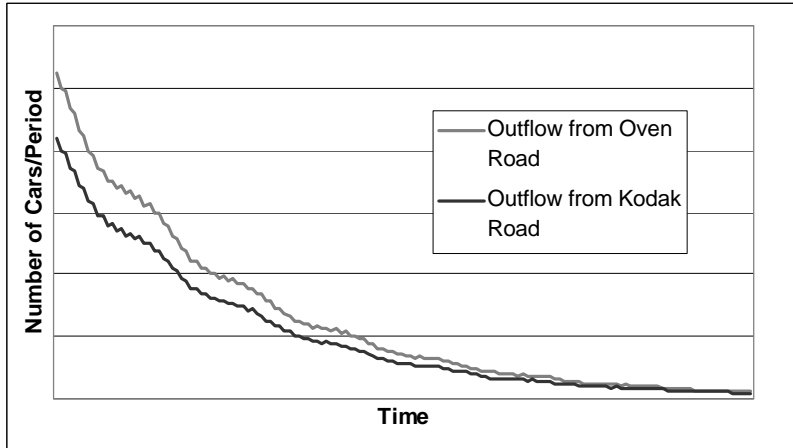


Figure 2 Hypothetical Outflow Behaviour

The outflows are initially at a high rate. But because of the closings of the junctions, the outflows decrease one after another. The decrease in one outflow causes the decrease of the other via the accumulation of the cars in the junction from where the cars of the other road outflow.

The oscillations in the behavior patterns are caused by the traffic lights.

Causal Loop Diagram

The causal loop diagram showing the relationship between the critical variables is shown in Figure 3. The loop that triggers the problem is the central loop. The two small loops function as regulatory loops.

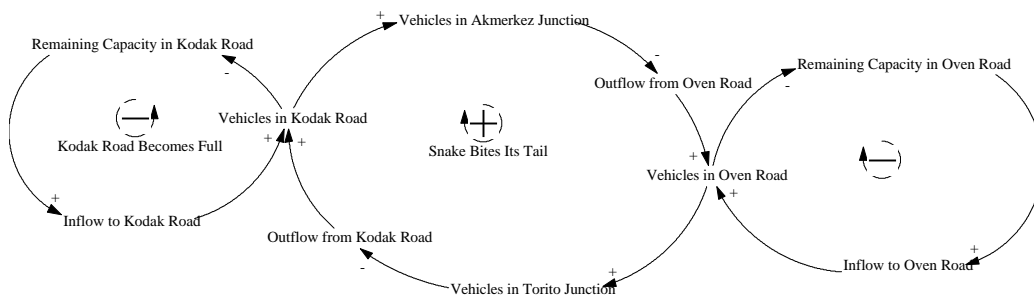


Figure 3 Causal Loop Diagram of Snake Tail Problem

The central causal loop is active only if the traffic on the Kodak and Oven Roads are already congested. At these times the number of vehicles in Oven Road is fairly high. When the number of vehicles in Oven Road increases more, some vehicles flowing

into the Oven Road stay in the Torito Junction. Thus the number of vehicles in Torito Junction increases. This prevents the outflow from Kodak Road. Which decreases the number of vehicles in Kodak Road compared to the state, when there was no decrease in the outflow from Kodak Road. As the number of vehicles in Kodak Road increases the number of vehicles in Akmerkez Junctions increases, as there is no remaining capacity for them in the Kodak Road. This stops up the outflow from the Oven Road through the Akmerkez Junction. Thus the outflow from the Oven Road decreases and consequently the number of vehicles in Kodak Road increases compared to the state, when there was no decrease in the outflow from Oven Road.

In summary, the increase in the number of vehicles in Oven Road results in a further increase in Oven Road. This is the dynamic behaviour of the central loop. This loop is called as “snake bites its tail”, because it triggers the snake tail problem. The snake tries to reach the goal. But this causes the goal to go further away.

The increase in the number of vehicles in Oven Road or Kodak Road is not unlimited. They are controlled by the capacities of the roads. The limiting behaviour is modelled by the two small loops in Figure 3. As the number of vehicles in Kodak Road increases, the remaining capacity decreases. As it decreases, the inflow to Kodak Road decreases as well. This results in a decrease of the vehicles in Kodak Road, when compared to the state that there was no decrease in inflow. The same dynamics occur in Oven Road.

Model Construction

The stock-flow model is developed in gradual steps. In this article, we will explain the gradual improvements in the model step by step. The first model, on which the improvements are made, is shown in Figure 4. There are two stock variables, one showing the number of vehicles in Kodak Road, the other the one in Oven Road. The loops shown in causal loop diagram can also be seen in the stock flow diagram. The “snake bites its own tail” loop is the central loop in the stock-flow model. It starts from the stock variables and extend thru the Vehicles in Torito/Akmerkez Junction, Effect of Torito/Akmerkez Junction on Outflow Kodak/Oven and Outflow Kodak/Oven.

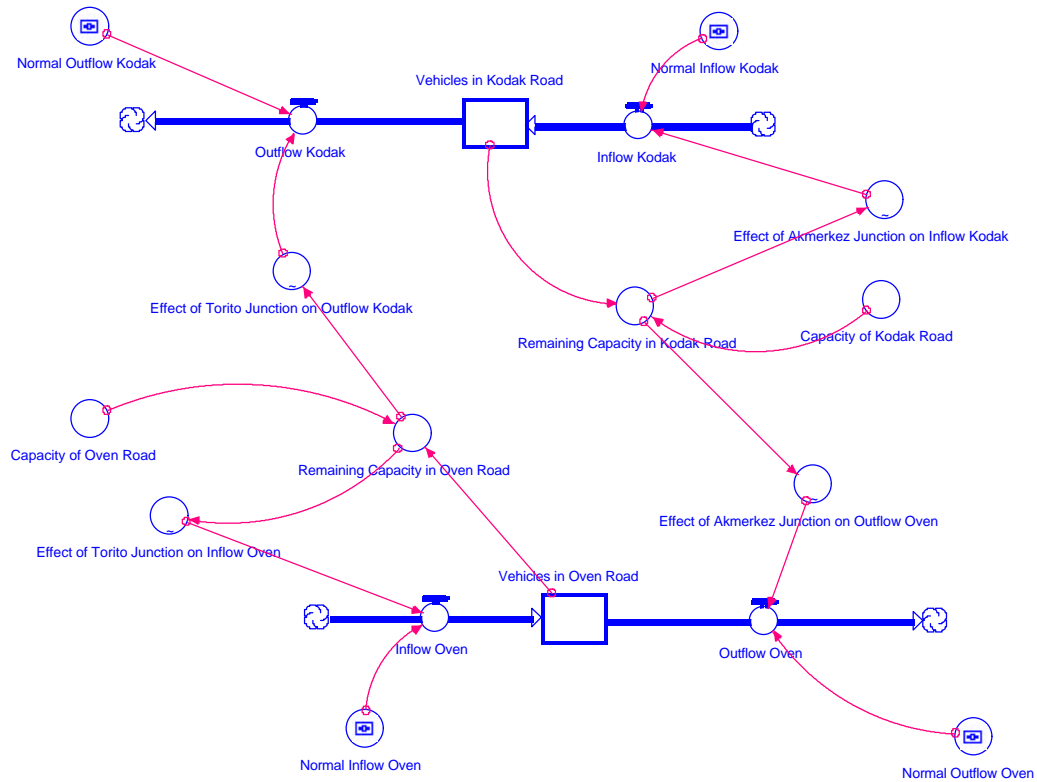


Figure 4 Initial Stock-Flow Model of the Snake Tail Problem

Variables

Stocks:

Vehicles in Kodak Road: The number of vehicles in Kodak Road { vehicles }

Vehicles in Oven Road: The number of vehicles in Oven Road { vehicles }

Flows:

Outflow Kodak: The number of vehicles flowing out of the Kodak Road through the Torito Junction per minute { vehicles/minute }

Inflow Kodak: The number of vehicles flowing into the Kodak Road through the Akmerkez Junction per minute { vehicles/minute }

Outflow Oven: The number of vehicles flowing out of the Oven Road through the Akmerkez Junction per minute { vehicles/minute }

Inflow Oven: The number of vehicles flowing into the Oven Road through the Torito Junction per minute {vehicles/minute}

Converters:

Capacity_of_Kodak_Road: The capacity of the Kodak Road –excluding the Akmerkez Junction – {vehicles}

Capacity_of_Oven_Road: The capacity of the Oven Road –excluding the Torito Junction – {vehicles}

Normal_Inflow_Kodak: The normal inflow rate into the Kodak Road – when there is no place limitation in the road {vehicles/minute}

Normal_Inflow_Oven: The normal inflow rate into the Oven Road – when there is no place limitation in the road {vehicles/minute}

Normal_Outflow_Kodak: The normal outflow rate from the Kodak Road through the Torito Junction – when there is no stopped up cars in the junction {vehicles/minute}

Normal_Outflow_Oven: The normal outflow rate from the Oven Road through the Akmerkez Junction – when there is no stopped up cars in the junction {vehicles/minute}

Effect_of_Akmerkez_Junction_on_Inflow_Kodak: The effect of the remaining capacity in the Kodak Road on the inflow rate into the Kodak Road. {no unit}

Effect_of_Akmerkez_Junction_on_Outflow_Oven: The effect of the vehicles stopped up in the Akmerkez Junction on the outflow rate from the Oven Road. {no unit}

Effect_of_Torito_Junction_on_Inflow_Oven: The effect of the remaining capacity in the Oven Road on the inflow rate into the Oven Road. {no unit}

Effect_of_Torito_Junction_on_Outflow_Kodak: The effect of the vehicles stopped up in the Torito Junction on the outflow rate from the Kodak Road. {no unit}

Remaining_Capacity_in_Kodak_Road: The remaining capacity in the Kodak Road. The variable can have positive or negative values. If it is positive, then it defines the space left in the Kodak Road. If it is negative, then Kodak Road is overloaded, i.e. some vehicles stop up in the Akmerkez Junction. {vehicles}

Remaining_Capacity_in_Oven_Road: The remaining capacity in the Oven Road. The variable can have positive or negative values. If it is positive, then it defines the space left in the Oven Road. If it is negative, then Oven Road is overloaded, i.e. some vehicles stop up in the Torito Junction. {vehicles}

In this model, the names of the variables “Remaining_Capacity_in_Kodak_Road” and “Remaining_Capacity_in_Oven_Road” are partially misleading. They do not show only the remaining capacity. They also show the number of vehicles stopped up in the Akmerkez and Torito Junction, respectively. If the variables become negative, then the roads are overloaded and the new coming cars stop up in the junctions. When the variables are positive, it is the remaining capacities of the roads.

Mathematical Relationships

The mathematical equations showing the relationships between the variables are the following ones:

$$\text{Vehicles_in_Kodak_Road}(t) = \text{Vehicles_in_Kodak_Road}(t - dt) + (\text{Inflow_Kodak} - \text{Outflow_Kodak}) * dt$$

INIT Vehicles_in_Kodak_Road = 5

INFLOWS:

Inflow_Kodak = if(mod(4*TIME,8)<6) then 0 else

Effect_of_Akmerkez_Junction_on_Inflow_Kodak*Normal_Inflow_Kodak

OUTFLOWS:

Outflow_Kodak = if(mod(4*TIME,8)<5) then 0 else

Normal_Outflow_Kodak*Effect_of_Torito_Junction_on_Outflow_Kodak

$$\text{Vehicles_in_Oven_Road}(t) = \text{Vehicles_in_Oven_Road}(t - dt) + (\text{Inflow_Oven} - \text{Outflow_Oven}) * dt$$

INIT Vehicles_in_Oven_Road = 5

INFLOWS:

Inflow_Oven = if(mod(4*TIME,8)<3) then 0 else

Effect_of_Torito_Junction_on_Inflow_Oven*Normal_Inflow_Oven

OUTFLOWS:

Outflow_Oven = if(mod(4*TIME,8)<2) then 0 else

Normal_Outflow_Oven*Effect_of_Akmerkez_Junction_on_Outflow_Oven

Capacity_of_Kodak_Road = 38

Capacity_of_Oven_Road = 38

Normal_Inflow_Kodak = 18

Normal_Inflow_Oven = 18

Normal_Outflow_Kodak = 4

Normal_Outflow_Oven = 4

Remaining_Capacity_in_Kodak_Road =

Capacity_of_Kodak_Road-Vehicles_in_Kodak_Road

Remaining_Capacity_in_Oven_Road = Capacity_of_Oven_Road-

Vehicles_in_Oven_Road

Effect_of_Akmerkez_Junction_on_Inflow_Kodak =

GRAPH(Remaining_Capacity_in_Kodak_Road)

(-3.00, 0.00), (-0.7, 0.175), (1.60, 0.295), (3.90, 0.575), (6.20, 0.705), (8.50, 0.81),
(10.8, 0.875), (13.1, 0.93), (15.4, 0.965), (17.7, 0.985), (20.0, 1.00)

Effect_of_Akmerkez_Junction_on_Outflow_Oven =

GRAPH(Remaining_Capacity_in_Kodak_Road)

(-3.00, 0.00), (-2.70, 0.015), (-2.40, 0.1), (-2.10, 0.39), (-1.80, 0.655), (-1.50, 0.84), (-
1.20, 0.93), (-0.9, 0.965), (-0.6, 0.98), (-0.3, 0.995), (-3.33e-016, 1.00)

Effect_of_Torito_Junction_on_Inflow_Oven =

GRAPH(Remaining_Capacity_in_Oven_Road)

(-1.50, 0.00), (0.65, 0.175), (2.80, 0.295), (4.95, 0.575), (7.10, 0.705), (9.25, 0.81),
(11.4, 0.875), (13.6, 0.93), (15.7, 0.965), (17.9, 0.985), (20.0, 1.00)

Effect_of_Torito_Junction_on_Outflow_Kodak =

GRAPH(Remaining_Capacity_in_Oven_Road)

(-1.50, 0.00), (-1.35, 0.015), (-1.20, 0.1), (-1.05, 0.39), (-0.9, 0.655), (-0.75, 0.84), (-
0.6, 0.93), (-0.45, 0.965), (-0.3, 0.98), (-0.15, 0.995), (-1.67e-016, 1.00)

The graphical functions of the Effect of Akmerkez/Torito Junction on Inflow Kodak/Oven are shown in Appendix B, Figure 36 and Figure 37 respectively. Similarly the graphical functions of Effect of Akmerkez/Torito Junction on Oven/Kodak Outflow are shown in Figure 38 and Figure 39, respectively.

The capacities of Oven Road and Kodak Road are measured as 38 vehicles. This number doesn't include the excess capacity of the road, when the Torito Junction is congested. Therefore the stock variable Vehicles in Oven Road may exceed the Capacity of Oven Road by the capacity of the Torito Junction. The same is also valid for the Kodak Road. The capacities of the Torito and Akmerkez Junctions are 1.5 and 3 vehicles, respectively. Thus the maximum allowable level of the stock variables Vehicles in Oven and Kodak Road are 39.5 and 41, respectively.

All the graphical functions defining the effect variables are selected as s-shape functions. The effect function of the vehicles in Torito Junction on Kodak Outflow - Figure 39- states that if there is no vehicle in Torito Junction, then it doesn't effect the Kodak Outflow, if the junction is full of cars, then the Kodak Outflow is totally prevented. Between the extreme values we assumed the relationship to be s-shaped. If there is only 0.5 cars on the junction, then the cars may pass through the junction by some intricate manoeuvre, which is happening in these junctions, in real life. The effect of partial load on the junction is the slower movement of the cars through the junction, which results in a lower outflow rate. The deceleration is at an increasing rate at first until some threshold and then it occurs at a decreasing rate, which justifies the s-shape of the effect function. The same is also valid for the effect of Akmerkez Junction on the Oven Outflow.

The effect of the remaining capacity in the Oven Road –which is reflected by the variable Vehicles in Torito Junction – on the inflow rate into Oven Road is similar. First of all, as the remaining capacity decrease, the inflow rate must decrease. This occurs because of the flow dynamics of the vehicles. The vehicle drivers determine their speed according to the spacing between their vehicle and the next vehicle and the speed of the next vehicle. The speed of the next vehicle is determined in the same way. From the statistical point of view, the normal speed of the cars on a road depends only on the spacing between the consecutive cars. When the spacing between the consecutive cars is higher than a threshold value, the speed of the cars are limited

by their normal speed on the road. When the spacing is zeroing the speed is zero as well. When the spacing between the cars is a little lower than the threshold, their speed is affected in a very low amount. But as the spacing decreases further, the effect on the speed is stronger. Thus starting from zero point, the effect of the spacing on the speed is at an increasing rate until some inflection point. Then it occurs at a decreasing rate until the normal speed. The remaining capacity on the road is directly proportional with the spacing between the consecutive cars. So the s-shape relationship between the remaining capacity and the inflow rate is justified.

Parameters

There are certain constant parameters in the model, Table 1. The parameters Normal_Outflow_Kodak, Normal_Outflow_Oven, Capacity of Akmerkez Junction, Capacity of Torito Junction, Capacity_of_Kodak_Road, Capacity_of_Oven_Road are measured parameters. The outflow rates are measured at a time, when there was no junction congestion problem and the roads were loaded with sufficient cars to supply the normal outflow rate. The normal inflow rates depend highly on the remaining capacity. Therefore a measurement for the normal rate is not possible. But we estimated them to be slightly higher than the normal outflow rate into the Kodak Road, because the normal outflow rate from the Kodak Road is measured at a time, when there was a balance between the inflow and outflow. But since the number of cars flowing into the roads is higher at evening, they are taken slightly higher.

Table 1 Parameters of the Model

DT	0.1 minute
Capacity_of_Kodak_Road	38 vehicles
Capacity_of_Oven_Road	38 vehicles
Normal_Inflow_Kodak	18 vehicles/minute
Normal_Inflow_Oven	18 vehicles/minute
Normal_Outflow_Kodak	4 vehicles/minute
Normal_Outflow_Oven	4 vehicles/minute
Capacity of Akmerkez Junction	3 vehicles
Capacity of Torito Junction	1.5 vehicles

The initial values for the stocks are taken near to their capacities, which is the normal case during the after work hours.

Verification

The Extreme Condition Tests:

When the normal inflow rate into the Oven Road is zero, after some while there will remain certainly no other car in the Oven Road. The simulation model gave the correct behaviour, Figure 5.

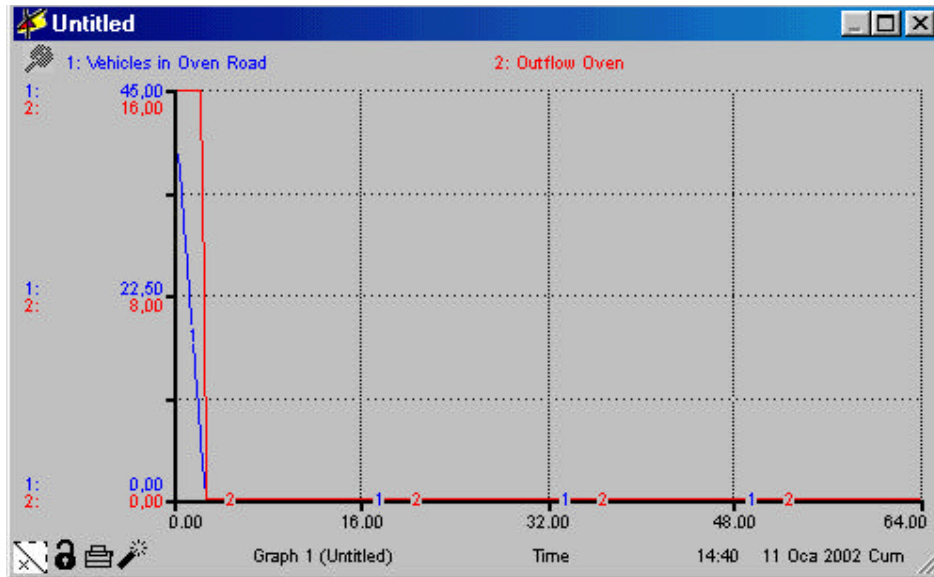


Figure 5 Normal Inflow Oven = 0

The second extreme condition test is the reverse. The outflow from the Kodak Road is taken as zero. In this case, the inflow into the Kodak Road will cause the vehicles in the road to increase upto the maximum allowable capacity, which is 41. After that the inflow cannot push the stock to increase any further.

The simulation run is performed and we found that the inflow to the Kodak Road doesn't continue forever. The capacity of the road except the junction is 38. The capacity of the junction is 3. Therefore the total number of the vehicles in Akmerkez road cannot exceed 41. The number of vehicles in Akmerkez road vs. time is displayed in Figure 6. The steady state is achieved at 41 which is the capacity of the

road including the junction. The inflow to the Kodak Road goes to zero as time passes.

Also after the Kodak Road has reached its capacity of 41 , the Oven Road’s outflow decreases up to zero , and it also reaches its capacity .

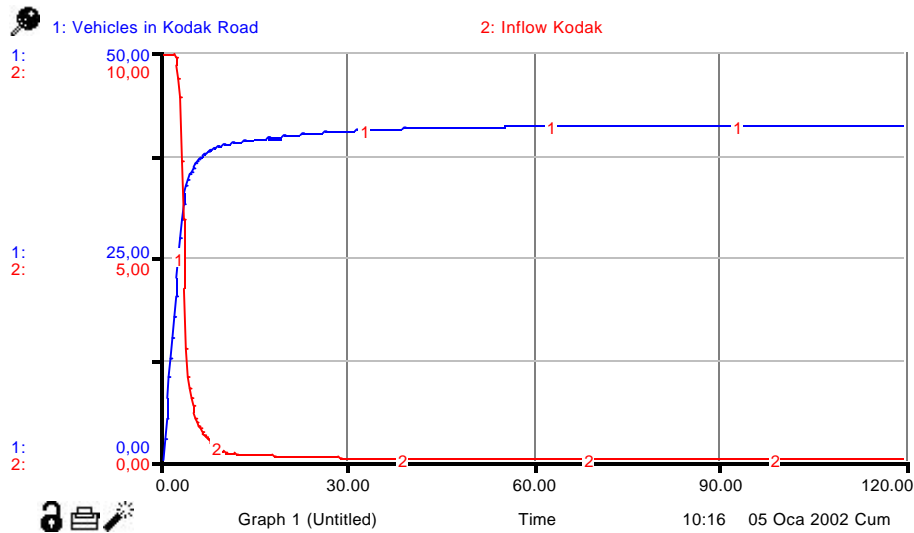


Figure 6 Outflow Kodak = 0

Partial Tests

The next test is done by activating both the input and the outflow from the Kodak Road, see Appendix B Figure 40. The outflow rate is taken constant as 5 cars per minute. Equilibrium in Vehicles in Kodak Road is attained at 32 cars. The inflow decreased to the level of the outflow and remained stable, because of the limiting influence of Effect of Vehicles in Akmerkez Junction, Appendix B Figure 41.

The same verification runs are made for the Oven Road. The results are reasonable, Figure 7.

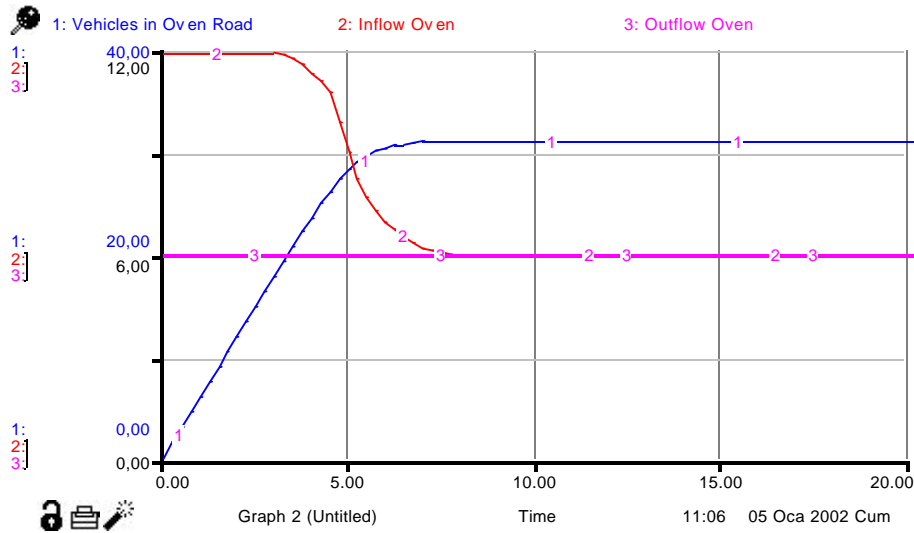


Figure 7 Partial Run (Inflow vs. Constant Outflow) - Oven Alone

Another simulation run is done in order to verify that the effect formulation works properly. The effect of the number of vehicles in Torito Junction – in the model, this number is defined in the variable Remaining Capacity in Oven Road – on Kodak Outflow is activated – see Appendix B Figure 39 for the relationship between the variables. The outflow from Oven Road is taken as zero. This caused the number of vehicles in the Oven Road to increase up to the full capacity 39.5. After that the Torito Junction is congested. And this caused the outflow from Kodak Road to decrease down to zero.

Next we verified the effect of Torito Junction on Kodak Outflow, when there is no car in Torito Junction, Appendix B Figure 42 and Figure 43. To do this we allowed the outflow from Kodak Road to be a positive number. Thus the inflow into the Kodak Road didn't increase the number of vehicles in Kodak Road such that its capacity is not fully utilized. The result is displayed in Figure 8. In this case, the number of vehicles in Kodak Road is independent of the number of vehicles in Oven Road.

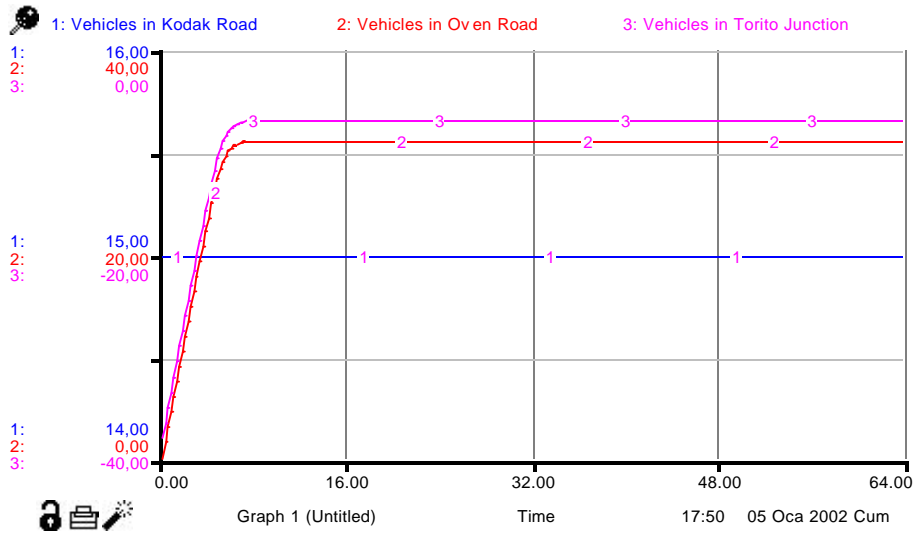


Figure 8 Partial Run (Effect of Torito Junction on Kodak Outflow Activated) – Outflow from Oven Road is taken as six

Validation

Behaviour Validity

During the after work hours, sometimes the normal outflow rates from the Oven decreases further below the values measured by our observations. This is due to the congestion in the Zincirlikuyu Road. When this road becomes congested, the outflow from the Oven Road is down-limited by the remaining capacity in the Zincirlikuyu Road. According to our trials the normal outflow/inflow ratio should be 1/20. Only after this ratio, the model reproduces the hypothetical dynamic behaviour. The simulation outputs and hypothetical dynamic behaviour graphs are shown in Figure 9, Figure 10 and Figure 11. The simulation runs regenerate the general pattern in the hypothetical dynamic behaviour graphs.

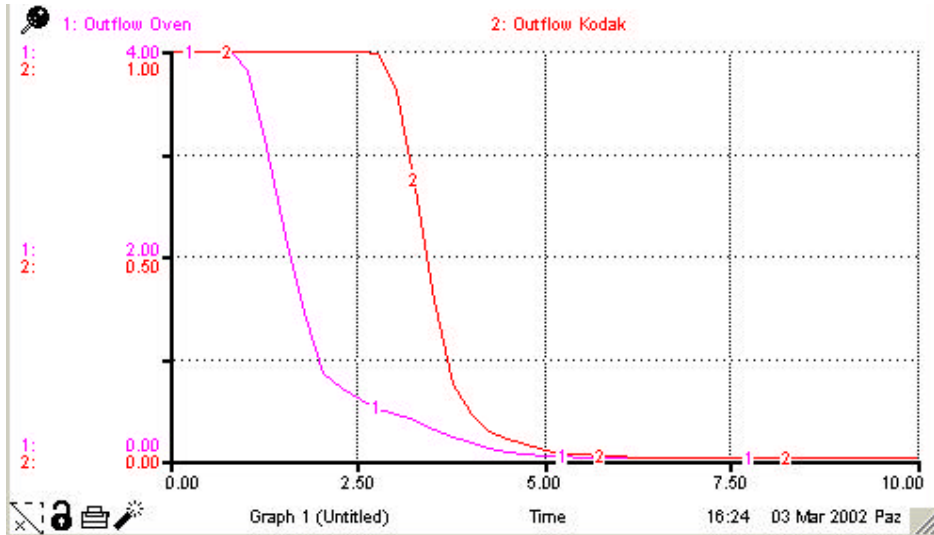


Figure 9 Simulated Dynamic Behaviour of the Outflow Rates

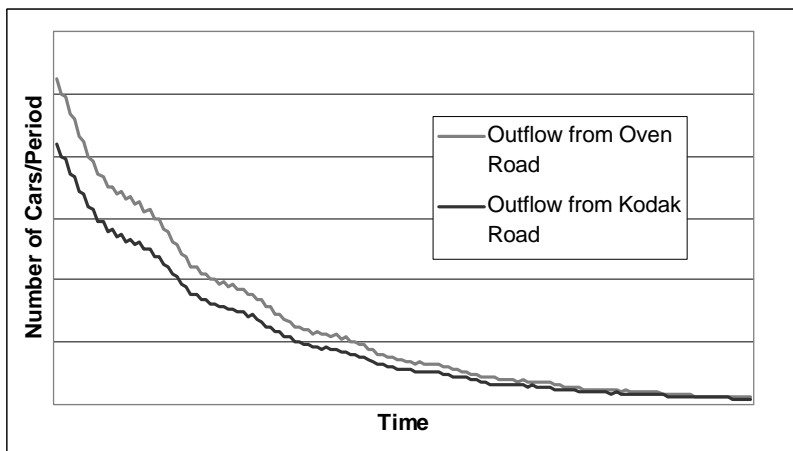


Figure 10 Hypothetical Behaviour of the Outflow Rates

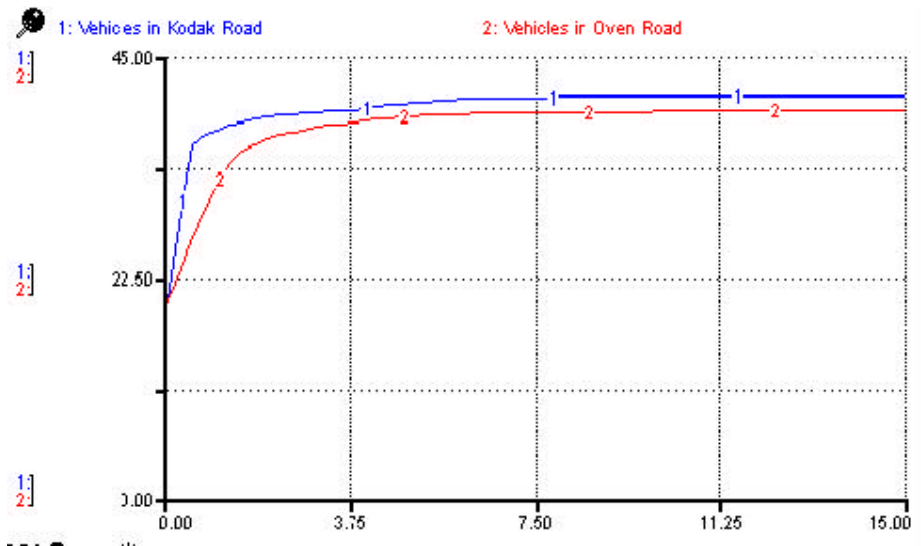


Figure 11 Simulated Dynamic Behaviour of the Stocks

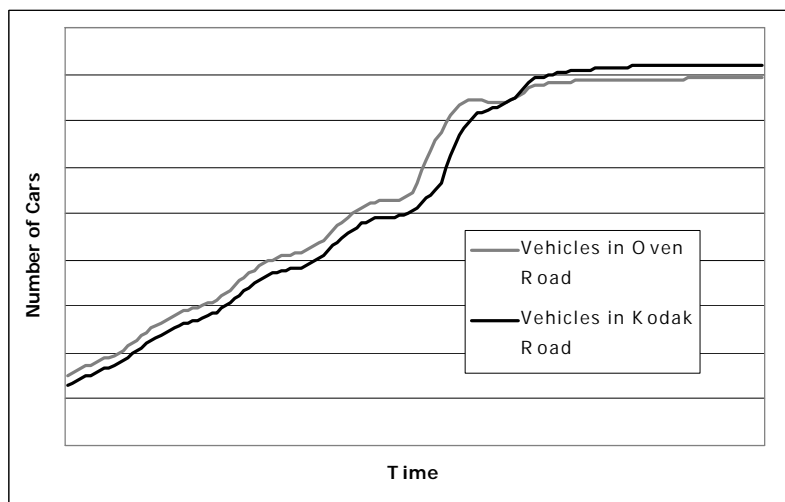


Figure 12 Hypothetical Behaviour of the Number of Vehicles

The above results are appropriate for the model without traffic lights. However when traffic lights are included in the model, an oscillatory behaviour is observed. That is because the traffic lights stop the flows for some durations of time, and stocks are also effected by this property.

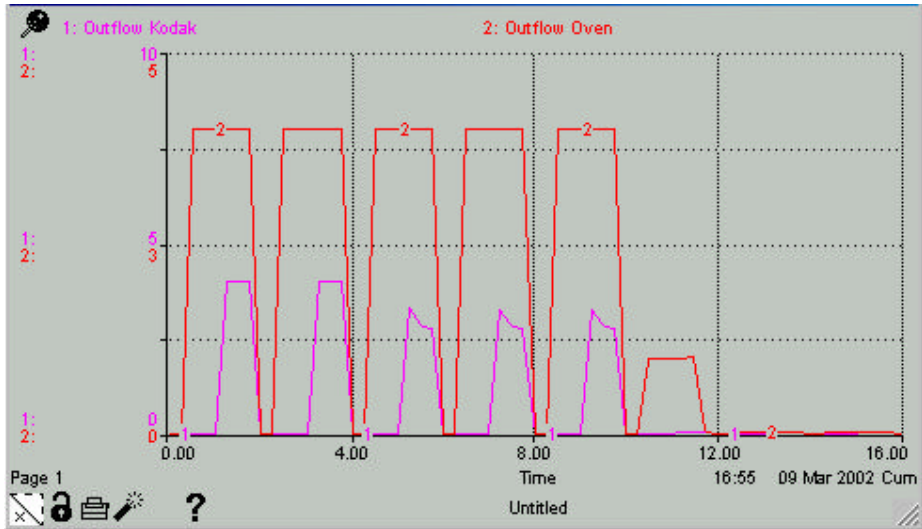


Figure 13 Dynamic Behaviour of the Outflow Rates

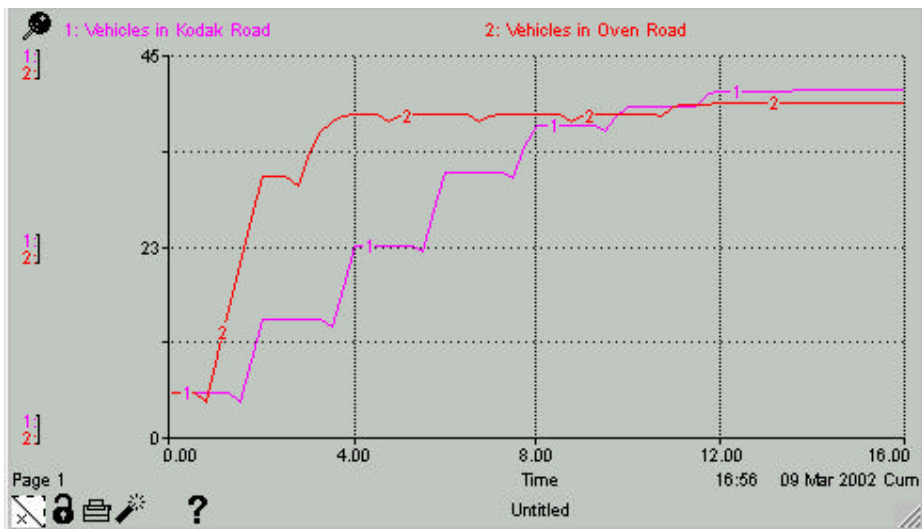


Figure 14 Dynamic Behaviour of the Stocks

Experiments

Model 1

This model does not include traffic lights and delays .It is ran for several values of inflows and outflows and the following results are obtained.

Run 1

STOCKS

Vehicles In Kodak	5
Vehicles In Oven	5

CONVERTERS

Normal Inflow Kodak	18
Normal Inflow Oven	18
Normal Outflow Oven	4
Normal Outflow Kodak	4

Results

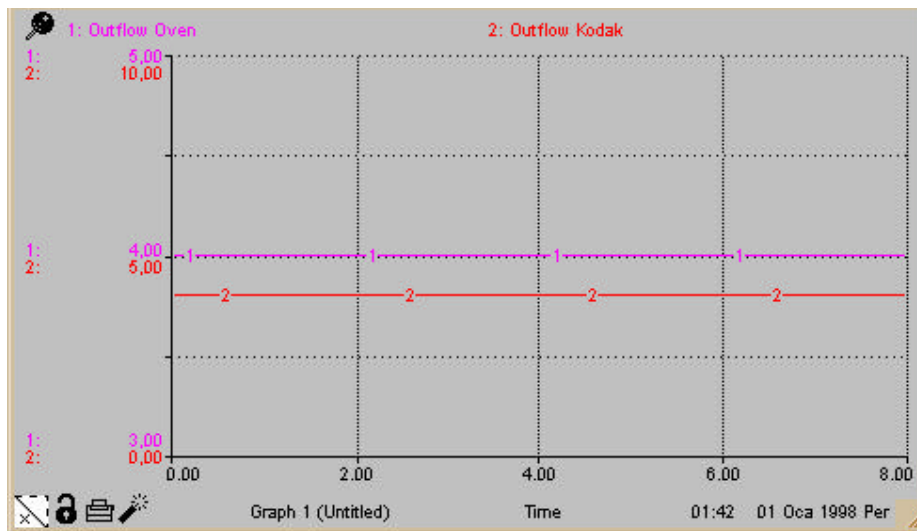


Figure 15 Dynamic Behaviors of Outflows

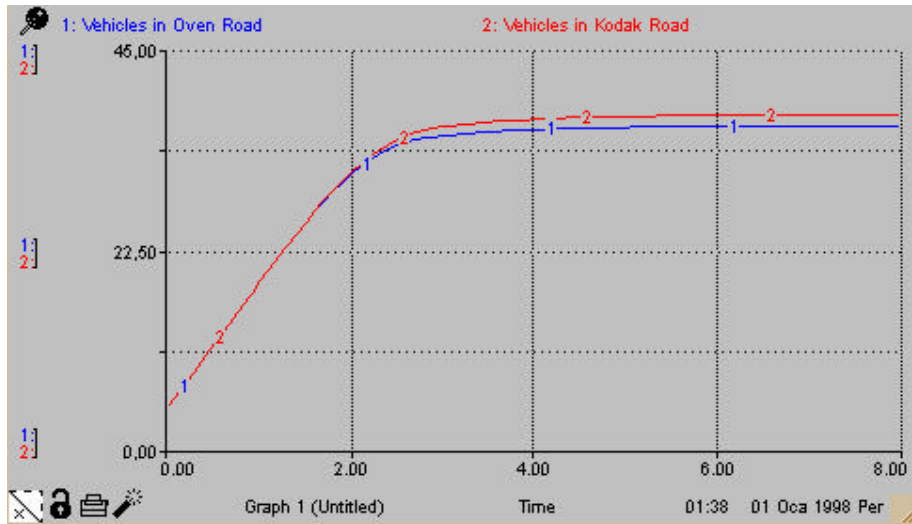


Figure 16 Dynamic Behaviour of Stocks

The above graph shows the fact that the inflows to the roads are not high enough to cause a traffic paralysis. Namely, outflow/inflow ratios for both of the stocks are high and the system comes to an equilibrium where the inflows of the stocks equal the outflows. Although inflows are higher than the outflows initially, as the stocks of Kodak and Oven begin to fill, inflows decrease to the level of outflows and the system comes to a dynamic equilibrium.

Run 2

STOCKS

Vehicles In Kodak	5
Vehicles In Oven	5

CONVERTERS

Normal Inflow Kodak	18
Normal Inflow Oven	18
Normal Outflow Oven	1
Normal Outflow Kodak	1

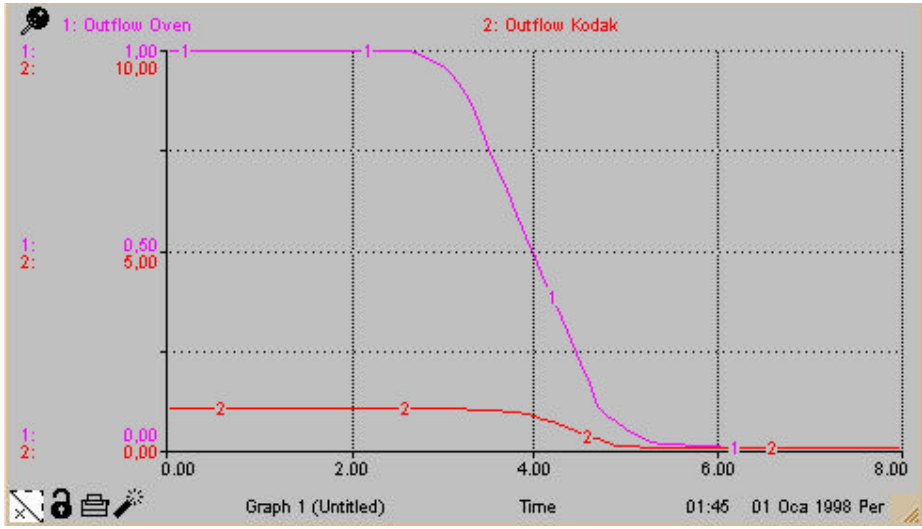


Figure 17 Dynamic Behaviour of Outflows

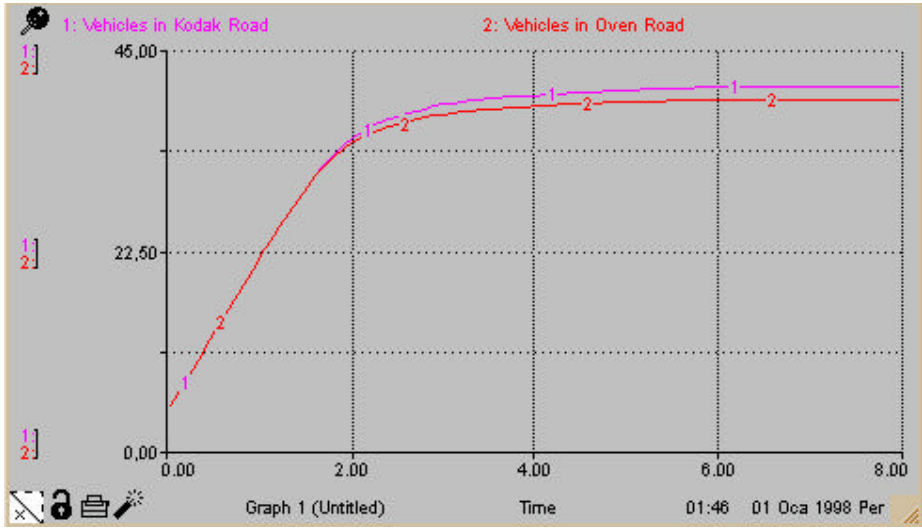


Figure 18 Dynamic Behaviour of Stocks

RESULTS

When the above results are analyzed, it is observed that the Kodak and Oven Road stocks begin to increase gradually. Since inflow never becomes lower than the outflow until the stocks are full, stocks increase up to their capacity level and when that level is reached both inflow and outflow becomes zero. This event is called “snake eating its tail “. When we analyze more; the previous simulation did not lead to such a behavior, because outflow rates were higher in that run. So traffic was flowing at a low rate, but it did not stop. But when we decrease the outflows, the junction points of Oven & Kodak begin to fill up with cars. Eventually the cars in the

junctions block both inflows and outflows and the “ snake eating its tail “ behavior occurs.

MODEL 2

This model includes the traffic lights.

They operate according to following schedule. (Durations are estimated values)

Flow Name	Duration
Kodak Outflow	45 seconds
Oven Inflow	75 seconds
Kodak Inflow	30 seconds
Oven Outflow	90 seconds

Model Description:

This model is different from the previous model in the respect that it schedules the flow of the roads according to the real life traffic light schedule .To achieve this, TIME function of STELLA is used.

For the flows the below equations are updated.

$\text{Inflow_Kodak} = \text{if}(\text{mod}(4*\text{TIME},8)<6) \text{ then } 0 \text{ else}$

$\text{Effect_of_Akmerkez_Junction_on_Inflow_Kodak}*\text{Normal_Inflow_Kodak}$

$\text{Outflow_Kodak} = \text{if}(\text{mod}(4*\text{TIME},8)<5) \text{ then } 0 \text{ else}$

$\text{Normal_Outflow_Kodak}*\text{Effect_of_Torito_Junction_on_Outflow_Kodak}$

$\text{Inflow_Oven} = \text{if}(\text{mod}(4*\text{TIME},8)>4) \text{ then } 0 \text{ else}$

$\text{Effect_of_Torito_Junction_on_Inflow_Oven}*\text{Normal_Inflow_Oven}$

$\text{Outflow_Oven} = \text{if}(\text{mod}(4*\text{TIME},8)>5) \text{ then } 0 \text{ else}$

$\text{Normal_Outflow_Oven}*\text{Effect_of_Akmerkez_Junction_on_Outflow_Oven}$

RUN 1

STOCKS

Vehicles In KODAK	5,00
Vehicles In Oven	5,00
CONVERTERS	
Normal Inflow Kodak	72,00
Normal Inflow Oven	24,00
Normal Outflow Oven	4,00
Normal Outflow Kodak	2,66

These values of inflows and outflows from the stocks are adjusted to be the same as in the previous run. Since we impede the flows for some time period, average flow of the system decreases if we do not change the values of converters. For example, inflow from Kodak Road is allowed for only 30 seconds / 2 minutes, so its average flow is 18 vehicles/minute. Again, if we assign 72 to converter.

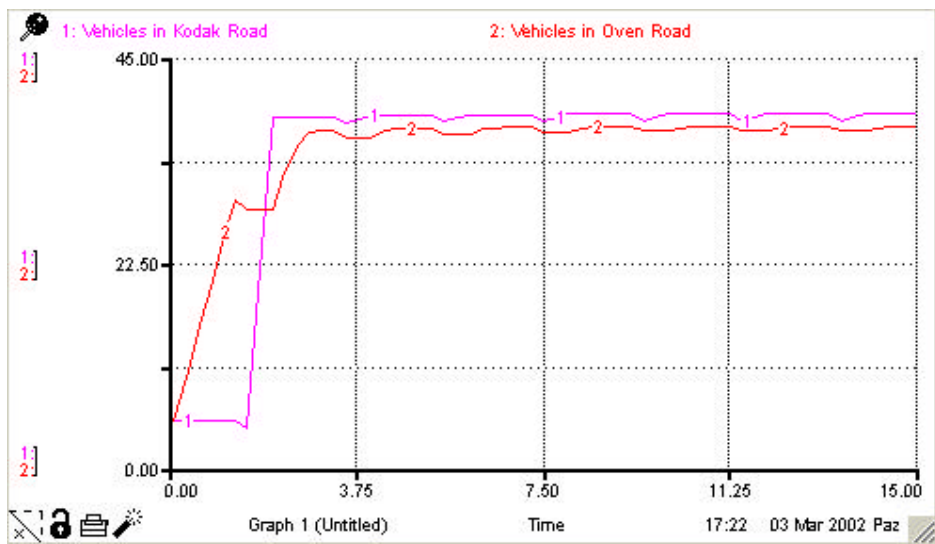


Figure 19 # of Vehicles in Kodak and Oven Roads

The other graphs related to this experiment are shown in Figure 44 and Figure 45, Appendix B.

Experiments on Driver Types

Driver Type 1: Advanced and Impatient Driver

We call this type of driver as advanced, because he/she can pass through the roads having very narrow blanks, which are partially blocked by other cars. Such a behavior is added to the model by modifying the effect graphs. As seen in the below graph such a driver is not stopped completely even if the road is partially blocked.

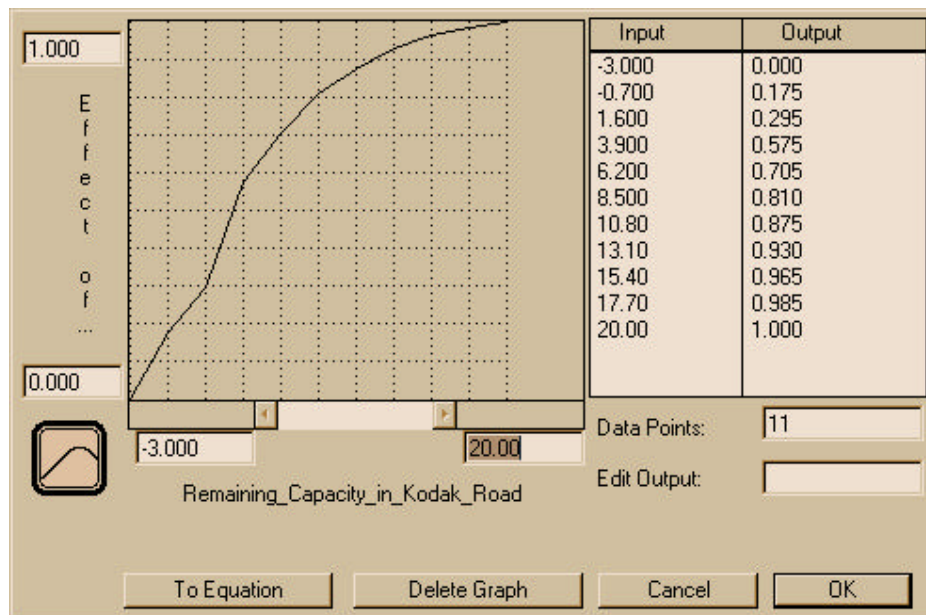


Figure 20 Effect of Remaining Capacity on Inflow-Graph of an Advanced Driver

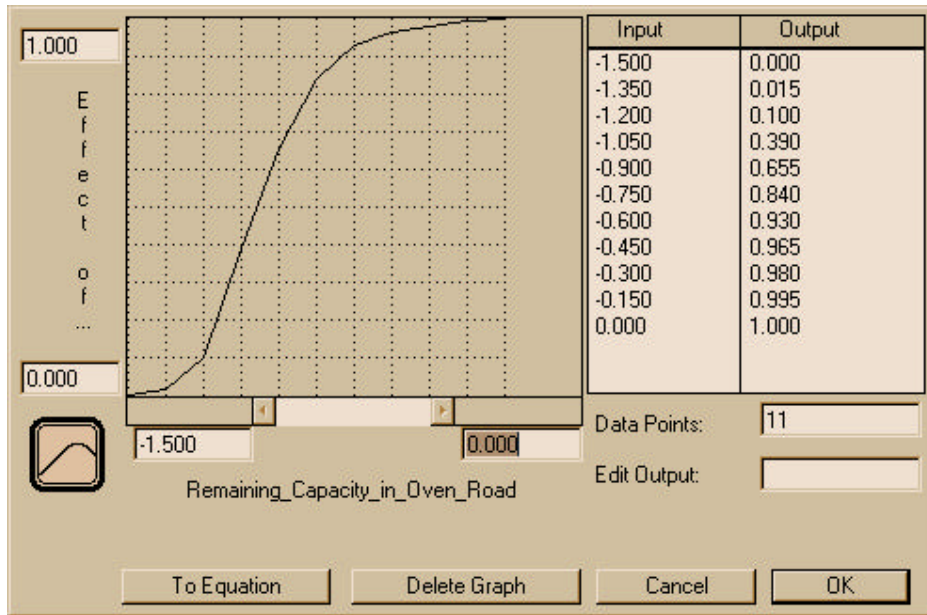


Figure 21 Effect of Remaining Capacity on Outflow-Graph of an Advanced Driver

Interpretation of Graphs:

The most basic characteristic of the above graphs is; the effect coefficient of the remaining capacity in the road is not reduced very much even if the road is partially full. As a result of this fact outflow and inflow values do not decrease as soon as the capacity of the road decreases. Consequently flows in the roads do not end even in the crowded situations and the traffic flow goes on.

Run (Hesitated Drivers):

STOCKS	
Vehicles In KODAK	5,00
Vehicles In Oven	5,00
CONVERTERS	
Normal Inflow Kodak	32.5
Normal Inflow Oven	32
Normal Outflow Oven	1.4
Normal Outflow Kodak	1.8

Result:

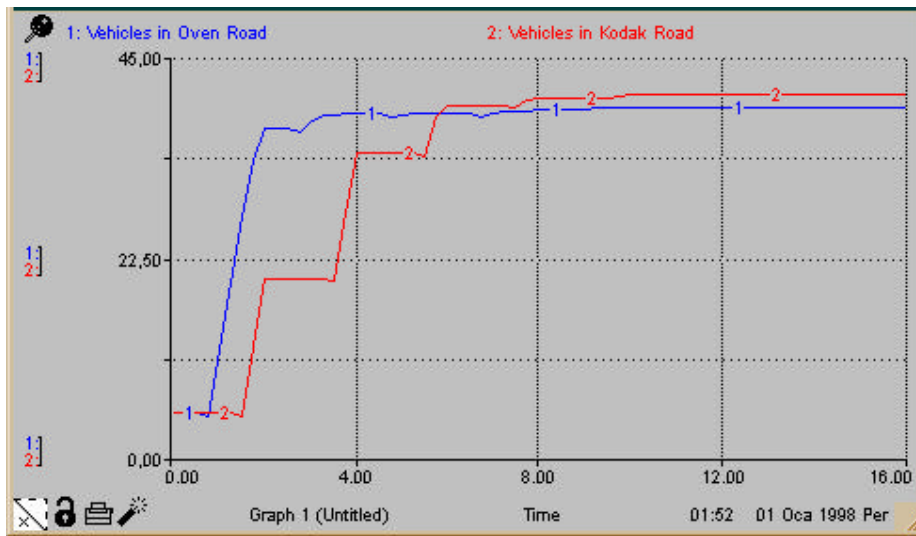


Figure 22 Dynamic Behaviour of the Stocks-Advanced (Hesitated) Driver

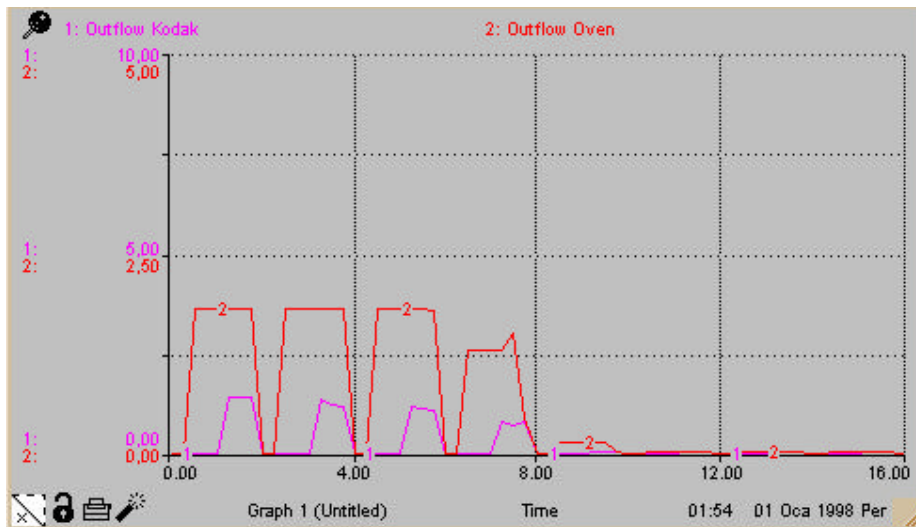


Figure 23 Dynamic Behaviour of the Flows-Advanced (Hesitated) Driver

Interpretation of Results:

As we can observe from the above graphs, inflow and outflow values go down to zero at time point 8. The “snake eating its tail Behaviour occurs because the hesitated drivers do not stop coming into the roads inspired by observing the crowd in the road, so as they come the junctions also become filled, consequently no other car can move any further.

Driver Type 2: Normal Driver

We call this type of driver as normal, because he/she drives more patiently than the hesitated drivers but more dangerously than the cautious ones. Such a behavior is added to the model by modifying the effect graphs.

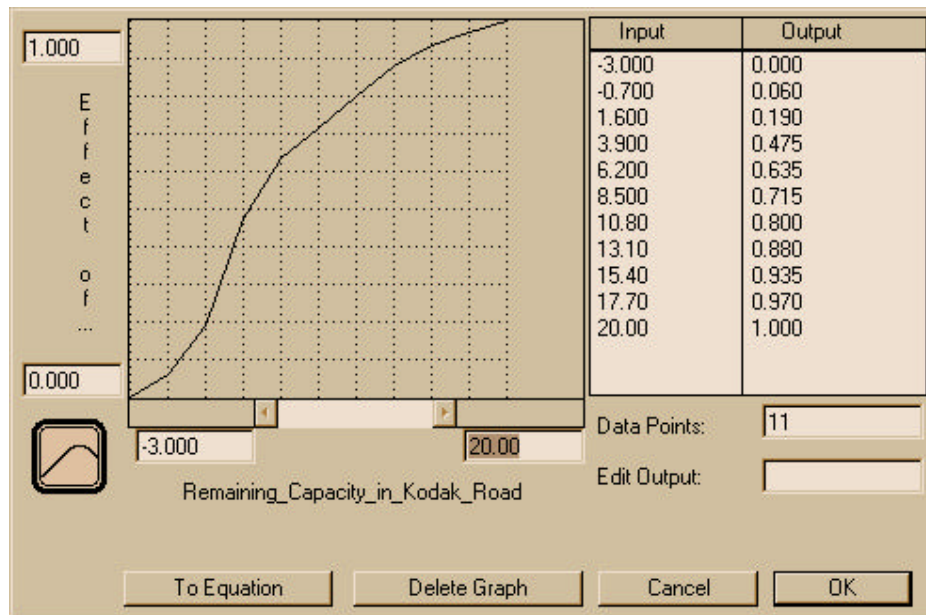


Figure 24 Effect of Remaining Capacity on Inflow-Graph of a Normal Driver

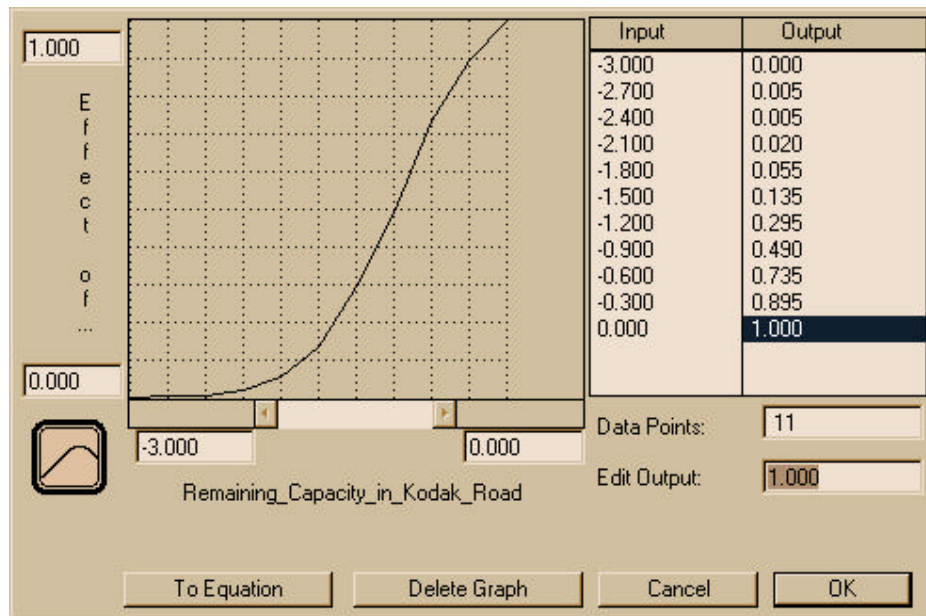


Figure 25 Effect of Remaining Capacity on Outflow-Graph of a Normal Driver

Interpretation of Graphs:

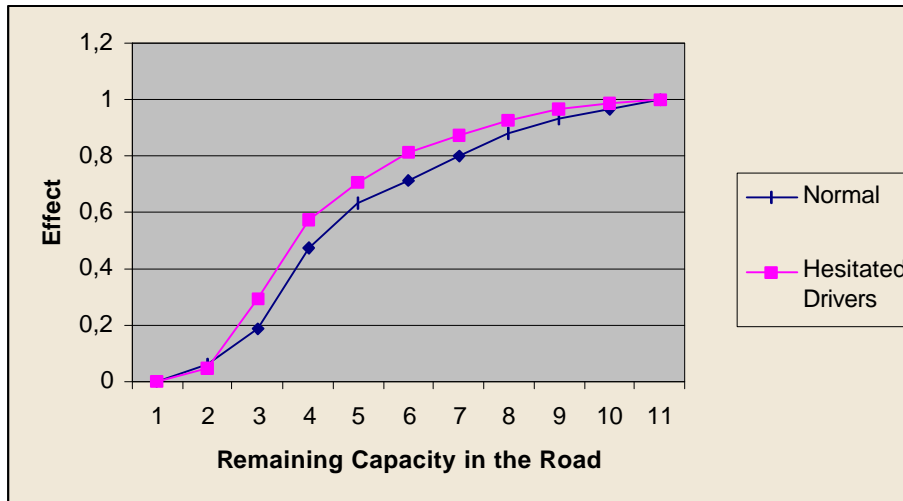


Figure 26 Remaining Capacity vs. Effect on Inflow Graph

When we analyze the above graph, it is observed that the hesitated driver has a higher effect value at the same level of remaining capacity in the road. Since the flow is $\text{effect} \times \text{Normal Flow}$, the actual flow value is more in the hesitated drivers case. As mentioned before this condition leads to an early filling of the road and the traffic flow ends before the Normal Driver's case.

Run (Normal Drivers Case)

STOCKS	
Vehicles In KODAK	5,00
Vehicles In Oven	5,00
CONVERTERS	
Normal Inflow Kodak	32.5
Normal Inflow Oven	32
Normal Outflow Oven	1.4
Normal Outflow Kodak	1.8

Result:

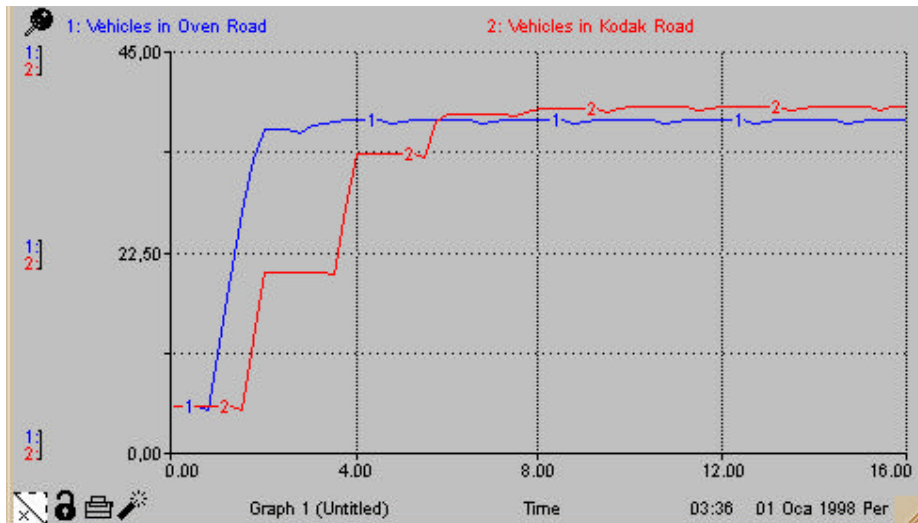


Figure 27 Dynamic Behaviour of the Stocks-Normal Driver

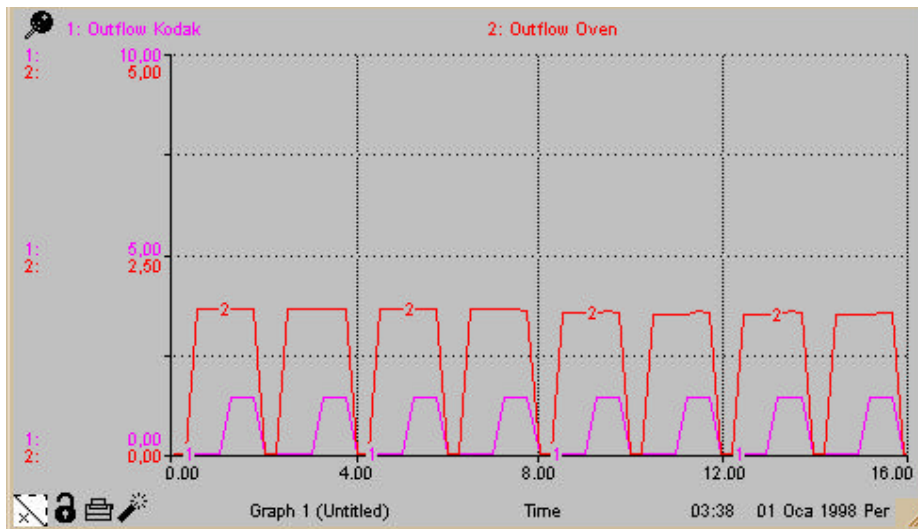


Figure 28 Dynamic Behaviour of the Flows-Normal Driver

Interpretation of Results:

Normal Driver case does not lead to a “snake eating its tail Behaviour” when the previous experiment is repeated with Normal Driver case effect graphs. System reaches equilibrium at the point of

Vehicles in Oven Road	35
Vehicles in Kodak Road	36.3

Consequently, Normal Driver case reaches its equilibrium point and the traffic flow does not end.

Driver Type 3: Cautious Driver

We call this type of driver as Causal, because he/she drives more patiently than the Normal Drivers. That is to say whenever there exists a crowd in the junctions of the roads, they immediately decrease in speed and their flow stops.

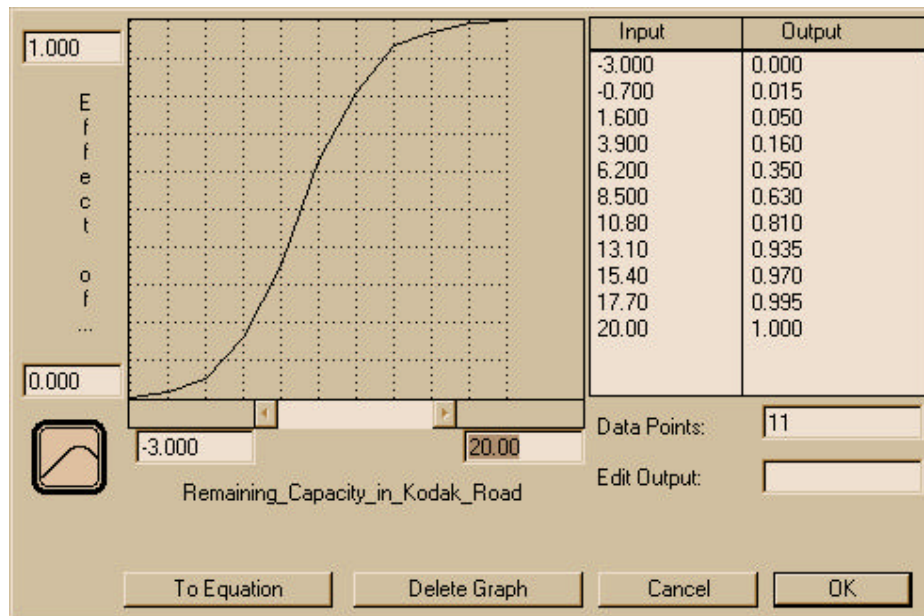


Figure 29 Effect of Remaining Capacity on Inflow-Graph of a Cautious Driver

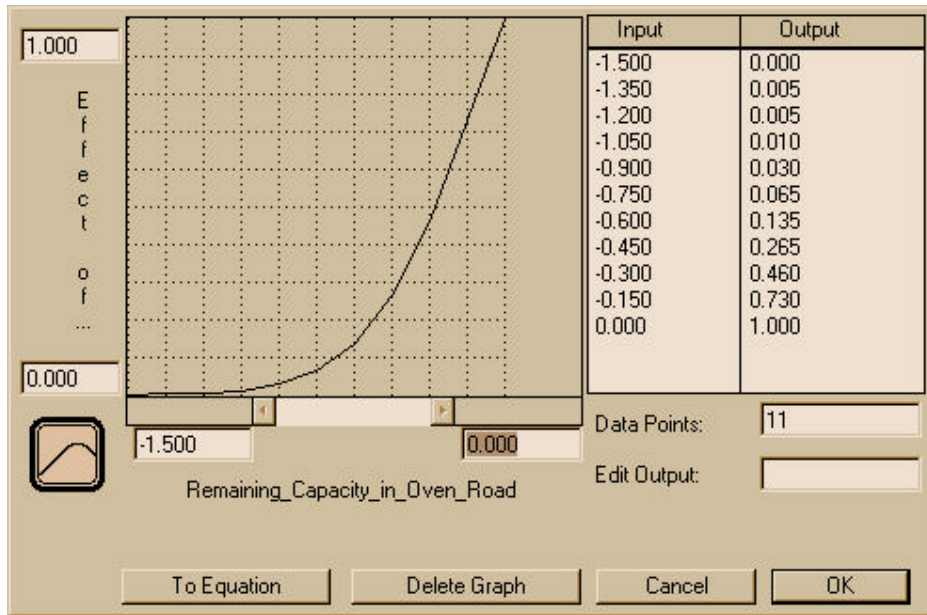


Figure 30 Effect of Remaining Capacity on Outflow-Graph of a Cautious Driver

Interpretation of Graphs:

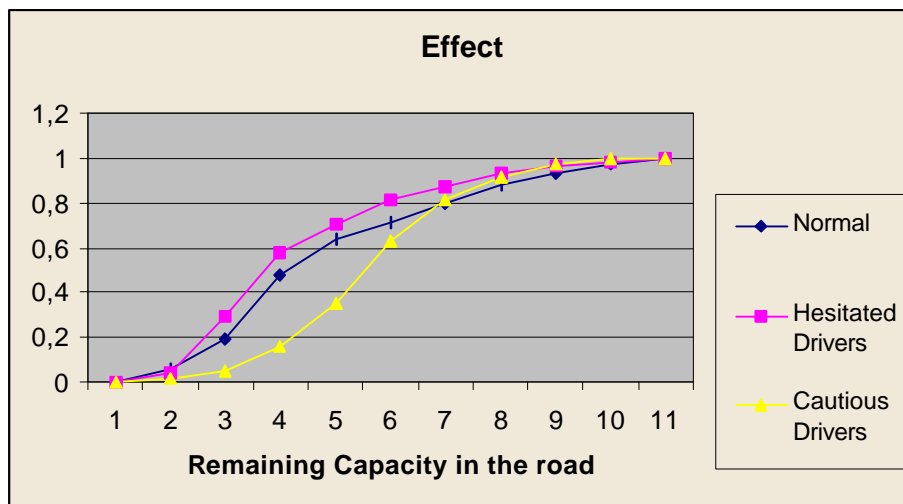


Figure 31 Remaining Capacity vs. Effect on Inflow Graph

When we analyze the above graph, it is observed that the Hesitated driver has a higher effect value at the same level of remaining capacity in the road than the Normal Driver, and Normal Driver has a higher effect value than the Cautious Driver. Since the flow is $\text{effect} \times \text{Normal Flow}$, the actual flow value is the most in the Hesitated Drivers Case and the least in the Cautious Drivers Case.

Run (Cautious Drivers Case)

STOCKS	
Vehicles In KODAK	5,00
Vehicles In Oven	5,00
CONVERTERS	
Normal Inflow Kodak	32.5
Normal Inflow Oven	32
Normal Outflow Oven	1.4
Normal Outflow Kodak	1.8

Result:

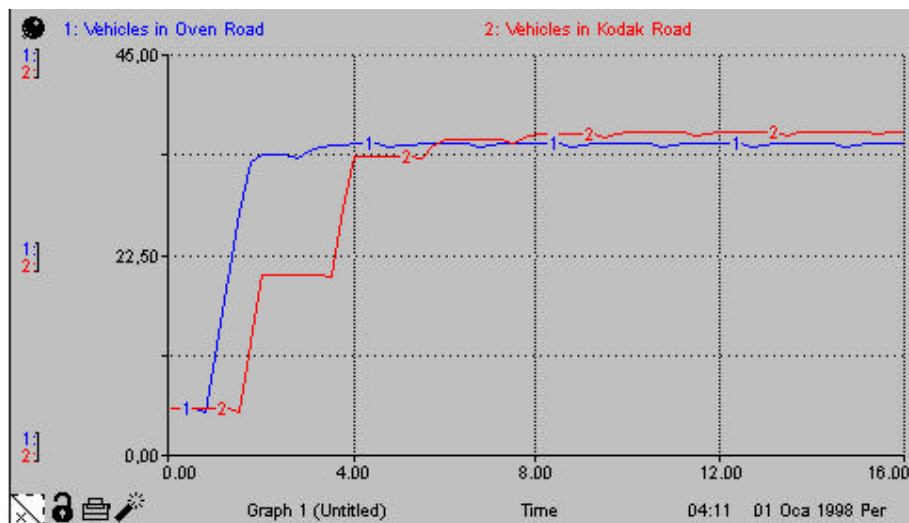


Figure 32 Dynamic Behaviour of the Stocks-Normal Driver

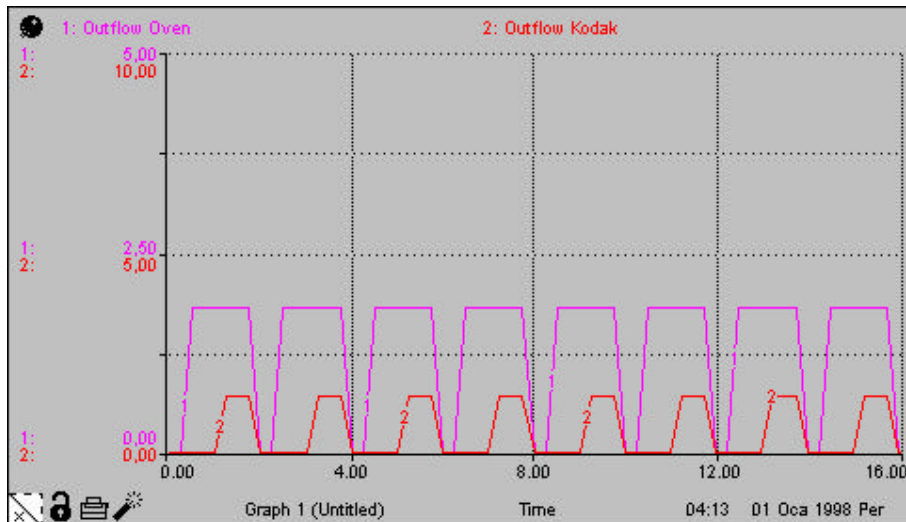


Figure 33 Dynamic Behaviour of the Flows-Normal Driver

Interpretation of Results:

Cautious Driver case does not lead to a “snake eating its tail Behaviour” when the previous experiment is repeated with Cautious Driver case effect graphs. System reaches equilibrium at the point of

Vehicles in Oven Road	35
Vehicles in Kodak Road	36.3

Consequently, Cautious Driver case reaches its equilibrium point and the traffic flow does not end.

Conclusions:

Our local system has an important implication about the systems view. That is the disorder caused by the drivers’ personal behaviors. For a system to maintain its operations correctly, organizational Behaviour is a must. In the above system we observed that drivers are trying to optimize their traveling times. In spite of observing that the road that they will enter is filled with cars, they enter the road. Since the road is full of capacity, the last entering car stays in the middle of the junction point. By doing so, the driver causes the other road to be blocked by his car. Since the other is also blocked, the outflow of this road becomes blocked and none can move anywhere. However if the driver hadn’t entered the road, he wouldn’t cause the junction to be blocked, and after a while his road would also become empty. Namely, by trying to

optimize his traveling time, he blocked the whole system. In the view of this explanation, we can conclude that, this model is supporting evidence that individual movements (movements which do not take care about the system structure and condition) lead to system crash.

Future Work:

In the future, the roads (such as Zincirlikuyu and TRT Ortakoy Roads) that are feeding the Etiler Region should be analyzed. The effects of blocking Behaviour in Etiler Region on those roads are worth investigating.

Also in the current model inflow and outflows are assumed to include no random Behaviour. However that is not the case in real life. Namely, to imitate the real life situations in a more realistic manner, stochastic should be added to flows.

Appendix A

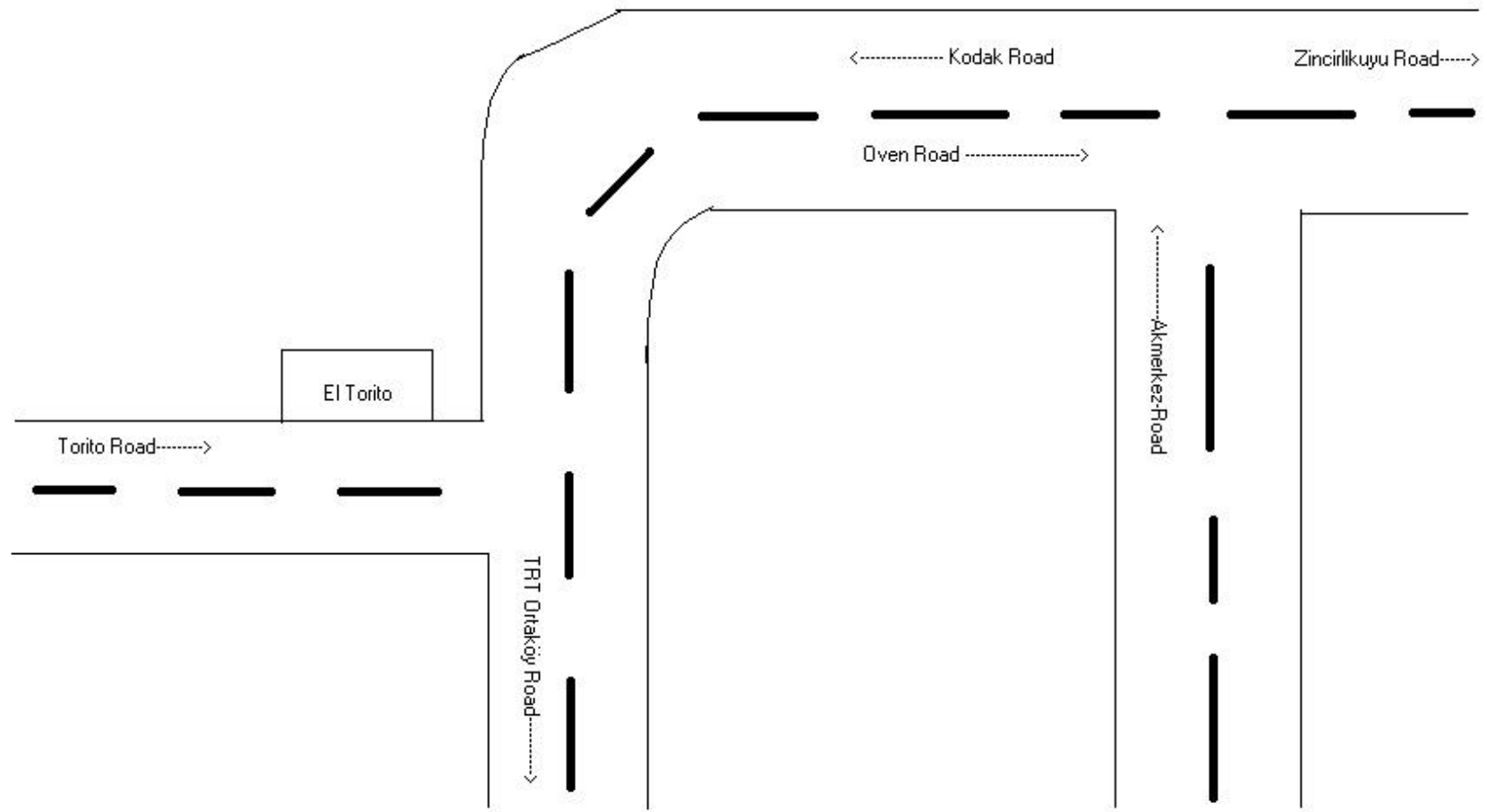


Figure 34 The Bird's Eye View of Etiler Region

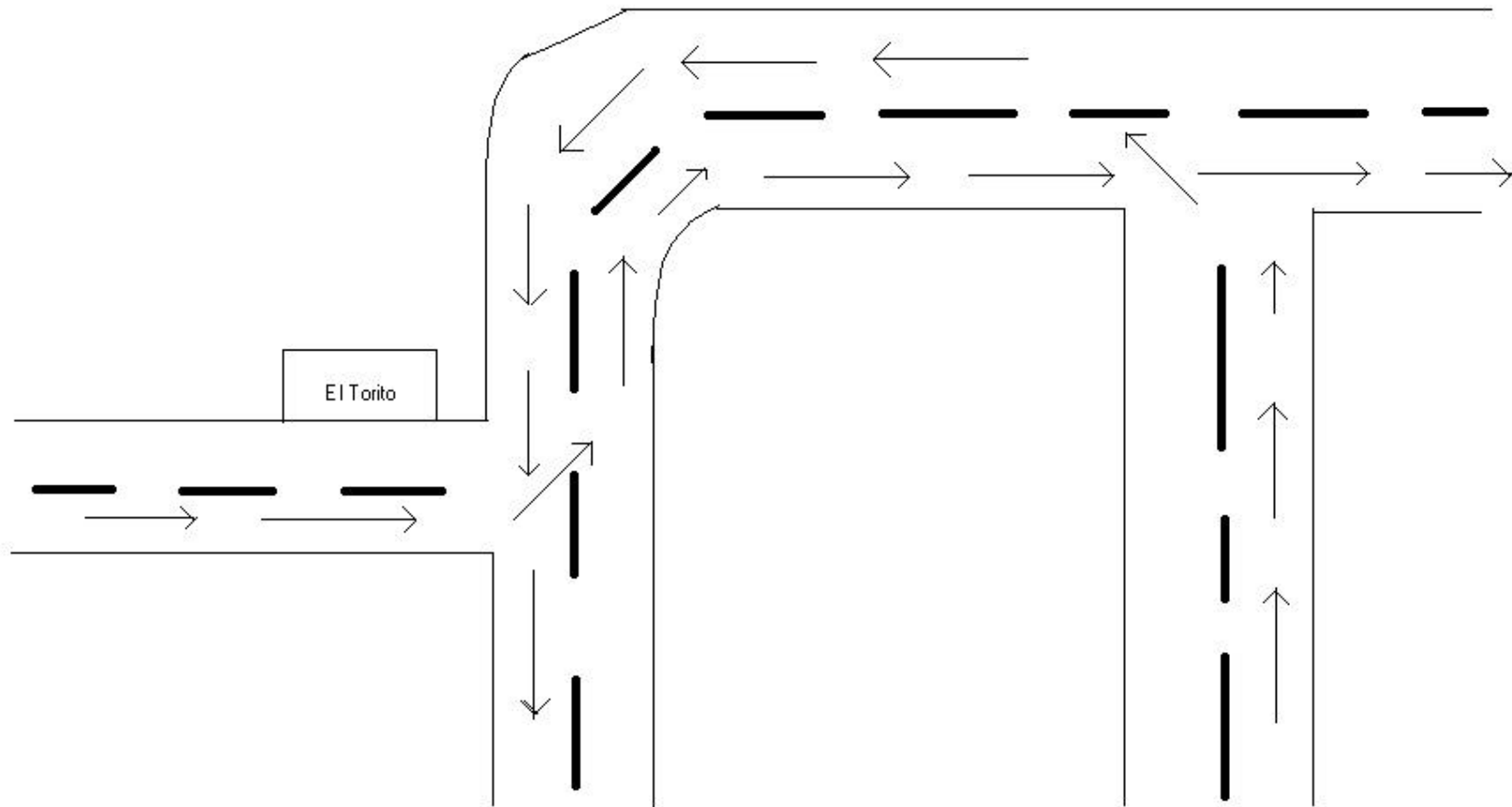


Figure 35 Etiler Region Direction of Traffic Flow

Appendix B

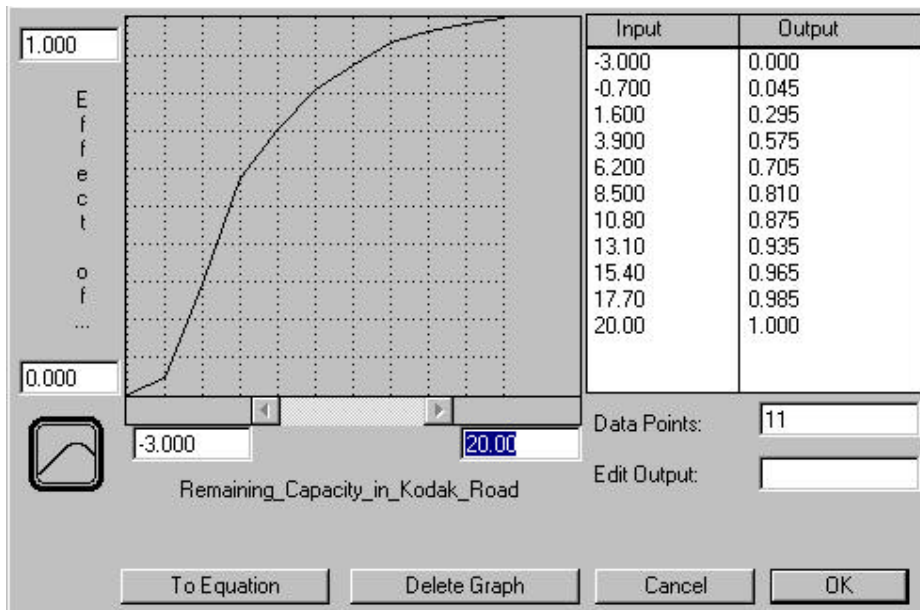


Figure 36 Graphical Function of Effect of Vehicles in Akmerkez Junction on Inflow Kodak

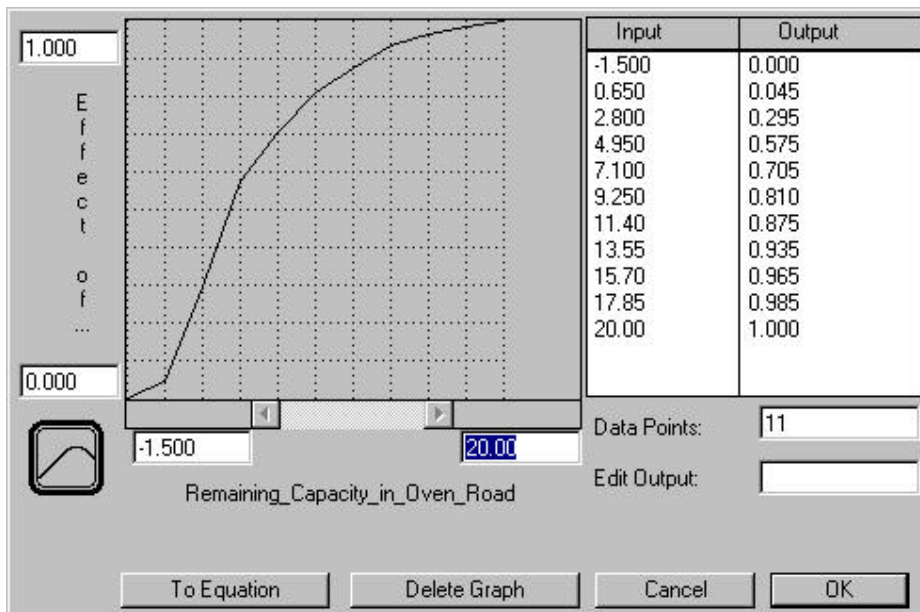


Figure 37 Graphical Function of Effect of Vehicles in Torito Junction on Inflow

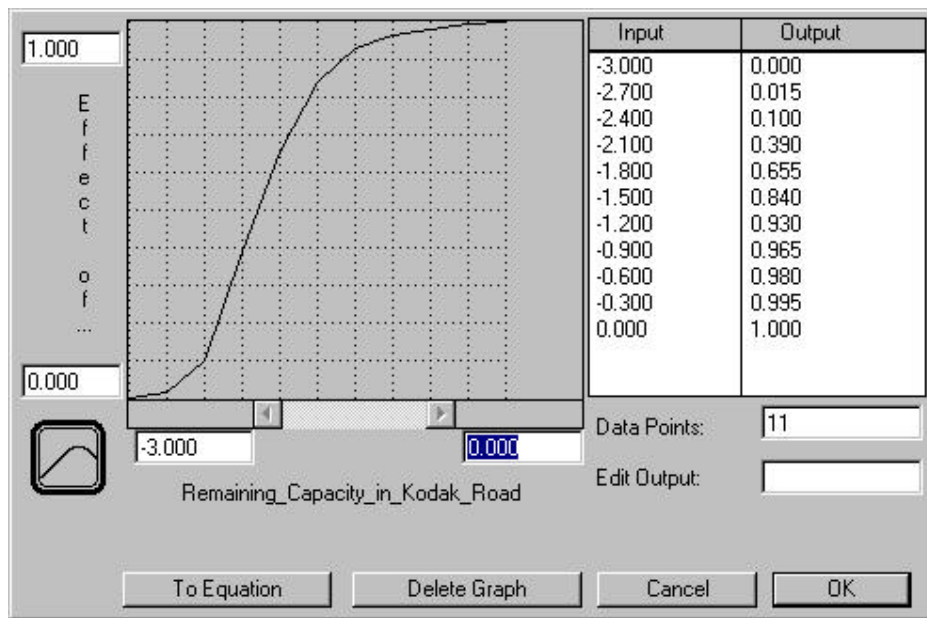


Figure 38 Graphical Function of Effect of Akmerkez Junction on Oven Outflow

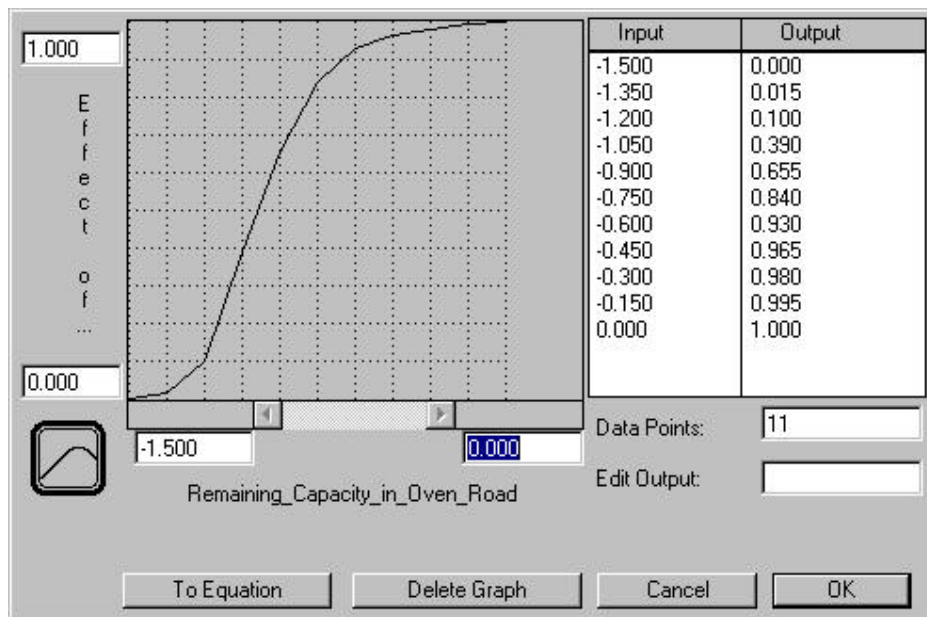


Figure 39 Graphical Function of Effect of Torito Junction on Kodak Outflow

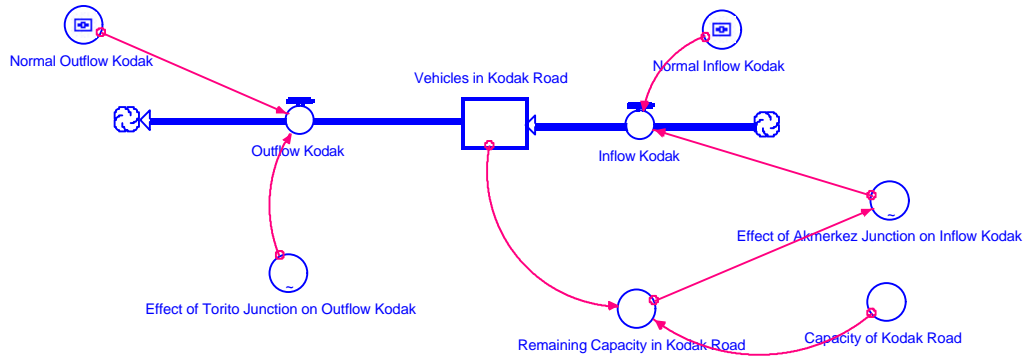


Figure 40 Partial Model (Outflow and Inflow Kodak Active)

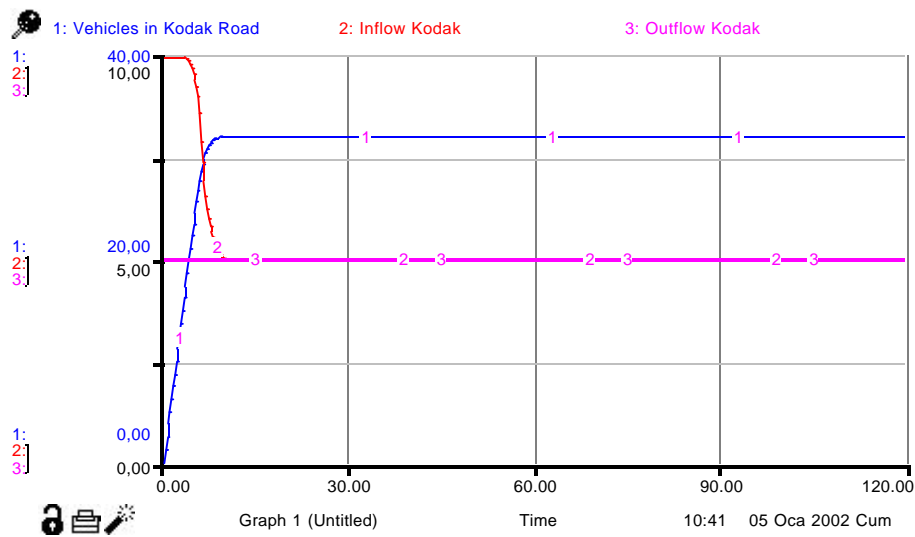


Figure 41 Partial Run (Inflow vs. Constant Outflow) – Kodak Road Alone

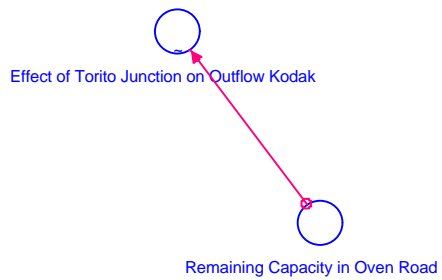


Figure 42 Effect of Torito Junction on Kodak Outflow

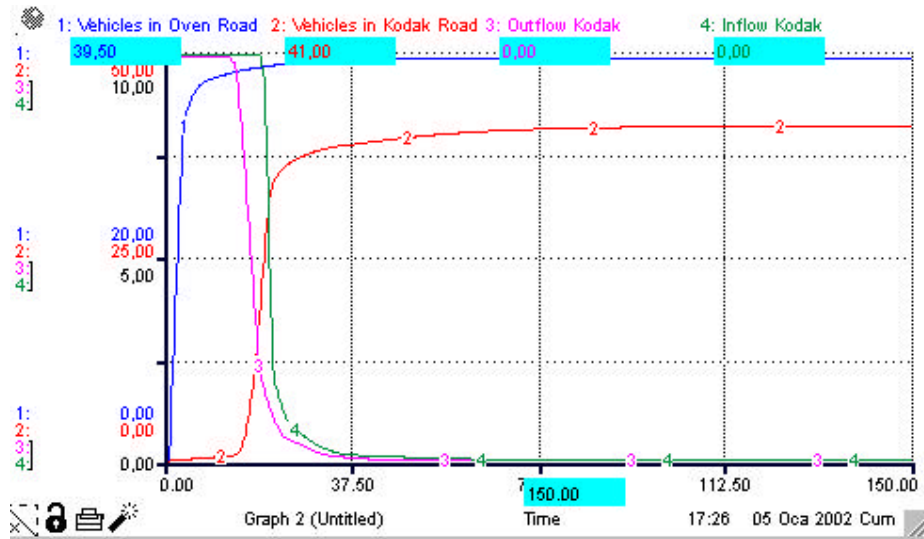


Figure 43 Partial Run (Effect of Torito Junction on Kodak Outflow Activated) – Outflow from Oven Road is taken as zero

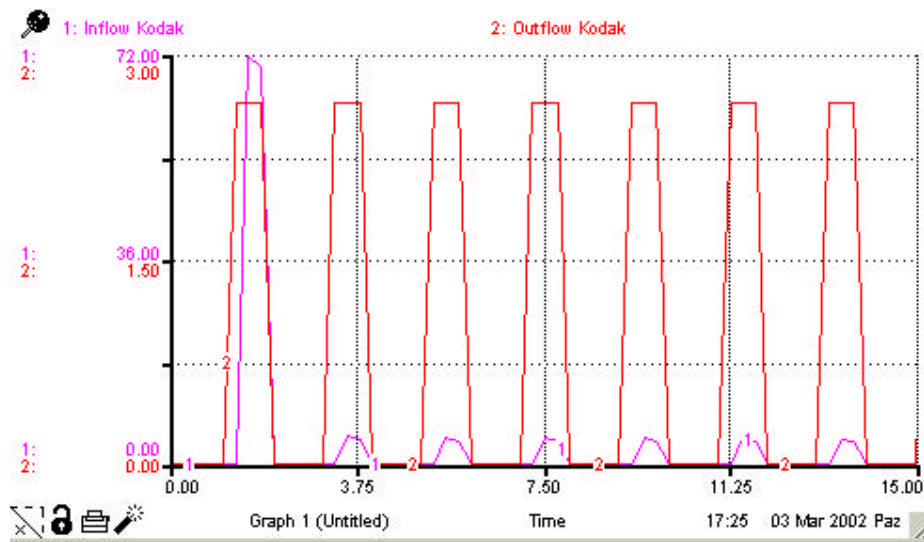


Figure 44 Inflow and Outflow of the Kodak Road

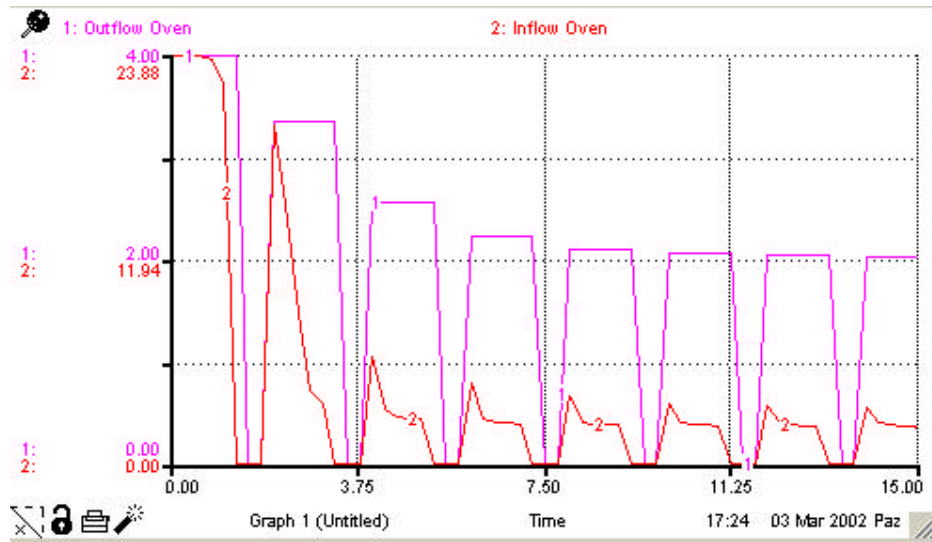


Figure 45 Inflow and Outflows of the Oven Road

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