SIMULATION OF A VEHICULAR TRAFFIC SYSTEM BASED ON QUEUING NETWORK MODELS

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Abstract: This work is part of the research activities developed in our department on the construction of vehicle traffic system simulators (*TASK Quart.* **22** (2) 135 [1], **20** (1) 9 [2], **17** (3) 155 [3], **20** (3) 273 [5], **14** (4) 405 [6], **9** (4) 397 [7], *Simulation Modelling Practice and Theory* **17** (4) 625 [8]). The modeling of the traffic system is implemented through the use of queuing networks. In this case we analyze, through a simulation, the impact on traffic flows of a structural change that the Municipal Administration has implemented on the urban road system. The study refers to some works published by us previously about the procedures applied by us to build a simulator. In this case we have developed software allowing us to analyze the data tracked by the system simulations to display it graphically. This procedure enables us to clearly compare the traffic system behavior in its new configuration with the traffic system behavior in the previous configuration.

Keywords: vehicular traffic systems, queuing networks, modeling and simulation

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1. Introduction

In this paper we study the behavior of vehicular flows in the Siena North road network illustrated in Figure 1. In particular we consider the changes that have recently been made to this system by the Municipal Administration. The intervention area is highlighted in Figure 1 by an ellipse containing the crossroads of the system that has been modified.

Referring to the results already presented in some previous works [1, 2], we develop the following issues:

1. Modeling of the current road system;
2. Generation of the model.dat file updated to the current system data;
3. Simulation of the traffic flow in the system;

4. Development of an application to display the results;
5. Comparison of results.

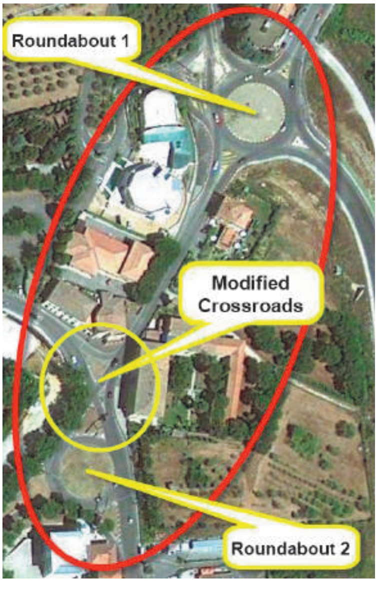


Figure 1. Siena North system

Therefore, this study consists in the evaluation of the impact of the changes made to the road system on the vehicular flows that characterize this area of the road network of Siena. In relation to our previous works [1, 2] in which we studied the Siena North road system in its original configuration, the new system is characterized by the fact that Crossroad 4 was removed and the functionality of Crossroad 2 was modified.

The following image illustrates the original configuration of the system before changes were made.

Figure 2 shows the system before the change, highlighting how the traffic will be regulated by two different crossroads, one directing vehicles in Cassia Nord (Crossroad 4), and the other towards Roundabout 2 (Crossroad 3).

Below we report some images of the modified system taken by Street View.

The new system manages traffic through a single crossroad in proximity of the Chiantigiana Lato Stellino road, prioritizing vehicles coming from Roundabout 2 and heading to the Cassia Nord road.

2. Modeling

The model of the system in the current configuration is illustrated in Figure 9. This model is composed by three crossroads identified as:

- Crossroad 1: it is Roundabout 1 which is located in the northern area of the system.

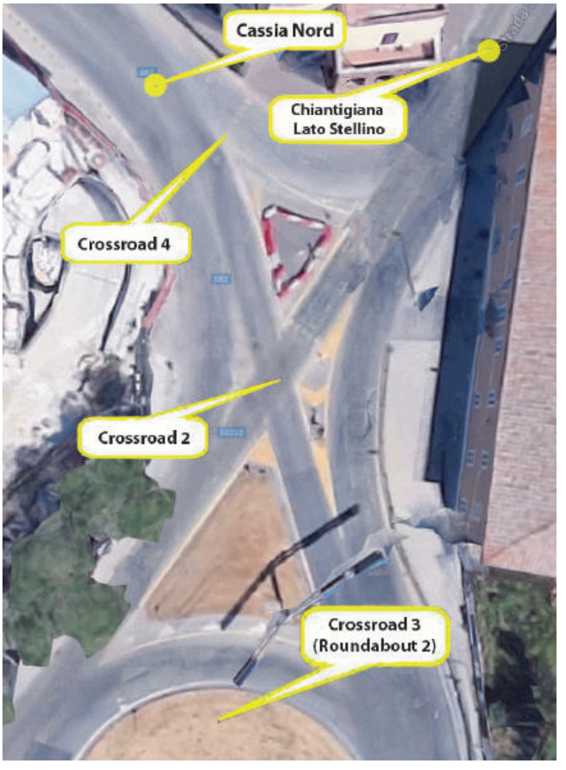


Figure 2. System structure before changes

- Crossroad 2: it is the intersection that regulates the flow of vehicular traffic coming from Roundabout 1 towards Roundabout 2 or towards Cassia Nord, the vehicular flow from via Cassia Nord towards Roundabout 2 and the vehicular flows from Roundabout 2 towards via Cassia Nord.
- Crossroad 3: it is Roundabout 2 which is located in the southern area of the system.

Figure 9 illustrates how Roundabout 1 manages vehicular flows coming from the Chantigiana national road, the Castellina in Chianti side, Via Valle D'Aosta, Via Montecelso, the Chiantigiana national road, the Stellino side and from Strada Fiume.

Roundabout 2 manages traffic flows from Via Cassia Nord, Via delle Province, Via Fiorentina and the Chiantigiana national road, the Stellino side, which connects this second roundabout with the northern one.

Roads are numbered so that these identifiers can be used in the model.dat file, which will be described later in this work. Two-way streets are considered individually by being represented with two different numbers in the model. The different coloring of roads is described according to the scheme shown below:

– **red** indicates exit roads, *i.e.* roads that lead vehicular flows outside of the system,

Figure 3. Crossroad 2 sideways

Figure 4. Crossroad 2 view from Roundabout 2

Figure 5. Crossroad 2 view from Chiantigiana Lato Stellino

Figure 6. Crossroad 2, view from Roundabout 2

Figure 7. Crossroad 2, view from via Cassia Nord

Figure 8. Crossroad 2, view from Roundabout 2

- **green** indicates entrance roads. These roads are connected to a device that generates incoming vehicles by reproducing flows that have been detected by the Municipal Administration,
- **yellow** indicates internal system roads.

In summary, we have a total of 18 routes which are:

- 7 **entry roads** (1, 3, 5, 9, 11, 14, 16)
- 7 **exit roads** (2, 4, 8, 10, 13, 15, 18)
- 4 **internal roads** (6, 7, 12, 17).

3. Crossroads

In this section we present the modeling of the single crossroads of the Siena Nord road system in its new configuration. At the base of the modeling of each crossroad we have the object **Sections**, which are strictly related to the previous works. In particular, in the modeling we use the following Section types:

- **Input Section**, in the graphic representation of the model they are shown as green circles. These sections model the vehicle entry areas on the crossroad, they are similar to the channeling lanes of the vehicular flows entering the intersection.

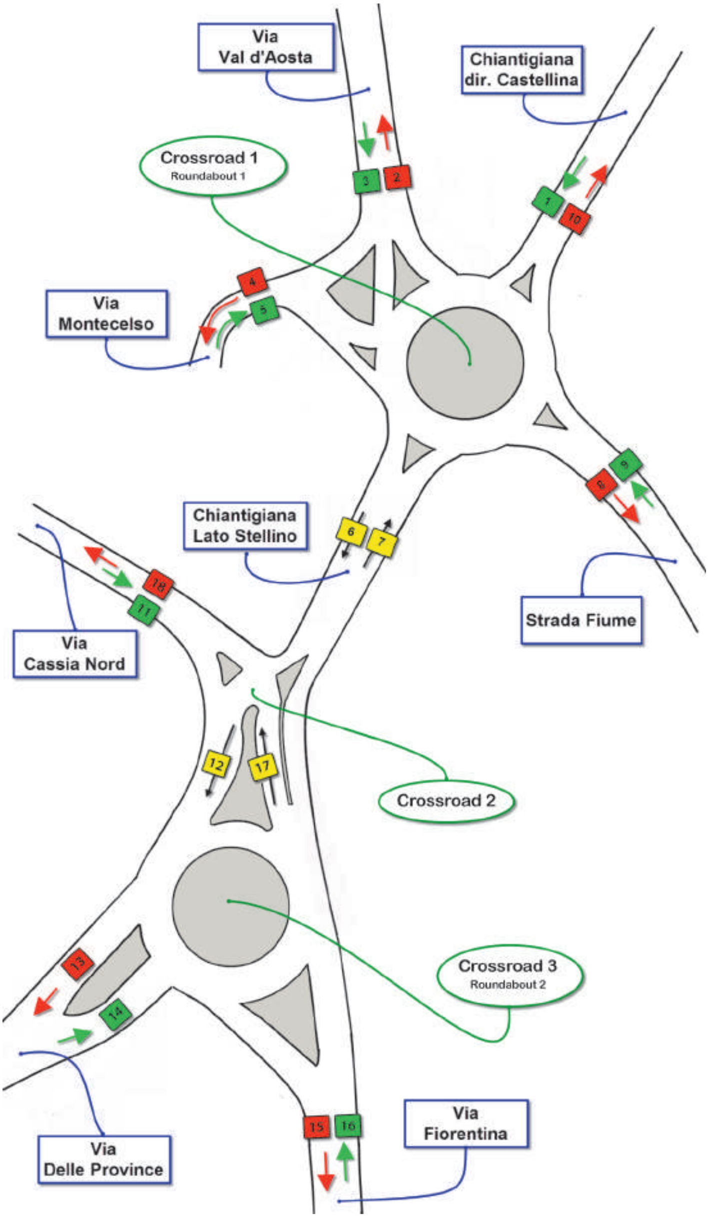


Figure 9. Current System showing road numbers

– **Output Section**, in the graphic representation of the model they are shown as red circles. These sections model the vehicles exit areas on the crossroad, they connect the crossroad to the exit roads from the intersection.
– **Internal Section**, in the graphic representation of the model they are shown as yellow squares in crossroads that are simple intersections, while on the roundabouts they are represented by arcs. These sections model the internal

areas of the crossroad that can be occupied simultaneously by a limited number of vehicles. The appropriately grouped internal sections determine what we call the crossing paths that a vehicle can follow during its movement within the intersection.

In the next paragraphs the input, output sections and the paths that can be crossed for each crossroad will be shown. Each section corresponds to a numeric **ID** that uniquely identifies them in the **model.dat** file, a file that summarizes all the data of the model.

3.1. Crossroad 1: Roundabout 1

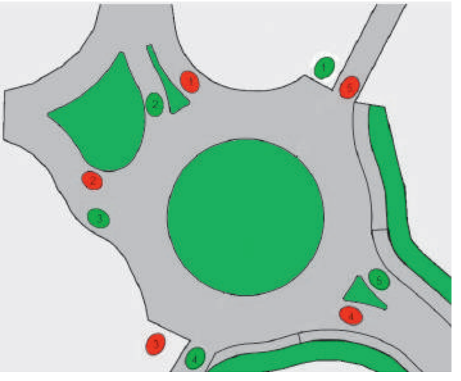


Figure 10. Roundabout 1 with input and output sections

Roundabout 1 has 5 input sections and 5 output sections.

Let us analyze the **input sections**:

- Input Section 1: the access point to the roundabout for vehicles coming from the Chiantigiana national road, Castellina in Chianti side;
- Input Section 2: the access point to the roundabout for vehicles coming from Via Valle D'Aosta;
- Input Section 3: the access point to the roundabout for vehicles coming from Via Montecelso;
- Input Section 4: the access point to the roundabout for vehicles coming from the Chiantigiana state road, Stellino side;
- Input Section 5: the access point to the roundabout for vehicles coming from Strada Fiume.

Let us analyze the **outputs sections**:

- Output Section 1: the exit point from the roundabout that leads to Via Valle D'Aosta;
- Output Section 2: the exit point from the roundabout that leads to via Montecelso;
- Output Section 3: the exit point from the roundabout that leads to the Chiantigiana national road, Stellino side;

- Output Section 4: the exit point from the roundabout that leads to Strada Fiume;
- Output Section 5: the exit point from the roundabout that leads to the Chiantigiana national road, Castellina in Chianti side.

Figure 11 shows the modeling of Roundabout 1 in which the input sections, the internal sections and the output sections are identified.

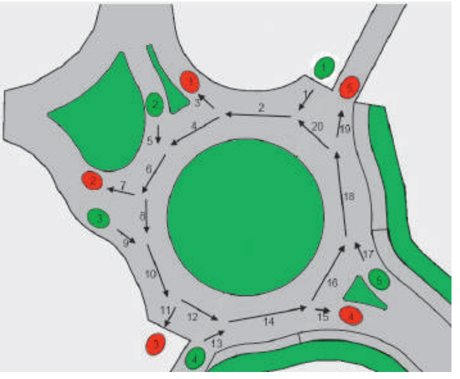


Figure 11. Roundabout 1 with input, internal and output sections

3.2. Crossroad 2: new structure

Figures 12 and 13 illustrate the structure of intersections 2 and 4 in the previous system presented in the work [2].

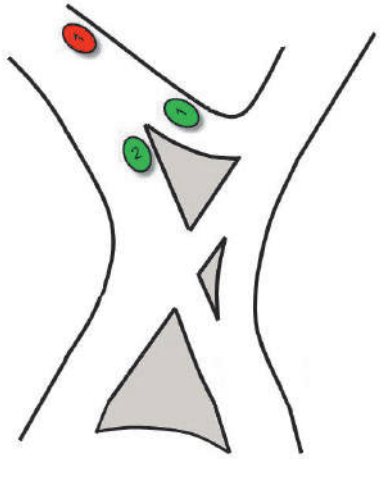


Figure 12. Crossroad 2 of the previous system

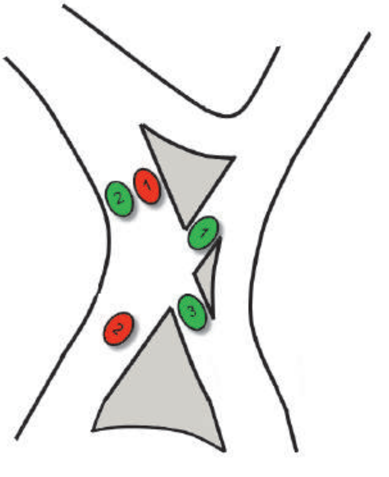


Figure 13. Crossroad 4 of the previous system

Figure 14 illustrates the modeling of Crossroad 2 in the new configuration of the Siena Nord road system. The new configuration simplifies the overall structure of the system, since the flow of vehicles coming from Roundabout 1

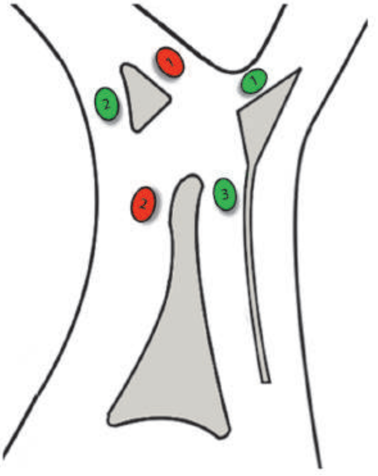


Figure 14. Crossroad 2 of the current system with input and output sections

along via Chiantigiana, Stellino side, is no longer separated in the two independent vehicular flows directed towards via Cassia Nord and towards Roundabout 2. The separation point of these two flows in the previous structure of the road system was located at the end of Road 6 which merged into the two streets 11 and 12. These streets constituted an entry channel towards Intersection 4 and Intersection 2, respectively [2].

In the new configuration of the system, Road 6 ends at Intersection 2, as shown in Figure 9. Therefore, the new traffic system configuration is characterized by the fact that Crossroads 2 and 4 of the system have been reduced to Crossroad 2 only.

Crossroad 2 has 3 input sections and 2 output sections.

Let us analyze the **input sections**:

- Input Section 1: the section from which vehicles coming from Roundabout 1 cross the Chiantigiana national road, Stellino side, southwards;
- Input Section 2: the section from which vehicles coming from via Cassia Nord go towards Roundabout 2;
- Input Section 3: the section from which vehicles that have crossed Roundabout 2 go towards via Cassia Nord.

Let us analyze the **output sections**:

- Output Section 1: the exit point leading to via Cassia Nord;
- Output Section 2: the exit point leading to Roundabout 2.

The following figures show the possible crossing paths of the crossroad that a vehicle can follow according to its entry section. From Input Section 1 a vehicle can head south towards Output Section 2 (Figure 15 (a)), or it can turn right towards Output Section 1 (Figure 16 (a)). These intersection crossing paths are described in more detail in Figures 15 (b) and 16 (b) in which the internal sections contained in their respective crossing paths are shown.

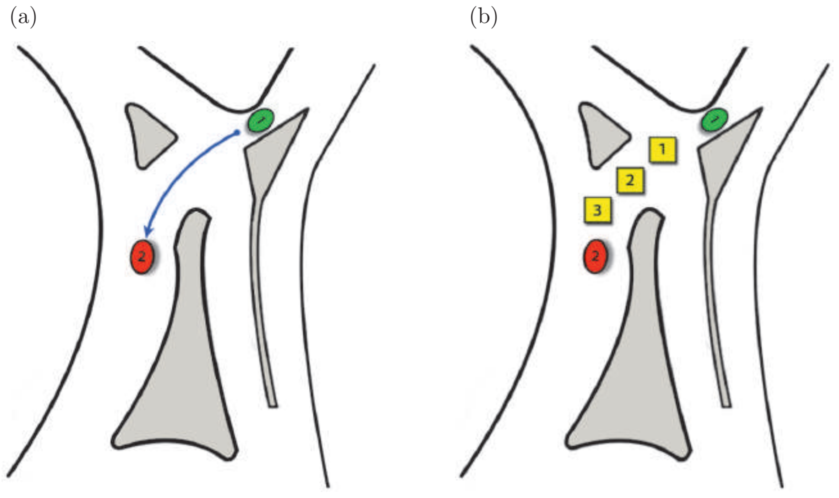


Figure 15. (a) The path of a vehicle coming from Entrance 1 towards Exit 2. (b) Internal sections crossed by a vehicle coming from Entrance 1 towards Exit 2

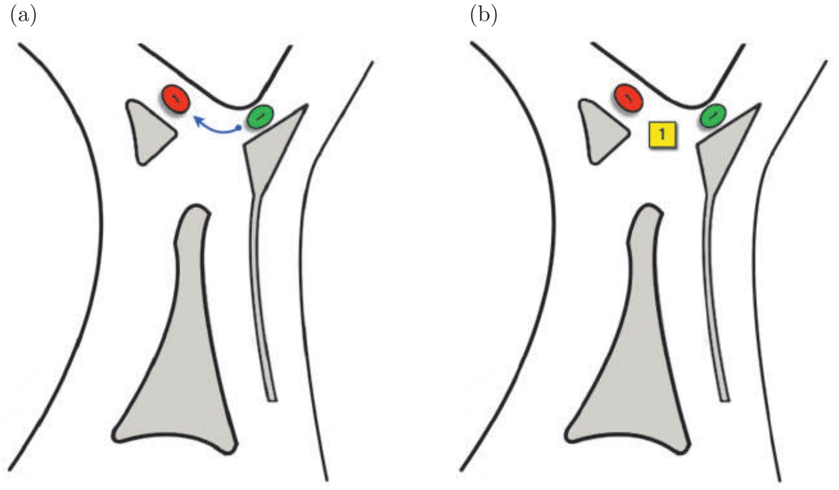


Figure 16. (a) The path of a vehicle coming from Entrance 1 towards Exit 1. (b) Internal sections crossed by a vehicle coming from Entrance 1 towards Exit 1

Regarding Input Section 2, the only admissible crossing path is the one going south towards Roundabout 2, as shown in Figure 17 (a) and in Figure 17 (b).

Finally, coming from Input Section 3 a vehicle can only continue towards Cassia Nord, *i.e.*, Output Section 1 as shown in Figure 18 (a) and Figure 18 (b).

3.3. Crossroad 3: Roundabout 2

Roundabout 2 has 4 input sections and 4 output sections.

Let us analyze the **input sections**:

- Input Section 1: is the access point to the roundabout for vehicles coming from the Via Cassia Nord branch;

(a) (b)

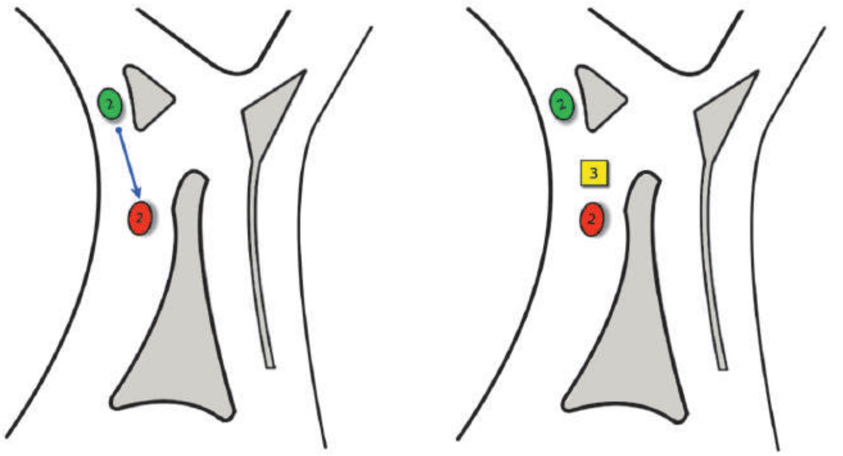


Figure 17. (a) Path crossed by a vehicle coming from Entrance 2. (b) Internal sections crossed by a vehicle coming from Entrance 2

(a) (b)

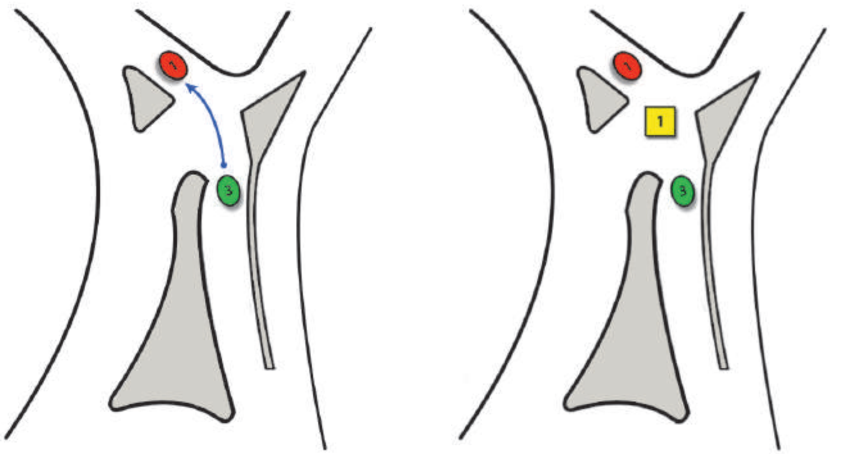


Figure 18. (a) Path crossed by a vehicle coming from Entrance 3. (b) Internal sections crossed by a vehicle coming from Entrance 3

- Input Section 2: is the access point to the roundabout for vehicles coming from Via Delle Province;
- Input Section 3: is the access point to the roundabout for vehicles coming from the internal road lane of Via Fiorentina;
- input Section 4: is the access point to the roundabout for vehicles coming from the external road lane of via Fiorentina.

Let us analyze the **output sections**:

- Output Section 1: is the exit point from the roundabout that leads to Via Delle Province;

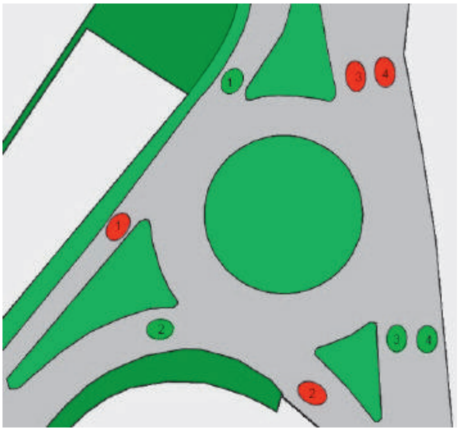


Figure 19. Roundabout 2 with entrance and exit sections

- Output Section 2: is the exit point from the roundabout that leads to Via Fiorentina;
- Output Section 3: is the exit point from the roundabout that enters the internal road number 17 in the model, leading to Crossroad 2;
- Output Section 4: is the exit point from the roundabout that leads to the Chiantigiana (Lato Stellino) state road reaching Roundabout 1.

Figure 20 shows the modeling of Roundabout 2 in which the input sections, the internal sections and the output sections are identified.

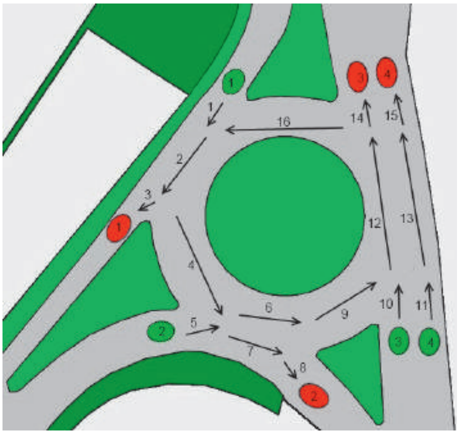


Figure 20. Roundabout 2 with input, internal and output sections

4. Traffic data

The vehicular traffic data of the Siena Nord system were provided by the Municipal Administration. The data was estimated at the entry and exit points of the system paying particular attention to the entrances and exits of the roundabouts that are parts of the system. The conducted detection counted the number of vehicles in transit through the entrances and exits of the system in 10-minute time intervals into which the three time slots of interest for the study were divided.

The sampling time slots are as follows:

- **7:30–9:20**
- **12:00–13:50**
- **17:30–19:20**

During the simulation of each time slot the variation of the input and output frequencies relative to the 10 minute intervals is reproduced through the use of specific Timers that activate data updating procedures at the end of each 10 minute interval without interrupting the simulation. In this way we are able to simulate variations of both traffic flows and probabilities of routing vehicles that take place in the system during simulation of each of the three time slots indicated above.

Table 1 contains the traffic flow data detected by the Municipality of Siena for each of the entry and exit points of the two roundabouts in the Siena Nord traffic system.

5. Building the model

The traffic system modeling is based on the use of complex objects that are composed by queue service devices. These objects were defined in a library that we presented in a previous work [3]. Working on a plan of the vehicular traffic system, individual library objects are mapped on the corresponding points of the road system. In this way we obtain a traffic system model structured as a complex queue network. Data related to individual implementations of library objects that appear in the traffic system model obtained by the procedure indicated above are contained in a text file called **”model.dat”.** This file is composed of a first section related to the general data for building the model and several following sections in which each individual component of the system is described. The file is generated by an editor implemented in a spreadsheet called Crea-Modeldat.xls, to simplify and automate the updating of data [2].

5.1. Model.dat – Current status of the model

The model.dat file reported below was generated through the modeling procedure applied to the current configuration of the Siena Nord vehicular traffic system. We considered a whole time slot. Here, we show a model.dat file of a system relative to the time slot that goes from 7:30 to 9:20 as an example.

The first section of the model.dat file is Section 1 which contains general data of the system. This data is presented in the following order: the number of crossroads, the number of roads, the number of crossroad multiplexers and road multiplexers in the traffic system model, the number of time intervals of 10 minutes taken into consideration in the simulation and the starting time of the simulation to identify the examined time slot.

Table 1. The traffic flows for the current system

		7:30–9:20																								12:00–13:50											
		07:30		07:40		07:50		08:00		08:10		08:20		08:30		08:40		08:50		09:00		09:10		09:20		12:00		12:10		12:20		12:30		12:40		12:50	
	street name	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out
Roundabout 1	SS Chiantigiana (Stellino)	87	103	127	97	172	106	196	116	125	76	150	113	131	98	145	98	146	96	156	117	125	72	122	105	152	113	149	117	136	113	118	114	117	140	100	110
	Strada Fiume	46	102	28	103	36	100	55	131	45	128	53	107	43	90	58	95	38	85	49	88	41	88	65	80	78	83	68	60	59	62	70	77	106	72	56	53
	SS Chiantigiana (Castellina)	48	130	69	157	77	170	77	159	76	173	83	191	67	182	75	180	60	199	58	197	65	200	56	187	72	157	75	180	84	175	72	136	70	180	93	185
	Via Valle D'Aosta	163	1	180	2	149	1	135	1	130	0	137	0	150	2	135	0	155	5	155	4	145	2	142	7	107	12	122	11	74	6	103	8	112	8	113	12
	Montecelso	5	2	2	3	2	3	9	5	18	2	16	3	23	2	12	2	9	1	9	3	9	5	9	1	17	4	10	4	10	6	9	7	11	3	14	2
Roundabout 2	SS Chiantigiana (Stellino)	103	87	97	127	106	172	116	196	76	125	113	150	98	131	98	145	96	146	117	156	72	125	105	122	113	152	117	149	113	136	114	118	140	117	110	100
	Via Fiorentina	35	40	56	80	86	115	65	100	95	92	71	74	88	61	115	72	145	90	117	77	101	100	67	72	50	35	73	90	115	85	95	89	110	75	122	94
	Via Delle Provincie	48	44	65	56	97	64	103	81	71	80	84	76	44	67	91	102	80	80	105	95	95	70	96	80	75	68	80	76	82	79	72	78	80	79	93	96
	Via Cassia Nord	45	25	120	38	115	80	155	80	120	78	130	73	120	65	130	90	115	63	85	59	57	80	70	55	62	50	68	60	72	74	70	65	65	96	65	104

		12:00–13:50												17:30–19:20																							
		13:00		13:10		13:20		13:30		13:40		13:50		17:30		17:40		17:50		18:00		18:10		18:20		18:30		18:40		18:50		19:00		19:10		19:20	
	street name	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out
Roundabout 1	SS Chiantigiana (Stellino)	120	115	128	128	136	141	120	143	127	143	113	89	141	130	172	155	162	162	167	167	176	153	130	147	162	142	158	167	175	182	157	143	127	158	137	112
	Strada Fiume	84	56	88	48	80	68	89	68	71	47	72	63	102	79	125	85	152	95	100	73	130	75	110	72	100	56	93	66	92	75	87	85	90	87	83	75
	SS Chiantigiana (Castellina)	75	148	65	192	57	181	82	165	58	153	56	165	84	165	90	225	92	260	75	180	100	264	77	235	85	220	88	217	80	255	85	205	75	190	70	155
	Via Valle D'Aosta	87	7	97	17	105	11	90	3	101	9	93	8	95	13	128	7	116	8	103	7	102	14	116	14	118	11	96	14	118	11	127	11	97	12	99	9
	Montecelso	9	7	13	2	13	1	29	3	15	1	8	0	5	1	2	1	9	3	8	4	4	1	8	1	7	1	4	0	5	2	4	0	1	5	10	1
Roundabout 2	SS Chiantigiana (Stellino)	115	120	128	128	141	136	143	120	143	127	89	113	130	141	155	172	162	162	167	167	153	176	147	130	142	162	167	158	182	175	143	157	158	127	112	137
	Via Fiorentina	120	97	86	75	125	76	105	71	125	77	100	50	100	53	185	50	240	55	246	107	233	137	195	90	200	117	186	100	163	60	140	65	125	112	92	46
	Via Delle Provincie	84	105	110	118	87	81	93	107	83	90	94	95	98	72	95	60	88	74	75	52	92	82	108	75	75	56	95	61	65	40	75	44	67	52	102	62
	Via Cassia Nord	85	83	75	100	55	120	62	120	58	105	48	85	96	76	90	95	89	80	93	82	75	80	90	81	95	73	94	120	78	90	75	120	85	100	75	105

Next, in Section 2 the roads in the model are listed with the following data:

- an integer that identifies the street in the model;
- a binary variable that specifies whether the route is directed towards the outside (1) or the inside (0);
- the length of the road expressed in km;
- the number of incoming vehicles for each 12 10-minute interval of the model time slot;
- the number of leaving vehicles for each 12 10-minute interval of the model time slot;
- a binary flag that determines whether the route is connected to a multiplexer or a road multiplexer;
- a string with the real road name in the traffic system.

Section 1:

```
No._Intersections Roads MP Flows MP_Road No._Intervals Start_Time;
3 18 11 7 0 12 7.30;
```

Section 2:

```
ID External Road_length R_NB_IN R_NB_OUT Intersection MP or Road_MP Name;
1 0 0.3 48 69 77 77 76 83 67 75 60 58 65 56 0 0 0 0 0 0 0 0 0 0 0 0 1 1
''Via_Chiantigiana_Castellina'';
2 1 0.1 0 0 0 0 0 0 0 0 0 0 0 0 1 2 1 1 0 0 2 0 5 4 2 7 ''Via_Aosta'';
3 0 0.3 163 180 149 135 130 137 150 135 155 155 145 142 0 0 0 0 0 0 0 0 0 0 0 0
1 2 ''Via_Aosta'';
4 1 0.1 0 0 0 0 0 0 0 0 0 0 0 0 2 3 3 5 2 3 2 2 1 3 5 1 ''Via_Montecelso'';
5 0 0.3 5 2 2 9 18 16 23 12 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 1 3
''Via_Montecelso'';
6 0 0.12 0 0 0 0 0 0 0 0 0 0 0 0 103 97 106 116 76 113 98 98 96 117 72 105 1 6
''Via_Chiantigiana_Stellino'';
7 0 0.15 87 127 172 196 125 150 131 145 146 156 125 122 0 0 0 0 0 0 0 0 0 0 0 0
1 4 ''Via_Chiantigiana_Stellino'';
8 1 0.1 0 0 0 0 0 0 0 0 0 0 0 0 102 103 100 131 128 107 90 95 85 88 88 80
''Via_Fiume'';
9 0 0.3 46 28 36 55 45 53 43 58 38 49 41 65 0 0 0 0 0 0 0 0 0 0 0 0 1 5
''Via_Fiume'';
10 1 0.1 0 0 0 0 0 0 0 0 0 0 0 0 130 157 170 159 173 191 182 180 199 197 200
187 ''Via_Chiantigiana_Castellina'';
11 0 0.3 45 120 115 155 120 130 120 130 115 85 57 70 0 0 0 0 0 0 0 0 0 0 0 0 1
8 ''Via_Cassia_Nord'';
12 0 0.038 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 9 ''VIA12'';
13 1 0.1 0 0 0 0 0 0 0 0 0 0 0 0 44 56 64 81 80 76 67 102 80 95 70 80
''Via_delle_Provincie'';
14 0 0.3 48 65 97 103 71 84 44 91 80 105 95 96 0 0 0 0 0 0 0 0 0 0 0 0 1 10
''Via_delle_Provincie'';
15 1 0.1 0 0 0 0 0 0 0 0 0 0 0 0 40 80 115 100 92 74 61 72 90 77 100 72
''Via_Fiorentina'';
16 0 0.3 35 56 86 65 95 71 88 115 145 117 101 67 0 0 0 0 0 0 0 0 0 0 0 0 1 11
''Via_Fiorentina'';
17 0 0.04 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 7 ''VIA17'';
18 1 0.1 0 0 0 0 0 0 0 0 0 0 0 0 25 38 80 80 78 73 65 90 63 59 80 55
''Via_Cassia_Nord'';
```

Section 3 in the model.dat file follows, where the data relating to the traffic flow sources of the road system is reported. In this model there are 7 vehicle flow sources that are characterized by the following data:

- an integer that identifies the source in the model;
- the succession of average vehicle routing times in the individual 10-minute intervals of the time slot;
- the identifier of the road where vehicles are routed from the traffic source.

Section 3:

```
ID_Flow Time_Routing Time_Routing Time_Routing Time_Routing Time_Routing...
...ID_Road; 1 12.5 8.7 7.79 7.79 7.89 7.23 8.96 8 10 10.34 9.23 10.71 1;
2 3.68 3.33 4.03 4.44 4.62 4.38 4 4.44 3.87 3.87 4.14 4.23 3;
3 120 300 300 66.67 33.33 37.5 26.09 50 66.67 66.67 66.67 66.67 5;
4 13.04 21.43 16.67 10.91 13.33 11.32 13.95 10.34 15.79 12.24 14.63 9.23 9;
5 13.33 5 5.22 3.87 5 4.62 5 4.62 5.22 7.06 10.53 8.57 11;
6 12.5 9.23 6.19 5.83 8.45 7.14 13.64 6.59 7.5 5.71 6.32 6.25 14;
7 17.14 10.71 6.98 9.23 6.32 8.45 6.82 5.22 4.14 5.13 5.94 8.96 16;
```

Section 4 contains the data of the crossroad multiplexers that are present in the model. These devices are responsible for routing vehicles next to the entry points of crossroads. For each Multiplexer the data is the following:

- an integer that identifies the multiplexer in the model;
- the number of the input sections connected to the multiplexer;
- the identification number of the crossroad on which vehicles enter;
- the probabilities for a vehicle to access the associated entry sections. These probabilities may vary depending on the time intervals of 10 minutes in the time slot referred by the model.

Section 4:

```
&ID_MULTIPLEXER IN_SEC_NO INT_NO IN_SEC_ID PROB_1...PROB_N;
1 1 1 1 1;
2 1 1 2 1;
3 1 1 3 1;
4 1 1 4 1;
5 1 1 5 1;
6 1 2 1 1;
7 1 2 3 1;
8 1 2 2 1;
9 1 3 1 1;
10 1 3 2 1;
11 2 3 3 0.46 0.36 0.4 0.4 0.53 0.43 0.41 0.54 0.46 0.46 0.49 0.48 4 0.54 0.64
0.6 0.6 0.47 0.57 0.59 0.46 0.54 0.54 0.51 0.52;
```

In the model.dat file the sections containing the data related to the modeling of the single crossings in the road system are listed below. These sections of data are listed in the model.dat file ordered by the identification number of the crossroads in the model. In general "Section $n.m$" means the m^{th} data section of the crossroad identified by number n.

For each crossroad there is the general data section containing the following information:

- the identifier of the intersection in the model;
- the number of traffic light components of the crossroad;
- the number of crossroad internal sections;
- the number of crossroad entry sections;
- the number of crossroad exit sections;
- the number of paths that vehicles can follow to cross the intersection;
- the duration of a traffic light cycle;
- a Boolean variable that specifies whether the crossroad is a roundabout.

Section 1.1:

```
ID_INT NO_LIGHTS IN_SEC INTER_SEC OUT_SEC PATH LIGHT ROUNDABOUT;
1 0 5 20 5 19 0 1;
```

The second section of the data of each crossroad contains data relating to internal sections:

- the identifier of the internal section in the crossroad model;
- the average crossing time of the section for a vehicle;
- the capacity of the section.

Section 1.2:

```
ID_INTER_SEC TIME_SERVICE NO_VEHICLES;
1 1 1;
2 3 5;
3 1 1;
4 2.4 4;
5 1 1;
6 2.4 4;
7 1 1;
8 2.4 4;
9 1 1;
10 1.8 3;
11 1 1;
12 2.4 4;
13 1 1;
14 2.4 4;
15 1 1;
16 1.8 3;
17 1 1;
18 2.4 4;
19 1 1;
20 2.4 4;
```

The third section of crossroad data contains information about input sections:

- the identifier of the input section in the crossroad model;
- the average section crossing time for a vehicle;
- the identifier of the crossroad to which the section belongs;
- the capacity of the section.

Section 1.3:

```
ID_IN_SEC NO_PATH TIME_SERV INTERSECTION NO_VE;
1 4 1.2 1 2;
2 3 2.4 1 4;
3 4 1.8 1 3;
4 4 1.8 1 3;
5 4 1.2 1 2;
```

The fourth section of crossroad data contains the information about the output sections:

- the identifier of the output section in the crossroad model;
- the average crossing time of the section for a vehicle;
- the identifier of the internal section of the crossroad to which the output section is connected;
- the identifier of the street outside the crossroad which is accessed by vehicles through the exit section.

Section 1.4:

```
ID_OUT_SEC TIME_SERV IN_SEC_LINK LINK_ROAD_OUT;
1 1 3 2;
2 1 7 4;
3 1 11 6;
4 1 15 8;
5 1 19 10;
```

The fifth section of crossroad data contains data relating to the crossing paths that vehicles can make at the intersection:

- the identifier of the crossing path in the crossroad model;
- the length of the path, which is the number of internal sections from which it is composed;
- the ordered sequence of the internal section identifiers of the path with the priority level for access of vehicles following the crossing path;
- the identifier of the entrance section from which the crossing path begins;
- the identifier of the exit section where the crossing path ends.

Section 1.5:

```
ID_PATH PATH_LENGTH S_1 P_1 S_2 P_2 S_3 P_3 S_4 P_4 S5 P_5 S_6 P_6 S_7 P_7
IN_SEC OUT_SEC;
1 3 1 5 2 10 3 10 1 1;
2 5 1 5 2 10 4 10 6 10 7 10 1 2;
3 7 1 5 2 10 4 10 6 10 8 10 10 10 11 10 1 3;
4 9 1 5 2 10 4 10 6 10 8 10 10 10 12 10 14 10 15 10 1 4;
5 5 5 5 6 10 8 10 10 10 11 10 2 3;
6 7 5 5 6 10 8 10 10 10 12 10 14 10 15 10 2 4;
7 9 5 5 6 10 8 10 10 10 12 10 14 10 16 10 18 10 19 10 2 5;
8 3 9 5 10 10 11 10 3 3;
9 5 9 5 10 10 12 10 14 10 15 10 3 4;
10 7 9 5 10 10 12 10 14 10 16 10 18 10 19 10 3 5;
11 9 9 5 10 10 12 10 14 10 16 10 18 10 20 10 2 10 3 10 3 1;
12 3 13 5 14 10 15 10 4 4;
13 5 13 5 14 10 16 10 18 10 19 10 4 5;
```

```
14 7 13 5 14 10 16 10 18 10 20 10 2 10 3 10 4 1;
15 9 13 5 14 10 16 10 18 10 20 10 2 10 4 10 6 10 7 10 4 2;
16 3 17 5 18 10 19 10 5 5;
17 5 17 5 18 10 20 10 2 10 3 10 5 1;
18 7 17 5 18 10 20 10 2 10 4 10 6 10 7 10 5 2;
19 9 17 5 18 10 20 10 2 10 4 10 6 10 8 10 10 10 11 10 5 3;
```

The sixth and last section of the crossroad data contains a list, for each entry section, of the intersection crossing paths with the relative sequence of vehicle routing probabilities or routing frequencies on the path according to the time intervals of 10 minutes into which the time slot for the model studied is divided.

Section 1.6:

```
ID_INPUT_SEC;
ID_PATH1 PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8 PROB_9 PROB_10
PROB_11 PROB_12
ID_PATH2 PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8 PROB_9 PROB_10
PROB_11 PROB_12
ID_PATH3 PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8 PROB_9 PROB_10
PROB_11 PROB_12
ID_PATH4 PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8 PROB_9 PROB_10
PROB_11 PROB_12;
...
1;
1 0.4808 0.9756 0.4762 0.3953 0 0 1.0417 0 2.6738 1.8868 1.1976 3.6269;
2 0.9615 1.4634 1.4286 1.9763 0.9709 1.3453 1.0417 1.0256 0.5348 1.4151 2.994
0.5181;
3 49.5192 47.3171 50.4762 45.8498 36.8932 50.6726 51.0417 50.2564 51.3369
55.1887 43.1138 54.4041;
4 49.0385 50.2439 47.619 51.7787 62.1359 47.9821 46.875 48.7179 45.4545
41.5094 52.6946 41.4508;
2;
5 30.7463 27.1709 28.1915 28.5714 20.1592 27.4939 26.4865 26.2735 25.2632
29.1045 20 28.2258;
6 30.4478 28.8515 26.5957 32.266 33.9523 26.0341 24.3243 25.4692 22.3684
21.8905 24.4444 21.5054;
7 38.806 43.9776 45.2128 39.1626 45.8886 46.472 49.1892 48.2574 52.3684 49.005
55.5556 50.2688;
3;
8 30.6548 27.0195 28.1167 28.5012 20.1592 27.4939 26.3441 26.2735 24.9351
28.8177 19.8895 27.7045;
9 30.3571 28.6908 26.5252 32.1867 33.9523 26.0341 24.1935 25.4692 22.0779
21.6749 24.3094 21.1082;
10 38.6905 43.7326 45.0928 39.0663 45.8886 46.472 48.9247 48.2574 51.6883
48.5222 55.2486 49.3404;
11 0.2976 0.5571 0.2653 0.2457 0 0 0.5376 0 1.2987 0.9852 0.5525 1.847;
4;
12 43.4043 38.8679 36.4964 44.2568 42.2442 35.5482 32.6087 34.296 29.3103
30.137 29.8305 29.0909;
13 55.3191 59.2453 62.0438 53.7162 57.0957 63.4551 65.942 64.9819 68.6207
67.4658 67.7966 68;
14 0.4255 0.7547 0.365 0.3378 0 0 0.7246 0 1.7241 1.3699 0.678 2.5455;
15 0.8511 1.1321 1.0949 1.6892 0.6601 0.9967 0.7246 0.722 0.3448 1.0274 1.6949
0.3636;
5;
16 55.0847 60.6178 60.7143 56.5836 68.9243 62.215 64.0845 64.2857 66.113
```

```
61.3707 71.6846 62.3333;
17 0.4237 0.7722 0.3571 0.3559 0 0 0.7042 0 1.6611 1.2461 0.7168 2.3333;
18 0.8475 1.1583 1.0714 1.7794 0.7968 0.9772 0.7042 0.7143 0.3322 0.9346 1.7921
0.3333;
19 43.6441 37.4517 37.8571 41.2811 30.2789 36.8078 34.507 35 31.8937 36.4486
25.8065 35;
```

For Crossroad 2 the data sections contained in the model.dat file are the following:

Section 2.1:

```
ID_INT NO_LIGHTS IN_SEC INTER_SEC OUT_SEC PATH LIGHT ROUNDABOUT;
2 0 3 3 2 4 0 0;
```

Section 2.2:

```
ID_INTER_SEC TIME_SERVICE NO_VEHICLES;
1 1 1;
2 0.9 1;
3 1.1 1;
```

Section 2.3:

```
ID_IN_SEC NO_PATH TIME_SERV INTERSECTION NO_VE;
1 2 1 1 1;
2 1 1 1 1;
3 1 1 1 1;
```

Section 2.4:

```
ID_OUT_SEC TIME_SERV INTER_SEC_LINK LINK_ROAD_OUT;
1 1 1 18;
2 1 2 12;
```

Section 2.5:

```
ID_PATH PATH_LENGTH S_1 P_1 S_2 P_2 S_3 P_3 IN_SEC OUT_SEC;
1 3 1 5 2 10 3 10 1 2;
2 1 1 5 1 1;
3 1 3 10 2 2;
4 1 1 5 3 1;
```

Section 2.6:

```
ID_INPUT_SEC;
ID_PATH1 PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8...PROB_12;
ID_PATH2 PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8...PROB_12;
...
1;
1 48.5437 49.4845 49.0566 49.1379 48.6842 48.6726 48.9796 48.9796 48.9583
48.7179 48.6111 48.5714;
2 51.4563 50.5155 50.9434 50.8621 51.3158 51.3274 51.0204 51.0204 51.0417
51.2821 51.3889 51.4286;
2;
3 100 100 100 100 100 100 100 100 100 100 100 100;
3;
4 100 100 100 100 100 100 100 100 100 100 100 100;
```

For Crossroad 3 the data sections contained in the model.dat file are the following:

Section 3.1:

```
ID_INT NO_LIGHTS IN_SEC INTER_SEC OUT_SEC PATH LIGHT ROUNDABOUT;
3 0 4 16 4 9 0 1;
```

Section 3.2:

```
ID_INTER_SEC TIME_SERVICE NO_VEHICLES;
1 1 1;
2 1.2 2;
3 1 1;
4 2.4 4;
5 1 1;
6 1.8 3;
7 0.9 3;
8 0 1;
9 1.2 2;
10 0 1;
11 0 1;
12 4.2 6;
13 2.1 6;
14 0 1;
15 0 1;
16 2.4 4;
```

Section 3.3:

```
ID_IN_SEC NO_PATHS TIME_SERV INTERSECTION;
1 3 1.2 1 2;
2 3 2.4 1 4;
3 2 3 1 5;
4 1 3 1 5;
```

Section 3.4:

```
ID_OUT_SEC TIME_SERV INTER_SEC_LINK LINK_ROAD_OUT;
1 1 3 13;
2 1 7 15;
3 1 14 17;
4 1 15 7;
```

Section 3.5:

```
ID_PATH PATH_LENGTH S_1 P_1 S_2 P_2 S_3 P_3...S_7 P_7 IN_SEC OUT_SEC;
1 3 1 5 2 10 3 10 1 1;
2 5 1 5 2 10 4 10 7 10 8 10 1 2;
3 7 1 5 2 10 4 10 6 10 9 10 13 10 15 10 1 4;
4 3 5 5 7 10 8 10 2 2;
5 5 5 5 6 10 9 10 12 10 14 10 2 3;
6 5 5 5 6 10 9 10 13 10 15 10 2 4;
7 3 10 5 12 10 14 10 3 3;
8 5 10 5 12 10 16 10 2 10 3 10 3 1;
9 3 11 5 13 10 15 10 4 4;
```

Section 3.6:

```
ID_INPUT_SEC;
ID_PATH1 PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8...PROB_12;
ID_PATH2 PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8...PROB_12;
ID_PATH3 PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8...PROB_12;
...
1;
1 40.404 27.0588 23.6686 27.5701 31.4465 62.6263 33.5294 39.4444 31.7073 40
30.8511 39.0244;
2 36.3636 38.8235 43.1953 34.5794 36.478 61.6162 30.5882 27.7778 35.9756
32.4138 43.617 35.7724;
3 23.2323 34.1176 33.1361 37.8505 32.0755 65.6566 35.8824 32.7778 32.3171
27.5862 25.5319 25.2033;
2;
4 19.1083 7.5893 15.0888 13.7026 21.3768 14.8289 11.5207 23.0496 15.1079
14.3382 18.4783 13.7778;
5 25.4777 35.7143 34.0237 29.1545 33.3333 28.1369 28.1106 25.5319 32.3741
28.3088 36.2319 32;
6 55.414 56.6964 50.8876 57.1429 45.2899 57.0342 60.3687 51.4184 52.518 57.3529
45.2899 54.2222;
3;
7 40.5405 34.8837 31.9149 27.027 27.2727 28.3019 30.9278 22.7273 27.2727 24 30
27.2727;
8 59.4595 65.1163 68.0851 72.973 72.7273 71.6981 69.0722 77.2727 72.7273 76 70
72.7273;
4;
9 100 100 100 100 100 100 100 100 100 100 100 100;
```

6. Visualization and analysis of data

We have developed an application in Visual Basic that reads the data plotted during the simulation and creates a visual feedback. The simulation data traces the status of individual components of the detection system every thirty seconds during the entire simulation length. The application shows the data and the interface on a map of the vehicular traffic system as shown in Figure 21, the supply of descriptive tables is shown in Figure 22.

Form 1 of the application shows the map of the road system in which the individual arrows related to the model components described in the model.dat file are displayed. A list box containing the list of input, output and internal sections of each model crossroad is situated on the left of the map, while the list box on the right has the purpose of highlighting to the user only the sections that contain at least one vehicle in the queue.

Clicking on one of these sections opens Form 2, as shown in Figure 23. This form shows the status of the vehicle queue in the selected section and the respective request queue to access it. Form 2 indicates the vehicle identification numbers and access requests.

The colors of the arrows specify the traffic intensity of the corresponding model component. The arrow is green, if there are no access section requests, orange, when the number of requests is about one vehicle in excess on the capacity of the section, and red, if the requests exceed the capacity of the section by at

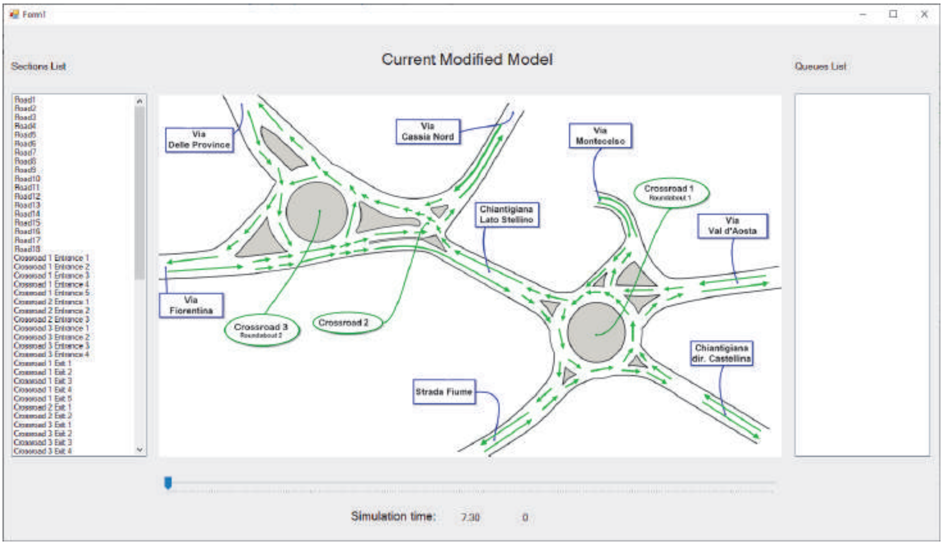


Figure 21. Application Form 1

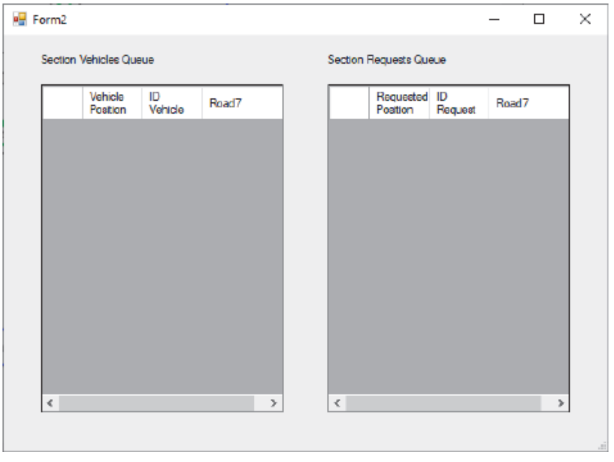


Figure 22. Application Form 2

least two units. Right below the model there is a scroll bar that allows choosing the time interval of thirty seconds to which the data displayed is referred. When the bar is moved, the results file will be read again and the data will change accordingly.

In the next paragraph, given the limited space available, we report only analyses carried out by us regarding the simulation of the traffic system model described by the model.dat file reported in this work. Hence, it is the Siena Nord system simulator in the time slot 07.30 AM to 09.20 AM. We analyzed the simulation data also for the two other time slots and we will report our observations in the conclusions of this work. The study is focused on the search for congestion events that can occur in the model components during the simulation

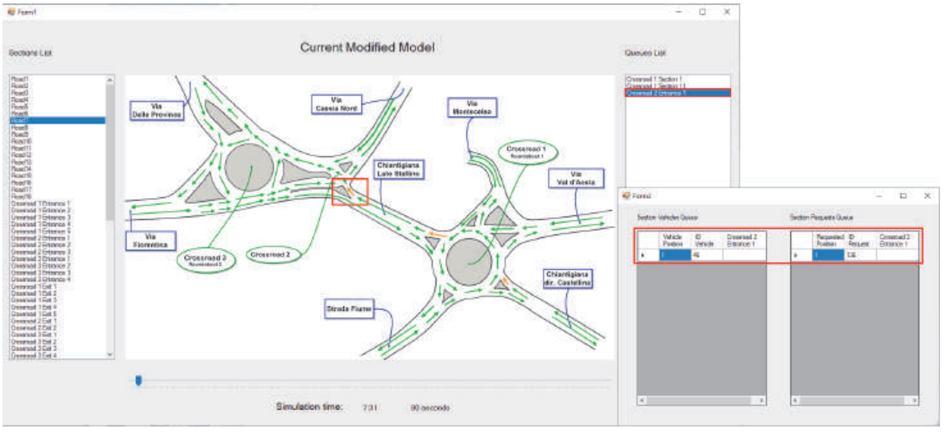


Figure 23. Example of Form 1 and Form 2 queue

and in comparison with the traffic system behavior when it was in its previous configuration.

Figure 24 and Figure 25 show the status of the system at 1:01 p.m. in the current and previous configurations, respectively.

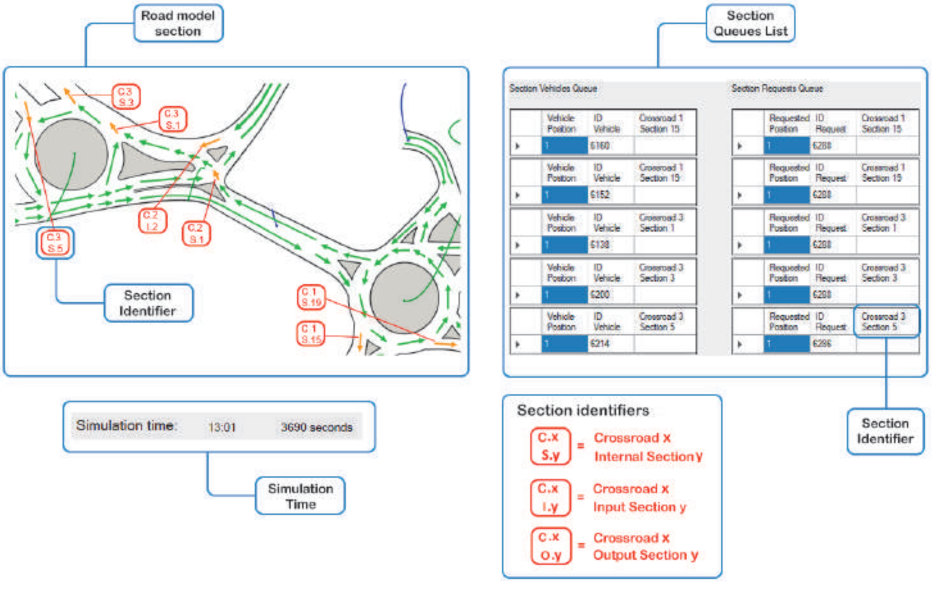


Figure 24. System status and graphic notation

6.1. Visualization of results

The time slot 07:30 AM to 09:20 AM in the first minutes of the simulation is described by the queues on the route sections of Intersection 2 that connects via Chiantigiana, Stellino side, to Roundabout 2 and on some sections of the entry

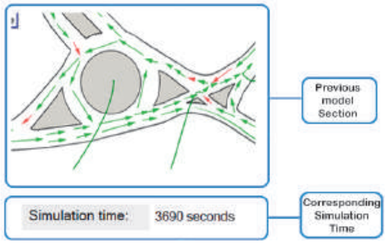


Figure 25. System status in the previous configuration

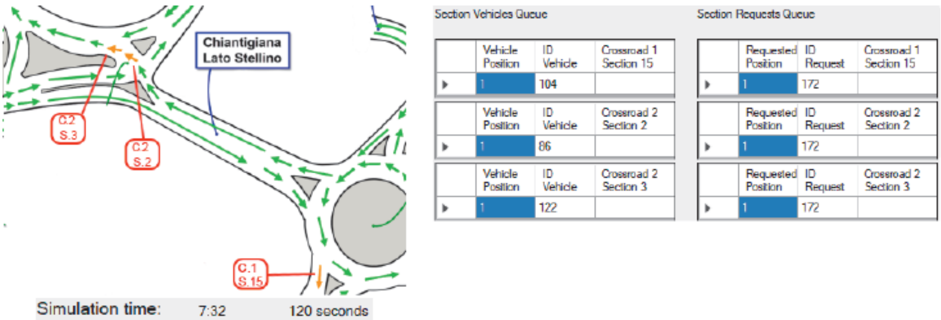


Figure 26. First queues at 120 seconds

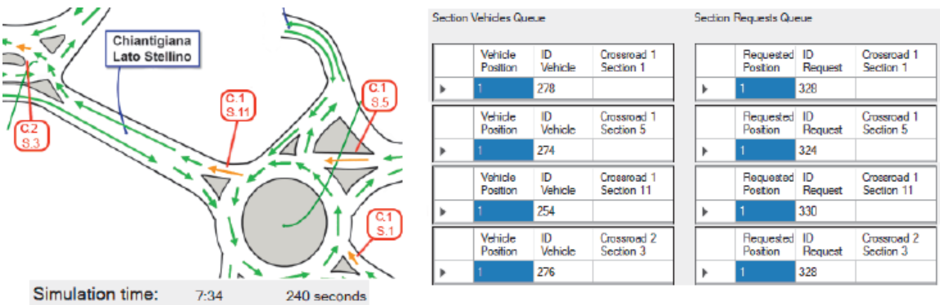


Figure 27. First queues at 240 seconds

and exit of Intersection 1, Figures 26 and 27 show some cases of queues on these sections.

The sections under interest are Section 3 and Section 2 of Crossroad 2, Sections 15, 11, 5 and 1 of Crossroad 1. The second form of each figure shows that the queues of interest to the sections just mentioned are formed by one vehicle only, therefore, we are not talking about real congestions. Over the next few minutes, the system will tend to become progressively populated.

Very soon this situation results in the first minimal congestion on Section 1 of Crossroad 2 specified by a red arrow of the corresponding flow, a section that belongs to the same path mentioned above:

The traffic starts to intensify also in the sections that allow access or exit from Crossroad 1, in particular Sections 5, 9, 13, 15 and 19, occasionally forming

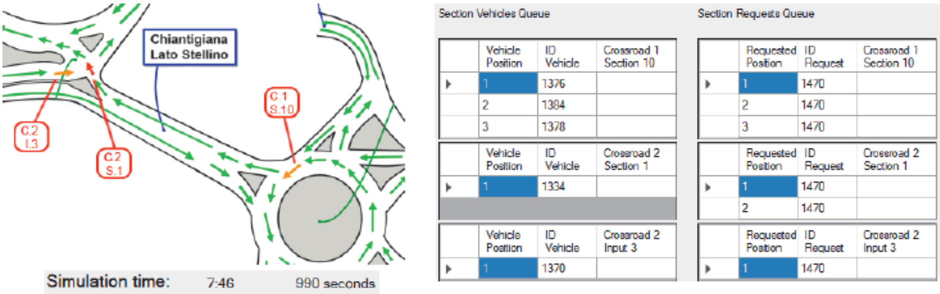


Figure 28. First queue formed by more than two vehicles at 990 seconds

queues of two vehicles. It should be kept in mind that the yellow flows indicate queues formed by a single vehicle, while red flows indicate more consistent queues, formed by two or more vehicles:

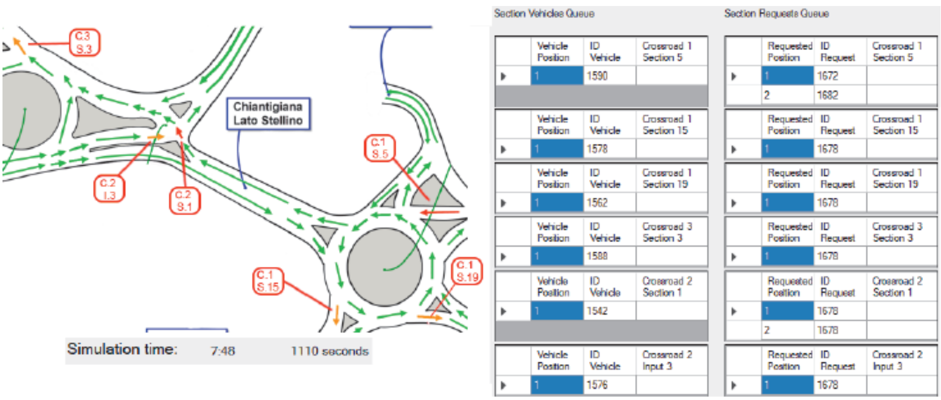


Figure 29. Examples of population of crossroads at 1110 seconds

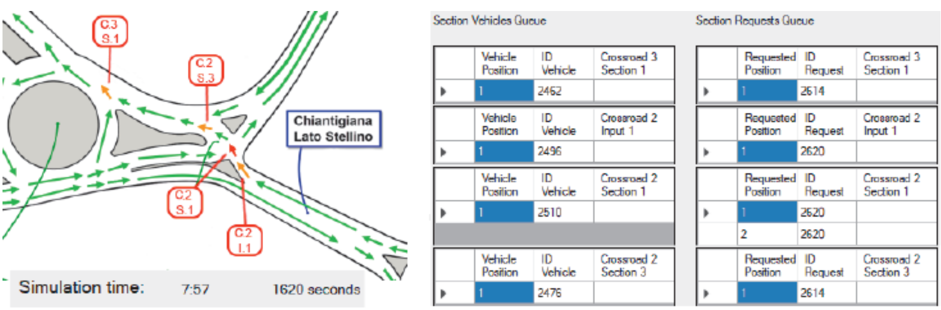


Figure 30. Examples of population of crossroads at 1620 seconds

An interesting scenario occurs at 8.45 am, where the entire route of Crossroad 2 that connects Via Chiantigiana, Stellino side, to Roundabout 2 is slowed down by queues in each of the sections that make it up, queues formed by a vehicle in the case of Sections 1 and 2, and queues of two vehicles in the case

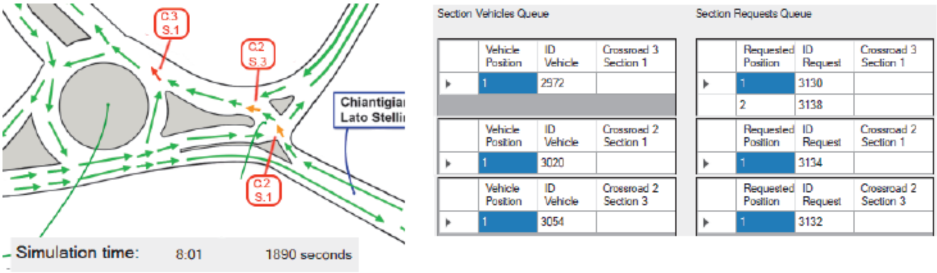


Figure 31. Examples of population of crossroads at 1890 seconds

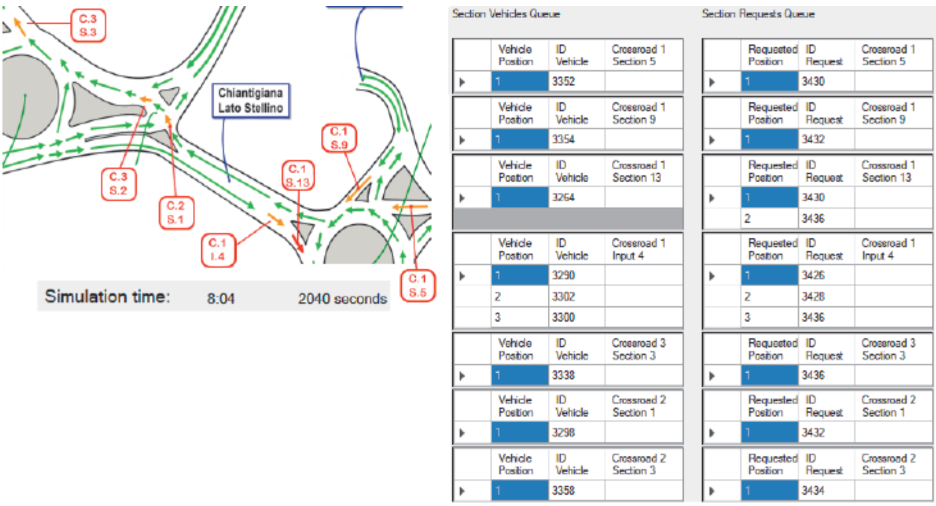


Figure 32. Examples of population of crossroads at 2040 seconds

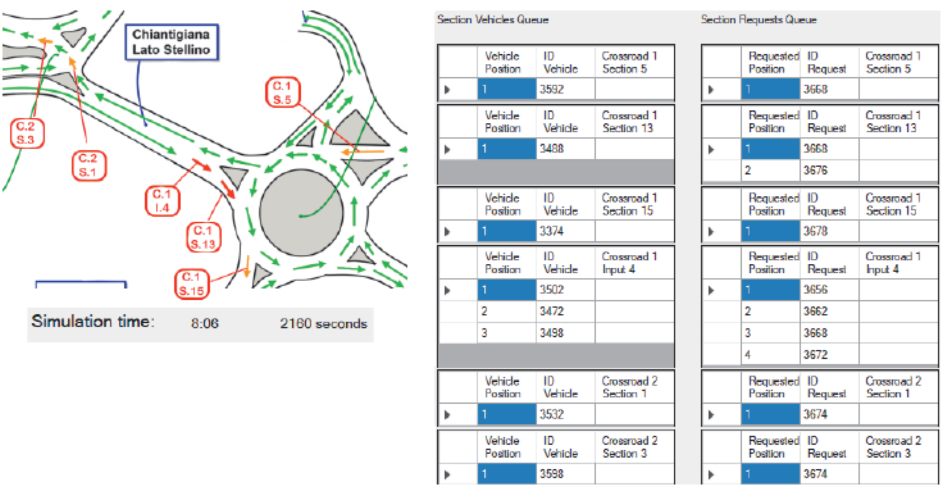


Figure 33. Examples of population of crossroads at 2160 seconds

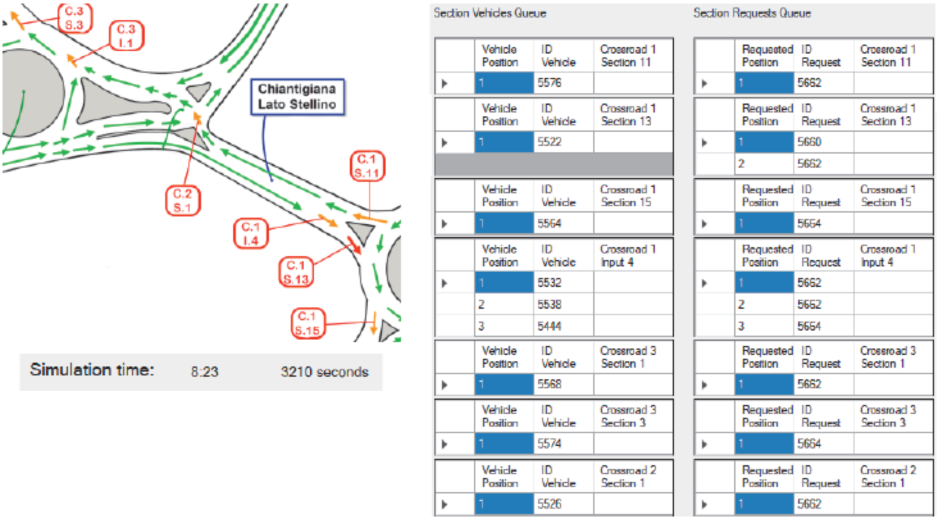


Figure 34. Examples of population of crossroads at 3120 seconds

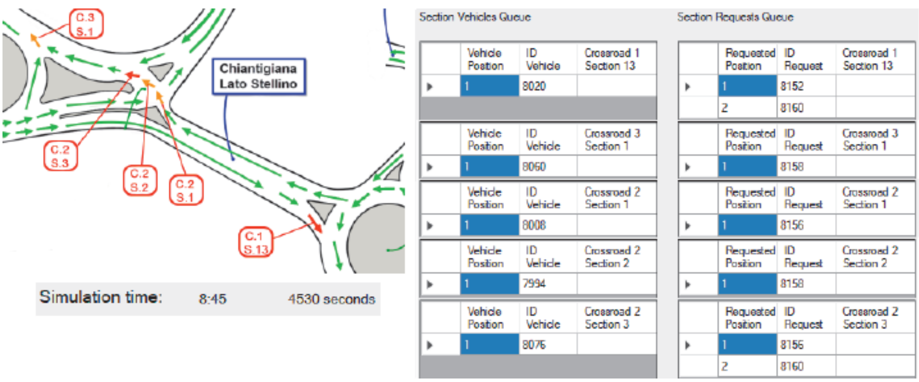


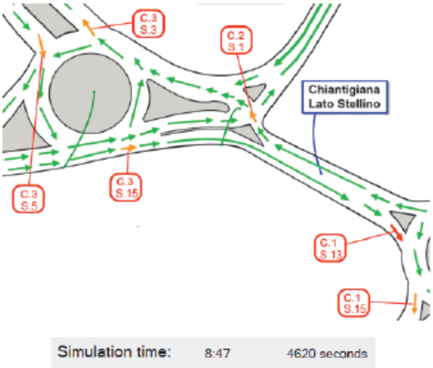
Figure 35. Congestion of a crossing path in Crossroad 2 at 4530 seconds

of Section 3, in Figure 37 we note a similar case which also includes Entry 1 of Crossroad 2:

Around 8:30 a.m., we can see how the vehicular flow starts to move towards Crossroad 3 (Roundabout 2) populating the system in its entirety. Let us look at some examples:

After 9 a.m. there are no other particular cases of congestion, in fact the number of requests rarely exceeds the capacity of the sections by two. The sections mainly involved are:

– Internal Sections 1, 2 and 3 of Crossroad 2;
– Input Sections 1 and 3 of Crossroad 2;
– Internal Sections 1, 5, 11, 13, 15, 17, 19 of Crossroad 1;
– Entrance 4 of Crossroad 1;
– Internal Sections 1, 3, 5, 15 of Crossroad 3.



Section Vehicles Queue

Vehicle Position	ID Vehicle	Crossroad 1 Section 13
1	8160	

Vehicle Position	ID Vehicle	Crossroad 1 Section 15
1	8188	

Vehicle Position	ID Vehicle	Crossroad 3 Section 3
1	8242	

Vehicle Position	ID Vehicle	Crossroad 3 Section 5
1	8260	

Vehicle Position	ID Vehicle	Crossroad 3 Section 15
1	8252	

Vehicle Position	ID Vehicle	Crossroad 2 Section 1
1	8196	

Section Requests Queue

Requested Position	ID Request	Crossroad 1 Section 13
1	8338	
2	8344	

Requested Position	ID Request	Crossroad 1 Section 15
1	8346	

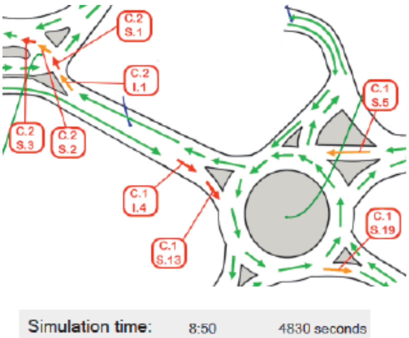
Requested Position	ID Request	Crossroad 3 Section 3
1	8346	

Requested Position	ID Request	Crossroad 3 Section 5
1	8340	

Requested Position	ID Request	Crossroad 3 Section 15
1	8344	

Requested Position	ID Request	Crossroad 2 Section 1
1	8336	

Figure 36. Queues on Crossroad 3 at 4620 seconds



Section Vehicles Queue

Vehicle Position	ID Vehicle	Crossroad 1 Section 5
1	8688	

Vehicle Position	ID Vehicle	Crossroad 1 Section 13
1	8612	

Vehicle Position	ID Vehicle	Crossroad 1 Section 19
1	8596	

Vehicle Position	ID Vehicle	Crossroad 1 Input 4
1	8630	
2	8598	
3	8624	

Vehicle Position	ID Vehicle	Crossroad 2 Input 1
1	8536	

Vehicle Position	ID Vehicle	Crossroad 2 Section 1
1	8652	

Vehicle Position	ID Vehicle	Crossroad 2 Section 2
1	8628	

Vehicle Position	ID Vehicle	Crossroad 2 Section 3
1	8594	

Section Requests Queue

Requested Position	ID Request	Crossroad 1 Section 5
1	8770	

Requested Position	ID Request	Crossroad 1 Section 13
1	8770	
2	8772	

Requested Position	ID Request	Crossroad 1 Section 19
1	8770	

Requested Position	ID Request	Crossroad 1 Input 4
1	8752	
2	8752	
3	8770	
4	8770	

Requested Position	ID Request	Crossroad 2 Input 1
1	8770	

Requested Position	ID Request	Crossroad 2 Section 1
1	8770	
2	8770	

Requested Position	ID Request	Crossroad 2 Section 2
1	8770	

Requested Position	ID Request	Crossroad 2 Section 3
1	8770	
2	8770	

Figure 37. Queues on Crossroad 3 at 4830 seconds

Most of these sections correspond to areas next to the entrance of each crossroad, that is, the most critical points of the system where vehicles wait to be routed with a higher probability of creating queues.

The system does not present excessive cases of congestion in this time slot, but in most of the intervals observed, Crossroad 2 appears to be, partly or completely, subject to traffic slowdowns and queues.

We selected figures related to the previous system configuration in the time slot **07:30–09:20** to verify if there were improvements or worsening:

In most cases the pattern of queues is the same for both systems, especially in sections concerning Roundabout 1, considering that its structure has remained

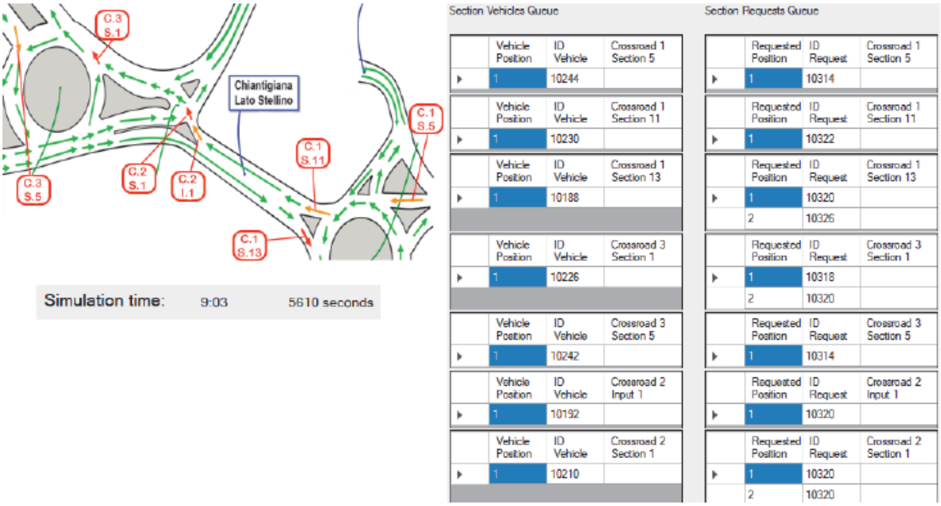


Figure 38. Queues on Crossroad 3 at 5610 seconds

unchanged. As for Intersection 2, queues appear mainly in the same intervals, however, given the modified general structure, in the current configuration the most crowded route is the one from via Chiantigiana, Stellino side, proceeding towards Roundabout 2, while in the previous configuration vehicles tend to slow down mainly along the route from Cassia Nord to Roundabout 2 and vice versa. This difference may be due to the conformation of the new Intersection 2, which merges vehicles coming from Chiantigiana Lato Stellino on the same crossing entrance, increasing the chances of creating queues, while in the previous configuration, the same vehicles were shared on two entrances at different crossroads.

A further element defined by us in the library to improve the detection of vehicle queues in traffic flow simulations is the `CODA_INT` object [2, 4]:

```
OBJECT CODA_INT(ID);
INTEGER INT,ID;
REF ROAD R;
REF INPSEC INP;
REF MP_INT M_INT;
REAL P;
END;
```

This object is composed of pointers to other system variables and makes it more practical to measure queues of vehicles created during the simulation at some specific points of the road system. The `CODA_INT` object allows measuring queues forming at the end of a street of the model at an entry point to a crossroad. Therefore, each path of the model that turns out to be an entrance to an intersection has a specific `CODA_INT` object associated with it. The internal variables of this object are:

- `INT` is the identifier of the crossroads on which the route ends in the system model;

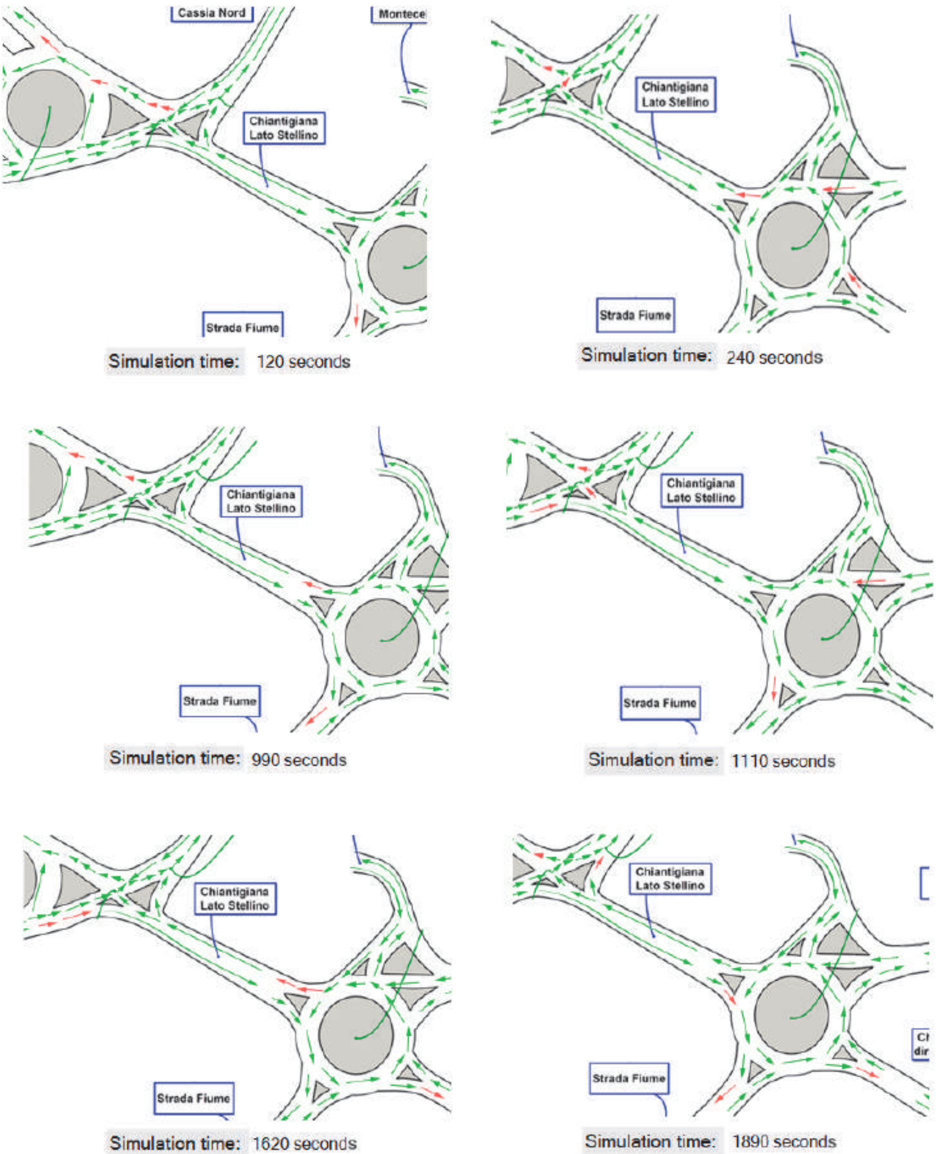


Figure 39. Comparisons corresponding to the unmodified model at 07:30–09:00

- `ID` is the identifier of the object;
- `R` is the pointer to the street to which it is associated;
- `M_INT` is the pointer to the crossroad multiplexer to which it refers;
- `INP` is the pointer to the input section to which it refers;
- `P` is the probability of vehicles being routed to the INP entry section.

During the simulation, this object calculates the total number of vehicles in the entry section of the crossroad and the number of requests for accessing

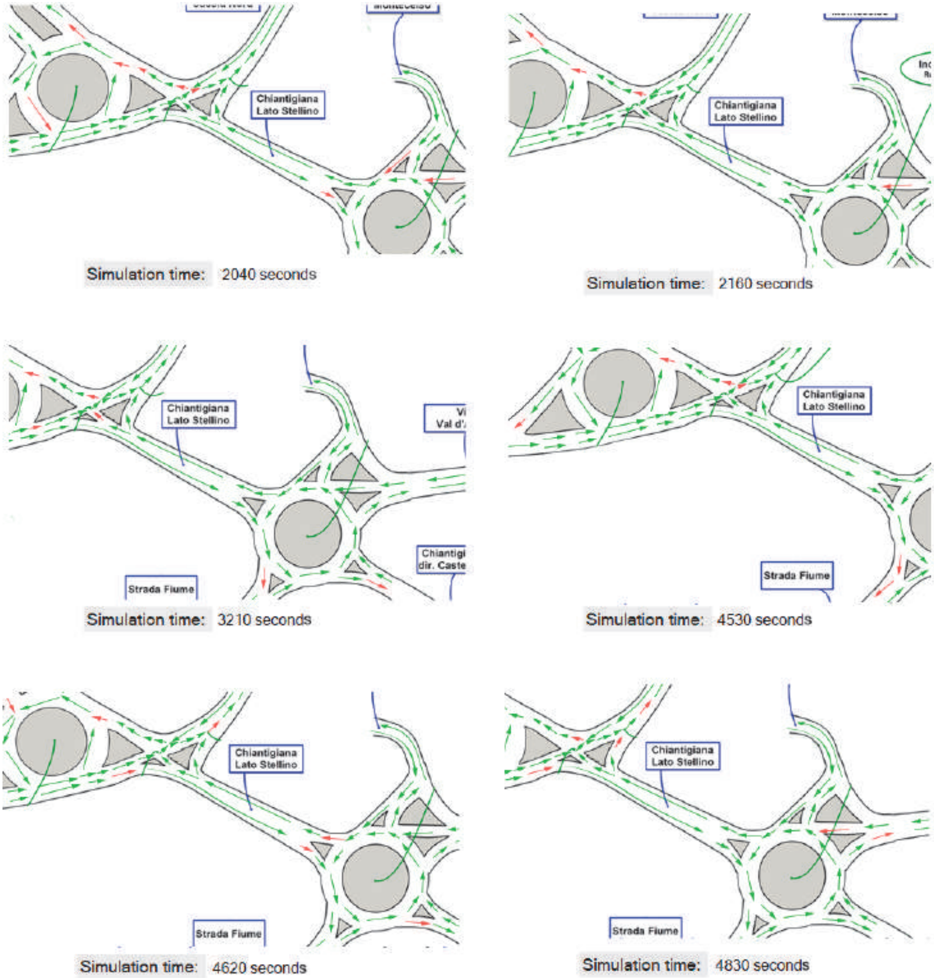


Figure 40. Comparisons corresponding to the unmodified model at 07:30–09:00

the multiplexer, posted by vehicles entering from the corresponding street, these values provide an estimation of the total length of the queue of vehicles entering the intersection from a specific direction. Such data detected during the simulation allows us to have a precise estimate of the queuing in the simulated system and allows us to perform an efficient comparison between the two configurations of the road system with regard to the management of vehicular flows. In particular, we will observe the behavior of the vehicular flows in the access section to Crossroad 2 for the current configuration, and the total requests to access sections at Crossroads 2 and 4 for the previous configuration. In the following figures we illustrate the two points for detecting vehicle queuing in relation to the two different road system configurations.

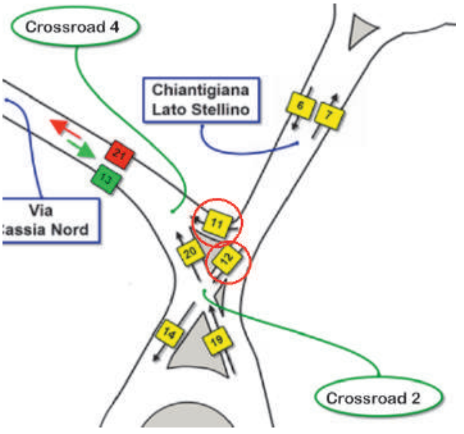


Figure 41. Multiplexers considered in the previous system configuration

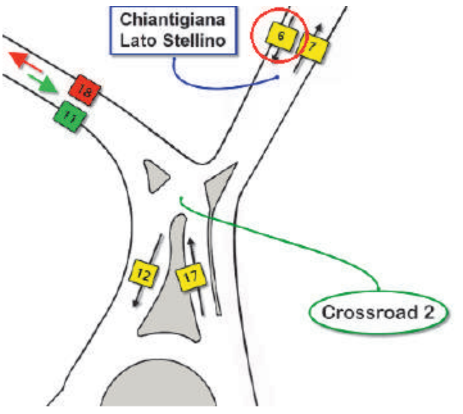


Figure 42. Multiplexer considered in the current system configuration

Looking at the data relating to this object during the current time slot (07:30–09:00) and comparing it with the data taken from the previous model in the same intervals, we obtain the Table 2.

Table 2 shows a direct comparison of the `CODA_INT` values in the intervals studied with the application. Tables 3 summarize the highest values achieved during the simulation: the table on the left contains the maximum values reached by the current model and the value of the previous model at the same time, while the table on the right contains the maximum values reached by the previous model and the corresponding value derived from the current model.

In this time slot we can see how the sum of the values of the `CODA_INT` object of the multiplexers of Via 11 and Via 12 of the previous model reach a value of 2 vehicles for almost twice the intervals compared to the modified model.

7. Conclusions

This study analyzes the road system of the Siena Nord area in the current situation after a change that was made to the previous structure of the road system. The study covered the 120-minute time slots in the hours 07:30–09:20, 12:00–13:50 and 17:30–19:20. The purpose was to compare the traffic congestion levels in the current system compared to those that occurred in the system in its previous configuration.

It is clear from the simulations that both models have the same critical points in which intense traffic tends to saturate the sections, therefore, we do not have a real improvement in the modification made to the system. Regarding the point of the system where the new structural modification was made, we can state that in the first time slot that runs from 07.30 to 09.20 the vehicle flows have fewer queues compared to what happened in the previous configuration. Our study also shows that in the time period from 12:00 to 13:50 the current situation is slightly worse than the previous one, while in the time period from 17:30 to 19:20 the

Table 2. Values of CODA_INT x for intervals analyzed in the application

Time slot	Interval	CODA_INT Modified model	CODA_INT Unmodified model
7:30–9:00	7:32 (120 seconds)	1	0
	7:34 (240 seconds)	0	0
	7:46 (990 seconds)	0	2
	7:48 (1110 seconds)	0	1
	7:57 (1620 seconds)	1	0
	8:01 (1890 seconds)	1	1
	8:04 (2040 seconds)	0	0
	8:06 (2160 seconds)	0	1
	8:23 (3210 seconds)	0	2
	8:45 (4530 seconds)	0	0
	8:47 (4620 seconds)	1	1
	8:50 (4830 seconds)	1	1

Table 3. Maximum values reached in both systems

Interval	CODA_INT Modified model	CODA_INT Unmodified model
1590 seconds	2	2
1800 seconds	2	0
2430 seconds	2	0
3360 seconds	2	1
3450 seconds	2	2
3540 seconds	2	0
3930 seconds	3	0
4410 seconds	2	0
4920 seconds	2	0
5280 seconds	2	1

Interval	CODA_INT Unmodified model	CODA_INT Modified model
900 seconds	3	0
990 seconds	2	0
1350 seconds	2	0
1430 seconds	2	0
1590 seconds	2	2
2010 seconds	2	1
2250 seconds	2	0
2370 seconds	3	1
2490 seconds	2	1
2730 seconds	2	0
3000 seconds	2	1
3210 seconds	2	0
3450 seconds	2	2
3780 seconds	2	0
4650 seconds	2	1
4680 seconds	2	0
4800 seconds	2	1
5250 seconds	2	0
5370 seconds	2	1

two configurations are practically equivalent with regard to the distribution of queuing. The new configuration of the system does not solve the critical problems of congestion of vehicular traffic that occur in the system and that we mentioned in our previous work [1].

Therefore, we can conclude that the simplification of the road system that has led to a reduction in the number of crossroads, roads and paths contained in the model has not solved the serious traffic congestion problems that occur in the system, but has slightly improved the flow of vehicles inside the system, in particular the flow passing from Roundabout 1 towards Roundabout 2 along via Chiantigiana, Stellino side.

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