

# EVALUATION OF THE IMPACT OF CHANGES IN THE CITY ROAD SYSTEM ON TRAFFIC FLOWS

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**Abstract:** This paper outlines a study carried out to answer the questions asked by an architect of the Siena Municipality Office during a conference at our Department on the management of traffic flows through the Siena North city road system. The purpose of the study was to ascertain if changes in the road system introduced and included in the new City Development Plan would resolve the current traffic congestion issues. In order to answer this question, we used the technology for the development of vehicle traffic system simulators which was introduced during our previous projects (*TASK Quart.* **14** (4) 405, **17** (3) 155, **20** (1) 9, **20** (3) 273).

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

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## 1. Introduction

In our previous works [1, 2], we introduced a new procedure for developing a city vehicle traffic system simulator. The procedure relies on the use of queue based service system networks as architectural models of the city vehicle traffic system components. To do this, we identified a group of traffic system components. For each such component, we defined a new type of an object inside the library used for creating an architectural model of the simulated system.

In [1] we described the technique that allows each city vehicle traffic system to be linked to a file containing the data describing the architectural model of the system. This file, called Model.dat file, is a text file containing all the description details of the system components, split into sections and listed following a preset order.

Therefore, in Section 3 of [1] we describe the procedure for creating a Model.dat file associated with the system for any city traffic system. The

Model.dat file describes the architectural model of the system created using objects from our library.

In Section 4 of [1] we defined the BuildMod procedure. This procedure automates the process of developing the traffic system simulator described by the Model.dat file. When carried out, the BuildMod procedure reads the data of the descriptive Model.dat file, generates components of the architectural model of the system and creates interconnections between them. The finished product of the BuildMod procedure is a traffic system simulator.

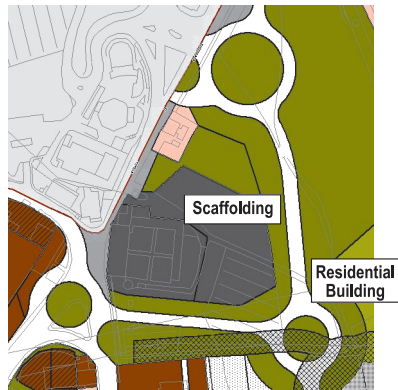
In this paper we discuss a study carried out to evaluate the impact of changes in the city road system on vehicle traffic flows designed by the Municipality Office to resolve some traffic congestion issues that occur during the course of the day.

The studied area is in Siena North. Figure 1 shows a Google Maps image of the current system configuration.



**Figure 1.** Google Maps image showing the current Siena North system configuration

Figure 2 shows the new traffic system contemplated by the project, consisting in the introduction of a third roundabout in addition to the already existing two roundabouts, and elimination of the road link between Roundabout 1 and Roundabout 2 in the current traffic system configuration.



**Figure 2.** New Project – Modified Siena North system configuration

## 2. The current system

This section outlines the roundabouts, the road intersections and the roads making up the current system. The system consists of four road intersections, two of which are roundabouts.

- Road Intersection 1: is the north roundabout of the system, which we will call Roundabout 1.
- Road Intersection 2: is the intersection point between the north-west outgoing flow of Roundabout 2, the incoming and outgoing flows of Via Cassia Nord and the flow from Roundabout 1 travel south along the Chiantigiana national road, the Stellino side.
- Road Intersection 3: is the south roundabout of the system, which we will call Roundabout 2.
- Road Intersection 4: is the intersection point of the vehicle flows coming from north and south, towards Via Cassia Nord.

Figure 3 shows that Roundabout 1 is the intersection point for the following roads: the Chiantigiana national road No. 222 (towards Castellina in Chianti), Via Valle D'Aosta, Via Montecelso, the Chiantigiana national road No. 222 (Stellino side) and Strada Fiume.

Roundabout 2 is the intersection point for the following roads: Via Cassia Nord, Via delle Province, Via Fiorentina and the national road Chiantigiana no. 222 (Stellino side), the bidirectional link between Roundabout 1 and Roundabout 2.

Figure 3 shows the numbering of the roads used in the description of the model. Two way roads are represented by two separate lanes, one per each direction, and are therefore identified by different numbers in the model. The roads used to exit the system are marked in red, while those to enter the system are marked in green (meaning the roads that allow entering the traffic flow from a source of the model). Internal system roads are marked in yellow. The model shows 21 roads, of which 7 incoming (1, 3, 5, 9, 13, 17, 18), 7 outgoing (2, 4, 8, 10, 15, 16, 21) and 7 internal (6, 7, 11, 12, 14, 19, 20).

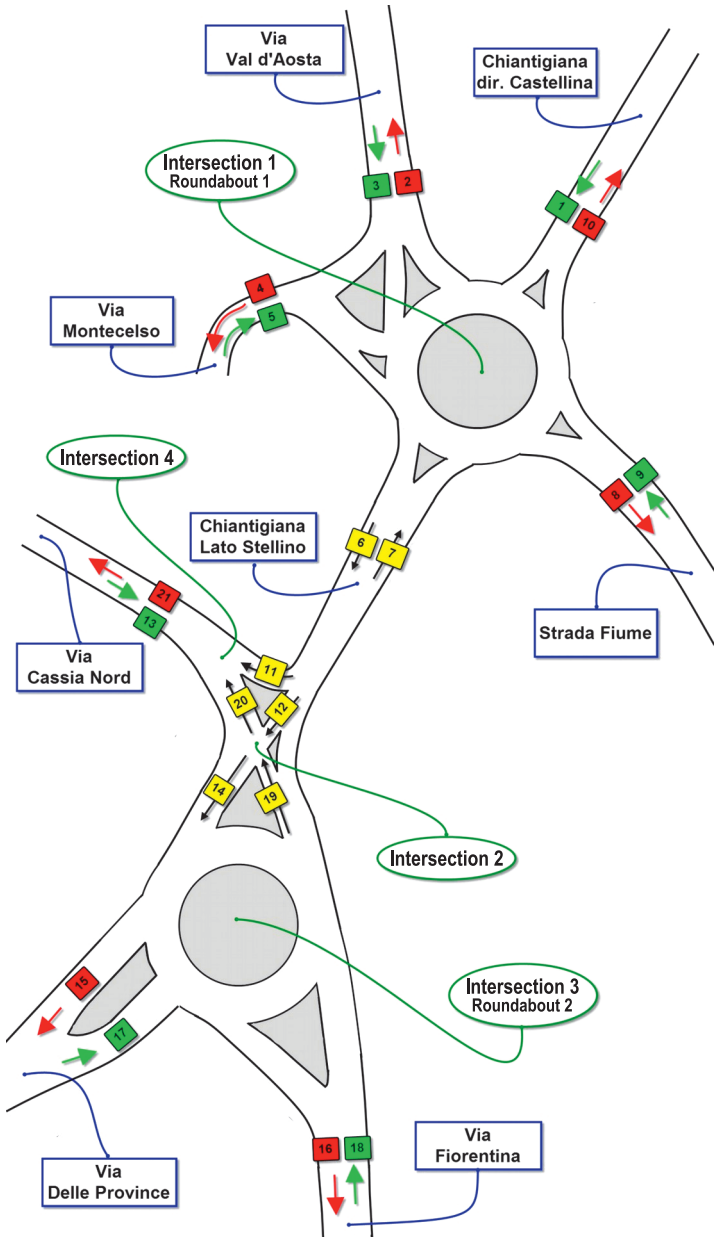


Figure 3. The Current System showing the road numbers

### 3. Road intersections in the current system

This section discusses the procedure for modeling the road intersections of the Current System. In particular, reference is made to one of our previous works [1, 2], where we used the Current System to show the use of library objects for creating the system model. Within this framework, we repeat the Current

System modeling procedure for the purpose of comparing it with the model proposed by the Municipality Office in the City Development Plan.

In the road intersection modeling, the incoming traffic sections are marked in green, while the outgoing traffic sections are marked in red. The internal sections are yellow in simple road intersections, while they are graphically represented by curved arrows in roundabouts.

### **3.1. Roundabout 1**

Figure 4 shows that Roundabout 1 has 5 incoming traffic sections and 5 outgoing traffic sections. The incoming traffic sections are:

- Incoming Traffic Section 1: the point of entrance to the roundabout for vehicles coming from the Chiantigiana national road (towards Castellina in Chianti);
- Incoming Traffic Section 2: the point of entrance to the roundabout for vehicles coming from Via Valle D'Aosta;
- Incoming Traffic Section 3: the point of entrance to the roundabout for vehicles coming from Via Montecelso;
- Incoming Traffic Section 4: the point of entrance to the roundabout for vehicles coming from the Chiantigiana national road, the Stellino side;
- Incoming Traffic Section 5: the point of entrance to the roundabout for vehicles coming from Strada Fiume.

The outgoing traffic sections are the following:

- Outgoing Traffic Section 1: exit from the roundabout into Via Valle d'Aosta;
- Outgoing Traffic Section 2: exit from the roundabout into Via Montecelso;
- Outgoing Traffic Section 3: exit from the roundabout into the Chiantigiana national road, the Stellino side;
- Outgoing Traffic Section 4: exit from the roundabout into Strada Fiume;
- Outgoing Traffic Section 5: exit from the roundabout into the Chiantigiana national road towards Castellina in Chianti.

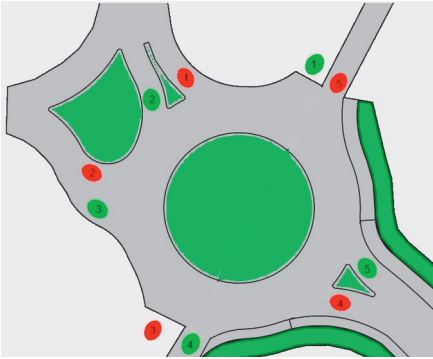
Figure 5 shows the roundabout internal sections. These sections are crossed by vehicles based on the roundabout crossing path that they can follow. A crossing path is defined as an ordered sequence of internal sections starting from an incoming section and ending at an outgoing section of the roundabout.

Each possible vehicle crossing path within the roundabout has a corresponding path object type in our library. The list of possible crossing paths for the roundabout is shown in the Model.dat file, in the road intersection data section.

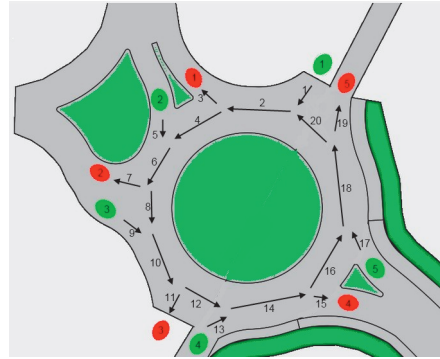
### **3.2. Roundabout 2**

Figure 6 shows that Roundabout 2 has 4 incoming traffic sections and 4 outgoing traffic sections. The incoming traffic sections are:

- Incoming Traffic Section 1: the point of entrance to the roundabout for vehicles coming from the Cassia Nord branch;
- Incoming Traffic Section 2: the point of entrance to the roundabout for vehicles coming from Via Delle Province;



**Figure 4.** Roundabout 1 with incoming and outgoing traffic sections



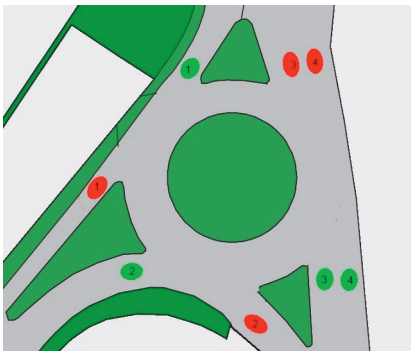
**Figure 5.** Roundabout 1 with incoming, internal and outgoing traffic sections

- Incoming Traffic Section 3: the point of entrance to the roundabout for vehicles coming from Via Fiorentina, internal lane;
- Incoming Traffic Section 4: the point of entrance to the roundabout for vehicles coming from Via Fiorentina, external lane.

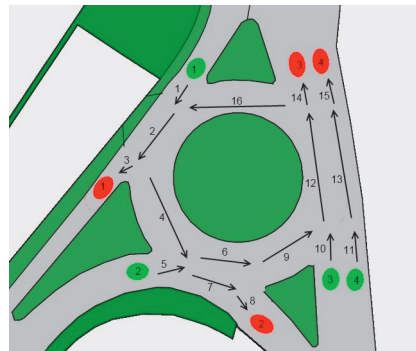
The outgoing traffic sections are:

- Outgoing Traffic Section 1: exit from the roundabout into Via Delle Province;
- Outgoing Traffic Section 2: exit from the roundabout into Via Fiorentina;
- Outgoing Traffic Section 3: exit from the roundabout into Road Intersection 2;
- Outgoing Traffic Section 4: exit from the roundabout into the Chiantigiana national road, the Stellino side, towards Roundabout 1.

Figure 7 shows the internal sections of the roundabout.



**Figure 6.** Roundabout 2 with incoming, internal and outgoing traffic sections



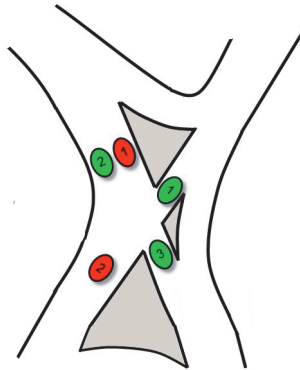
**Figure 7.** Roundabout 2 with incoming, internal and outgoing traffic sections

Internal sections are indicated by arrows and can have different lengths. These sections identify internal roundabout portions that may contain at the same time a number of vehicles that vary based on the section length. The object of the library that describes the internal sections of a road intersection is the Internal Section object. If the road intersection is a roundabout, the capacity of

the internal section may vary, and its value is shown as an item of data in the record containing the section data inside the Model.dat file.

### **3.3. Road Intersections**

Figure 8 shows that Road Intersection 2 has 3 incoming traffic sections and 2 outgoing traffic sections. The incoming traffic sections are:



**Figure 8.** Road intersection 2 with incoming and outgoing traffic sections

- Incoming Traffic Section 1: the point of entrance for vehicles from Roundabout 1 that have travelled through the Chiantigiana national road, the Stellino side;
- Incoming Traffic Section 2: the point of entrance for vehicles from Via Cassia Nord;
- Incoming Traffic Section 3: the point of entrance for vehicles coming from Roundabout 2 and going towards Via Cassia Nord.

The outgoing traffic sections are:

- Outgoing Traffic Section 1: exit towards Via Cassia Nord;
- Outgoing Traffic Section 2: exit towards Roundabout 2.

Figures 9–14 show the possible paths for crossing Road Intersection 2, based on the vehicle incoming section.

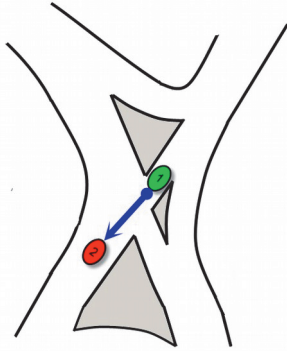
Figure 15 shows Road Intersection 4. This road intersection has 2 incoming traffic sections and 1 outgoing traffic section.

The incoming traffic sections are:

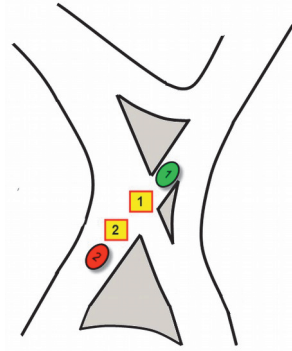
- Incoming Traffic Section 1: the point of entrance for vehicles that have left Roundabout 1, gone through the Chiantigiana national road, the Stellino side, and are now travelling towards Via Cassia Nord;
- Incoming Traffic Section 2: the point of entrance for vehicles that have left Road Intersection 2 and are now travelling towards Via Cassia Nord.

The outgoing traffic section is:

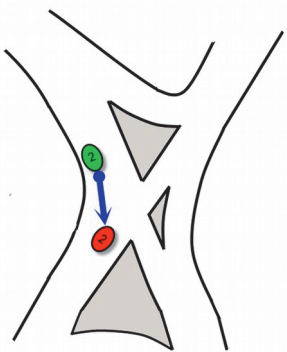
- Outgoing Traffic Section 1: this exit takes vehicle flows to Via Cassia Nord.



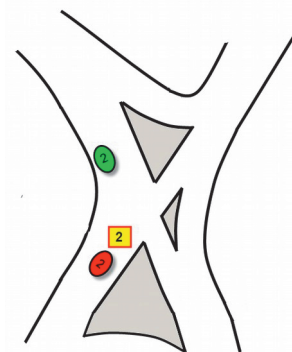
**Figure 9.** Path followed by a vehicle travelling from incoming traffic section 1



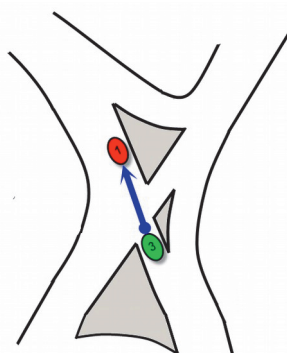
**Figure 10.** Internal sections crossed by a vehicle travelling from incoming traffic section 1



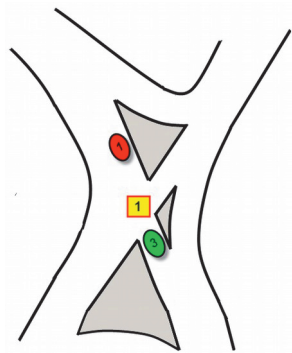
**Figure 11.** Path followed by a vehicle travelling from incoming traffic section 2



**Figure 12.** Internal sections crossed by a vehicle travelling from incoming traffic section 2



**Figure 13.** Path followed by a vehicle travelling from incoming traffic section 3



**Figure 14.** Internal sections crossed by a vehicle travelling from incoming traffic section 3



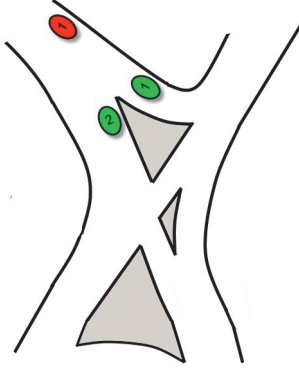


Figure 15. Road intersection 4 with incoming and outgoing traffic sections

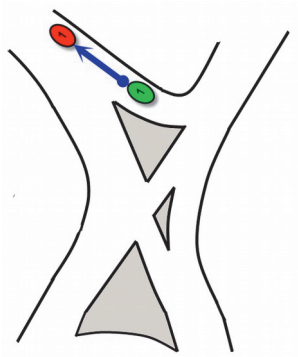


Figure 16. The route that can be followed from incoming traffic section 1

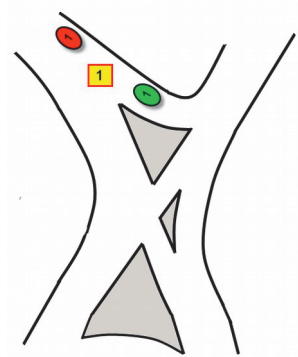


Figure 17. Road intersection 4 internal sections

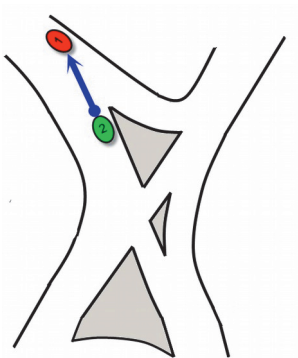


Figure 18. The route that can be followed from incoming traffic section 2

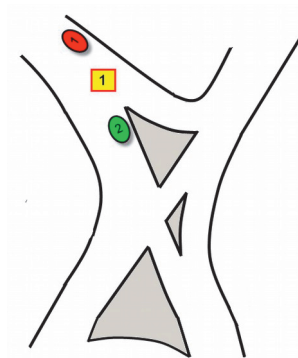


Figure 19. Road intersection 4 incoming section 2 internal sections

The crossing paths of Road Intersection 4 are shown in Figures 16–19, together with the road intersection internal sections.

### 4. New system with three roundabouts

The following section outlines a system with three roundabouts devised by the Municipality Office of the City of Siena, Italy, to improve circulation in the Siena North area. The purpose of this new system is to remove Road Intersections 2 and 4 from the current system, which cause significant traffic congestions, introduce a new roundabout and remove Internal Roads 6 and 7 from the current system shown in Figure 3. In our system, Roads 6 and 7 represent the Chiantigiana national road, the Stellino side, the direct link between Roundabout 1 and Roundabout 2.

The new system will therefore consist of three road intersections, which are roundabouts, and two new roads that link them together, as shown in more details in Figure 20:

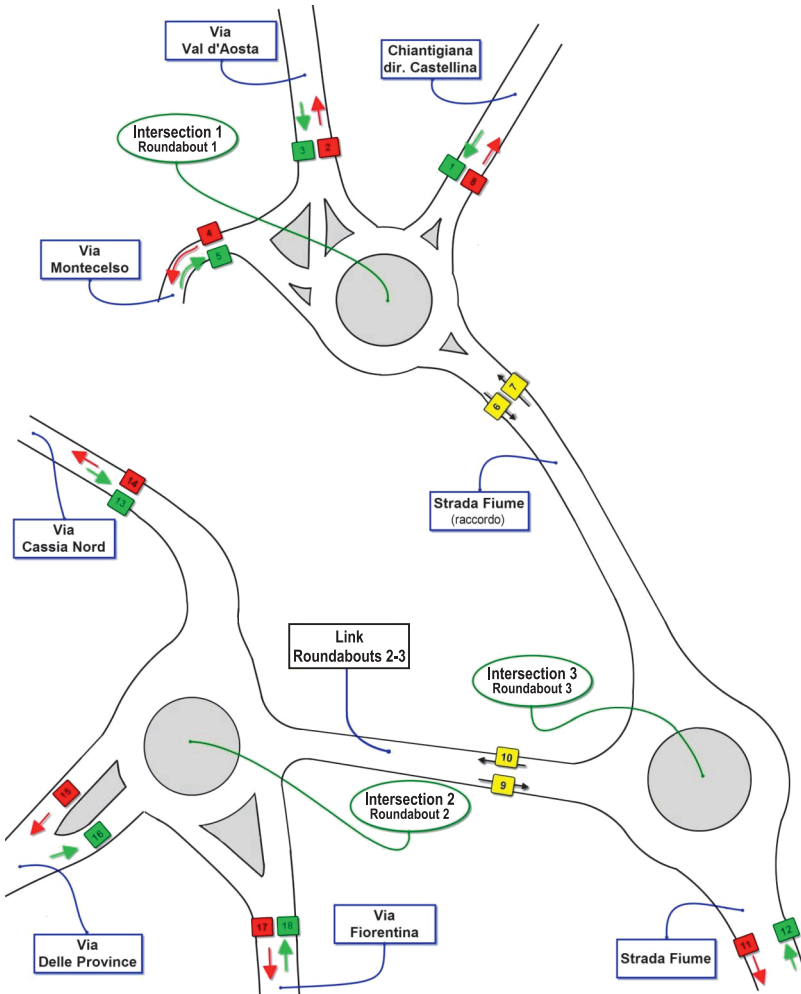


Figure 20. New system with three roundabouts

- Road Intersection 1: the northernmost roundabout, Roundabout 1.
- Road Intersection 2: the southernmost roundabout, Roundabout 2.
- Road Intersection 3: this is the new roundabout, Roundabout 3; in the new CDP project, this roundabout is along Strada Fiume, indicatively at the same level as Roundabout 2, but further eastwards.
- Strada Fiume link: this is the portion of Strada Fiume between Roundabout 1 and Roundabout 3.
- Roundabout 2 – Roundabout 3 link: according to the new CDP, this is the link road between Roundabout 2 and Roundabout 3.

The model in Figure 20 shows the numbering used for the roads: this road numbering will be maintained in the model.dat file that describes the model of the system analyzed, and which constitutes the input for the BuildMod procedure to generate the simulator. Also, in this model, two-way roads are represented as separate roads, one for each travel direction.

Figure 20 shows in red the system outgoing traffic roads (the roads that take vehicles out of the simulation); the incoming traffic roads are in green (the roads that take vehicles into the system, which are generated by a vehicle source in the simulation), while internal system roads are in yellow. In summary, the road system discussed consists of 18 roads split as follows:

- 7 for the incoming traffic, identified with the following numbers: 1, 3, 5, 12, 13, 16, 18;
- 7 for the outgoing traffic, identified with the following numbers: 2, 4, 8, 11, 14, 15, 17;
- 4 internal, identified with the following numbers: 6, 7, 9, 10.

## 5. Road intersections in the modified system

The modified system in Figure 20 shows three road intersections, which are roundabouts. Also, in this case we show the modeling of each individual roundabout, with a graphic description of the model sections. In the images, the incoming traffic sections are shown in green, and indicate the points of entrance to the roundabout; each incoming traffic section corresponds to an InpSec object in our library [2]. The outgoing traffic sections are marked in red and indicate the exit points from the roundabout. Each of them is an OutSec object from our library. Internal sections are represented with black arrows and indicate the portions of the roundabout on which vehicles travel while crossing it. Each internal section is a utilization of an IntSec object from our library. The data regarding each section of the road intersection is saved in Model.dat file.

### 5.1. Roundabout 1

Figure 21 shows Roundabout 1 with 4 incoming traffic and 4 outgoing traffic sections based on the new City Development Plan with the new system with three roundabouts.

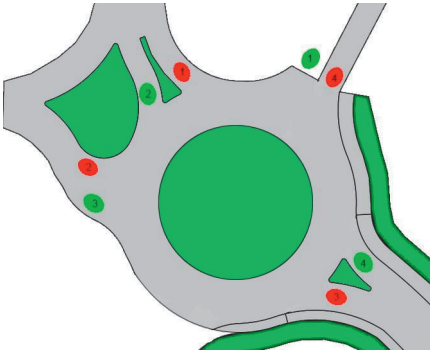
The incoming traffic sections are:

- Incoming Traffic Section 1: the point of entrance to the roundabout for vehicles coming from the Chiantigiana national road, Castellina in the Chianti side;
- Incoming Traffic Section 2: the point of entrance to the roundabout for vehicles coming from Via Valle D'Aosta;
- Incoming Traffic Section 3: the point of entrance to the roundabout for vehicles coming from Via Montecelso;
- Incoming Traffic Section 4: the point of entrance to the roundabout for vehicles coming from the Strada Fiume segment linking with Roundabout 3.

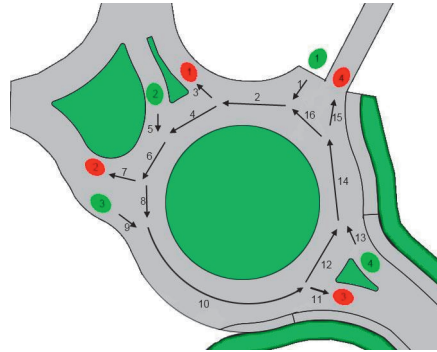
The outgoing traffic sections are:

- Outgoing Traffic Section 1: exit towards Via Valle d'Aosta;
- Outgoing Traffic Section 2: exit towards Via Montecelso;
- Outgoing Traffic Section 3: exit towards the road link to Roundabout 3;
- Outgoing Traffic Section 4: exit towards the Chiantigiana national road, Castellina in the Chianti side.

Figure 22 represents the disposition of the internal sections in line with the new configuration of Roundabout 1.



**Figure 21.** Roundabout 1 with incoming and outgoing traffic sections



**Figure 22.** Roundabout 1 with incoming, internal and outgoing traffic sections

## 5.2. Roundabout 2

Figure 23 shows the first stage of the procedure for the modeling of Roundabout 2, with identification of 4 incoming traffic and 4 outgoing traffic sections.

The incoming traffic sections are:

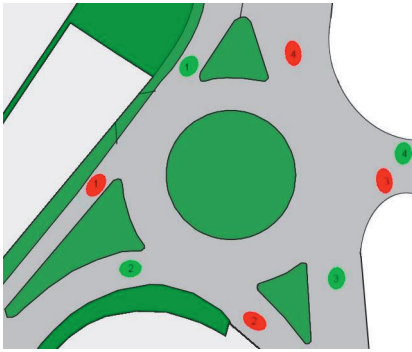
- Incoming Traffic Section 1: the point of entrance to the roundabout for vehicles coming from Via Cassia Nord;
- Incoming Traffic Section 2: the point of entrance to the roundabout for vehicles coming from Via Delle Province;
- Incoming Traffic Section 3: the point of entrance to the roundabout for vehicles coming from Via Fiorentina;

- Incoming Traffic Section 4: the point of entrance to the roundabout for vehicles coming from the link road with Roundabout 3.

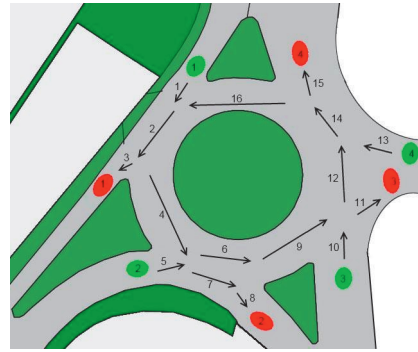
The outgoing traffic sections are:

- Outgoing Traffic Section 1: exit towards Via Delle Province;
- Outgoing Traffic Section 2: exit towards Via Fiorentina;
- Outgoing Traffic Section 3: exit towards the road link to Roundabout 3;
- Outgoing Traffic Section 4: exit towards Via Cassia Nord.

Also, in this case, the internal sections of the roundabout have been redesigned to reproduce the vehicle flows in a manner consistent with the new roundabout structure. The internal sections of Roundabout 2 are shown in Figure 24. It can be seen that the incoming traffic section from Via Fiorentina has become narrower than in the current situation. As shown in the map of the new CDP (Figure 2), the point of entry is reduced to one single lane, while in the current system it consists of two parallel lanes.



**Figure 23.** Roundabout 2 with incoming and outgoing traffic sections



**Figure 24.** Roundabout 2 with incoming, internal and outgoing traffic sections

### 5.3. Roundabout 3

Figure 25 shows the first stage of modeling of the new roundabout contemplated by the new CDP, located along Strada Fiume. The model has 3 incoming traffic sections and 3 outgoing traffic sections.

The incoming traffic sections are:

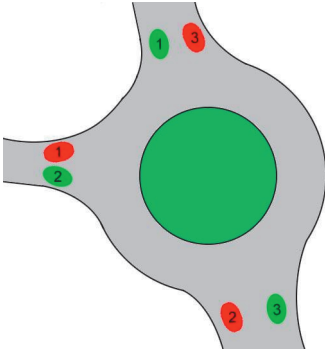
- Incoming Traffic Section 1: the point of entrance for vehicles from Roundabout 1;
- Incoming Traffic Section 2: the point of entrance for vehicles coming from the link road with Roundabout 2;
- Incoming Traffic Section 3: the point of entrance for vehicles coming from the Strada Fiume extension.

The outgoing traffic sections are:

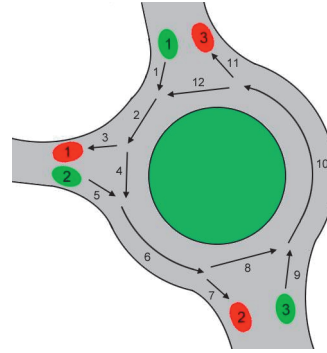
- Outgoing Traffic Section 1: exit towards the road link with Roundabout 2;
- Outgoing Traffic Section 2: exit towards the Strada Fiume extension;

- **Outgoing Traffic Section 3:** exit towards the road link with Roundabout 1.

Figure 26 shows the modeling of Roundabout 3, with the roundabout internal sections. These sections are in line with the map of the new City Development Plan.



**Figure 25.** Roundabout 3 with incoming and outgoing traffic sections



**Figure 26.** Roundabout 3 with incoming, internal and outgoing traffic sections

## 6. Traffic flow data

The Municipality Office of the City of Siena has provided the table showing the vehicle traffic flow data for the current system as shown in Figure 1. The measurements are for the incoming and outgoing traffic points of the two roundabouts of the Siena North traffic system. The detectors measured the numbers of incoming and outgoing vehicles for each 10-minute time interval during the three critical traffic congestion time bands.

The three-time bands are:

- 07:30 to 09:20
- 12:00 to 13:50
- 17:30 to 19:20

Table 1 shows the traffic flows for the current system.

As far as the modified system with three roundabouts is considered, we have no data regarding the incoming and outgoing traffic flows for the three roundabouts, as this is a new project of the new City Development Plan that has not been implemented yet. Therefore, we have created a table showing the number of incoming and outgoing vehicles for the three roundabouts based on the data collected for the current system and the routing limitations with which the vehicle flows will have to comply in the new system architecture. In particular, in the new City Development Plan, the direct link between Roundabout 1 and Roundabout 2 consisting of the Stellino side Chiantigiana road has been removed. Based on the characterization the vehicle flows in the system by origin and destination, we can say that we will have the following conditions at the points of entrance and exit of the three roundabouts contemplated by the draft new City Development Plan:

Table 1. The traffic flows for the current system

street name	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			
	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		
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	7	107	12	122	11	74	6	103	8	112	8	113	12				
Montecelso	5	2	2	3	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
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		

street name	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	
	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
SS Chiantigiana (Stellino)	120	115	128	128	136	141	120	143	127	143	113	89	141	130	172	155	162	162	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
SS Chiantigiana (Stellino)	115	120	128	128	141	136	143	120	143	127	89	113	130	141	155	172	162	162	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

- Roundabout 1:
  1. Strada Fiume (link with Roundabout 3): the number of entrances and exits are obtained respectively as the sums of the corresponding values of Via Fiume and Via Chiantigiana, the Stellino side in the Current System.
  2. As far as Via Chiantigiana, Castellina side, Via Valle D'Aosta and Via Montecelso are considered, the entrance and exit data is unchanged when compared with the Current System.
- Roundabout 2:
  1. Link road between Roundabout 2 and Roundabout 3: the numbers of entrances and exits are respectively equal to the number of exits from and entrances to Via Chiantigiana, the Stellino side in the Current System.
  2. As far as Via Fiorentina, Via Delle Province and Via Cassia Nord are considered, the entrance and exit data is unchanged when compared with the current system.
- Roundabout 3:
  1. Strada Fiume (link with Roundabout 1): the numbers of entrances and exits are equal to the numbers of exits from and entrances to Strada Fiume (link) contemplated for Roundabout 1, respectively.
  2. Link road between Roundabout 2 and Roundabout 3: the numbers of entrances and exits are equal to the numbers of entrance to and exits from Via Chiantigiana, the Stellino side in the Current System, respectively.
  3. Strada Fiume (extension): the numbers entrances and exits are equal to the number of entrances to and exits from of Strada Fiume in the Current System, respectively.

The traffic data table for the model modified following the new City Development Plan is shown in Table 2. The data in the table refers to the number of vehicle entrances and exits during the 10-minute intervals of the three-time bands considered. In the table, the data is listed on the basis of individual roads, which are grouped based on the roundabout of reference.

## 7. System modeling

The modeling of the two vehicle traffic systems for which we wish to create simulators is based on the use of an object from the library introduced in [1, 2]. This activity is directly carried out on the map showing the vehicle traffic system in a sufficiently detailed graphic scale to allow the introduction of all instances of library objects utilization required for modeling the analyzed system.

In the previous sections, we have outlined the procedure for graphic modeling of road intersections of the two compared traffic systems.

Each utilization of a library object required for modeling a system is characterized by specific values of the object library internal parameters. Therefore, the collection of the data describing the traffic system model consists in creating a data record for each utilization of a library object that appears in the traffic



**Table 2.** Traffic data table for the model modified following the new Town Development Plan

street name	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		
	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	
Strada Fiume – Raccordo	133	205	155	200	208	206	251	247	170	204	203	220	174	188	203	193	184	181	195	205	166	160	187	185	230	196	217	177	195	175	188	191	223	212	156	163	
SS Chiantigiana (Castellina)	48	130	69	157	77	170	77	159	76	173	83	191	67	182	75	180	60	199	58	197	62	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	
Montecello	5	2	2	3	2	3	2	3	9	5	18	2	16	3	23	2	12	2	9	1	9	3	5	9	1	17	4	10	4	10	6	9	7	11	3	14	2
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 Province	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	
Roundabout 2-3 link	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	
Roundabout 1-3 link	205	133	200	155	206	208	247	251	204	170	220	203	188	174	193	203	181	184	205	195	160	166	185	187	196	230	177	217	175	195	191	188	212	223	163	156	
Roundabout 2-3 link	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	
Proseccione 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	

street name	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	
	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
Strada Fiume – Raccordo	204	171	216	176	216	209	209	211	198	190	185	152	243	209	297	240	314	257	267	240	306	228	240	219	262	198	251	233	267	257	244	228	217	245	217	245
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	75	190
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	97	12
Montecello	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	1	5
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	125	112
Via Delle Province	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	67	52
Via Cassia Nord	85	83	75	100	55	120	62	120	58	105	48	85	96	76	90	95	80	80	93	82	75	80	90	81	95	73	94	120	78	90	75	120	85	100	85	100
Roundabout 2-3 link	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	158	127
Roundabout 1-3 link	171	204	176	216	209	216	211	209	190	198	152	185	209	243	240	207	257	314	240	267	228	306	219	240	198	262	233	251	237	267	228	244	245	217	245	217
Roundabout 2-3 link	120	115	128	128	136	141	120	143	127	143	113	80	141	130	172	155	162	162	167	167	176	153	130	147	162	142	158	167	175	182	157	143	127	158	127	158
Proseccione 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	90	87

system model. These data records are listed in the Model.dat file associated to the model based on a specific structure.

Model.dat is a text file split into sections, where the data records are grouped according to the object type of and are listed following the order of identification of object utilization in the model. In particular, we can identify the following data sections that appear in a model.dat file associated with a vehicle traffic system:

- Section of the model general data;
- Section of the roads included in the model;
- Section of the system incoming traffic flows;
- Section of the intersection Multiplexer devices found in the system;
- Section of the road Multiplexer devices found in the system;
- One section for each intersection in the system, containing the following subsections:
  1. General intersection data;
  2. Intersection internal section data;
  3. Intersection incoming traffic section data;
  4. Intersection outgoing traffic section data;
  5. Intersection crossing path data.

The two following sections outline the structure of the Model.dat file associated with the Siena North traffic system in its current configuration with two roundabouts, and the structure of the Model.dat file associated with the modified system, characterized by three roundabouts.

### ***7.1. The Model.dat file for the current system***

This section contains a description of the model.dat file generated by our procedure for modeling the traffic system with two roundabouts described in Sections 2 and 3. The provided data refers to the vehicle flows detected in the system in the 07:30–09:00 time band.

The first section of the model.dat file contains general system data. This section consists of a single data record set. The number of road intersections, the number of roads, the number of road intersection multiplexers, the number of flows and the number of road multiplexers making up the system model are listed in the record set in the stated order. The same record set shows the number of consecutive 10-minute intervals considered and the simulation start time.

#### **Section 1:**

```
&No._Intersections Roads MP Flows MP_Road NO_INTERVALS START_TIME;
4 21 13 7 1 9 7.30;
```

The data contained in Section 1 of the Model.dat file indicates that the model includes 4 road intersections, 21 roads, 13 road intersection multiplexers, 1 road multiplexer, 7 incoming traffic flows.

Section 2 lists records regarding the roads in the model. The first data of each record is the integer number identifying the road. This is followed in this order by: a binary flag specifying if the road in question is outgoing, value 1, or incoming, value 0; the length of the road, in km; the number of vehicles incoming to the road in 9 10-minute intervals of the time band considered; the number of outgoing vehicles with the same intervals; a binary flag determining if the road is connected to a multiplexer or a road multiplexer, a string identifying the name of the road in a real system.

**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 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 1 2 1 1 0 0 2 0 5 'Via_Aosta';
3 0 0.3 163 180 149 135 130 137 150 135 155 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 2 3 3 5 2 3 2 2 1 'Via_Montecelso';
5 0 0.3 5 2 2 9 18 16 23 12 9 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 0 103 97 106 116 76 113 98 98 96 0 1
'Via_Chiantigiana_Stellino';
7 0 0.15 87 127 172 196 125 150 131 145 146 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 0 102 103 100 131 128 107 90 95 85 'Via_Fiume';
9 0 0.3 46 28 36 55 45 53 43 58 38 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 0 130 157 170 159 173 191 182 180 199
'Via_Chiantigiana_Castellina';
11 0 0.024 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 12 'VIA11';
12 0 0.02 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 6 'VIA12';
13 0 0.3 45 120 115 155 120 130 120 130 115 0 0 0 0 0 0 0 0 0 1 7
'Via_Cassia_Nord';
14 0 0.018 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 9 'VIA14';
15 1 0.1 0 0 0 0 0 0 0 0 0 44 56 64 81 80 76 67 102 80
'Via_delle_Provincie';
16 1 0.1 0 0 0 0 0 0 0 0 0 40 80 115 100 92 74 61 72 90 'Via_Fiorentina';
17 0 0.3 48 65 97 103 71 84 44 91 80 0 0 0 0 0 0 0 0 0 1 10
'Via_delle_Provincie';
18 0 0.3 35 56 86 65 95 71 88 115 145 0 0 0 0 0 0 0 0 0 1 11
'Via_Fiorentina';
19 0 0.018 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 8 'VIA19';
20 0 0.022 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 13 'VIA20';
21 1 0.1 0 0 0 0 0 0 0 0 0 25 38 80 80 78 73 65 90 63 'Via_Cassia_Nord';
```

The data sections listed at the beginning of the Section follow in succession in the Model.dat file. In a previous work [1] we described the Model.dat file creation using the Current System as an example. However, in that case the model referred only to one single 10-minute interval, making the amount of data for each record much lower.

To make things simpler, we will not show here the other data sections found in the Model.dat file for the Current System, for which reference can be made to [1], where the description regarding the case with one single 10-minute time interval was discussed in details.

## 7.2. Model.dat file for the model with three roundabouts

In this Section we show the Model.dat file sections describing the model with three roundabouts contemplated by the new City Development Plan. Section 1 of the general data tells us that the model is designed for a three-intersection system with 18 roads, 7 incoming vehicle flows from the outside.

### Section 1:

```
&No_Intersections Roads MP Flows MP_Road NO_INTERVALS START_TIME;
3 18 11 7 0 9 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 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 1 2 1 1 0 0 2 0 5 'Via_Valle_D'Aosta';
3 0 0.3 163 180 149 135 130 137 150 135 155 0 0 0 0 0 0 0 0 0 1 2
'Via_Valle_D'Aosta';
4 1 0.1 0 0 0 0 0 0 0 0 0 2 3 3 5 2 3 2 2 1 'Via_Montecelso';
5 0 0.3 5 2 2 9 18 16 23 12 9 0 0 0 0 0 0 0 0 0 1 3 'Via_Montecelso';
6 0 0.138 0 0 0 0 0 0 0 0 205 200 206 247 204 220 188 193 181 1 5 'VIA6';
7 0 0.138 133 155 208 251 170 203 174 203 184 0 0 0 0 0 0 0 0 0 1 4 'VIA7';
8 1 0.1 0 0 0 0 0 0 0 0 130 157 170 159 173 191 182 180 199
'Via_Chiantigiana_Castellina';
9 0 0.121 87 127 172 196 125 150 131 145 146 0 0 0 0 0 0 0 0 0 1 6 'VIA9';
10 0 0.121 0 0 0 0 0 0 0 0 103 97 106 116 76 113 98 98 96 1 8 'VIA10';
11 1 0.1 0 0 0 0 0 0 0 0 102 103 100 131 128 107 90 95 85 'Via_Fiume';
12 0 0.4 46 28 36 55 45 53 43 58 38 0 0 0 0 0 0 0 0 0 1 7 'Via_Fiume';
13 0 0.3 45 120 115 155 120 130 120 130 115 0 0 0 0 0 0 0 0 0 1 9
'Via_Cassia_Nord';
14 1 0.1 0 0 0 0 0 0 0 0 25 38 80 80 78 73 65 90 63 'Via_Cassia_Nord';
15 1 0.1 0 0 0 0 0 0 0 0 44 56 64 81 80 76 67 102 80
'Via_delle_Provincie';
16 0 0.3 48 65 97 103 71 84 44 91 80 0 0 0 0 0 0 0 0 0 1 10
'Via_delle_Provincie';
17 1 0.1 0 0 0 0 0 0 0 0 40 80 115 100 92 74 61 72 90 'Via_Fiorentina';
18 0 0.3 35 56 86 65 95 71 88 115 145 0 0 0 0 0 0 0 0 0 1 11
'Via_Fiorentina';
```

### Section 3:

```
&ID_FLOW TIME_ROUTING TIME_ROUTING TIME_ROUTING TIME_ROUTING 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 1;
2 3.68 3.33 4.03 4.44 4.62 4.38 4 4.44 3.87 3;
3 120 300 300 66.67 33.33 37.5 26.09 50 66.67 5;
4 13.04 21.43 16.67 10.91 13.33 11.32 13.95 10.34 15.79 12;
5 13.33 5 5.22 3.87 5 4.62 5 4.62 5.22 13;
6 12.5 9.23 6.19 5.83 8.45 7.14 13.64 6.59 7.5 16;
7 17.14 10.71 6.98 9.23 6.32 8.45 6.82 5.22 4.14 18;
```

### Section 4:

```
&ID_MULTIPLEXER IN_SEC_NO INT_NO IN_SEC PROB_1;
1 1 1 1 1;
2 1 1 2 1;
```

```

3 1 1 3 1;
4 1 1 4 1;
5 1 3 1 1;
6 1 3 2 1;
7 1 3 3 1;
8 1 2 4 1;
9 1 2 1 1;
10 1 2 2 1;
11 1 2 3 1;

```

### Section 5: Roundabout 1 data

```

&ID_INT NO_LIGHTS IN_SEC INTER_SEC OUT_SEC PATH LIGHT ROUNDABOUT;
1 0 4 16 4 11 0 1;

```

```

&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 6 10;
11 1 1;
12 1.8 3;
13 1 1;
14 2.4 4;
15 1 1;
16 2.4 4;

```

```

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

```

```

&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;

```

```

&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 5 5 5 6 10 8 10 10 10 11 10 2 3;
5 7 5 5 6 10 8 10 10 10 12 10 14 10 15 10 2 4;
6 3 9 5 10 10 11 10 3 3;
7 5 9 5 10 10 12 10 14 10 15 10 3 4;
8 7 9 5 10 10 12 10 14 10 16 10 2 10 3 10 3 1;
9 3 13 5 14 10 15 10 4 4;
10 5 13 5 14 10 16 10 2 10 3 10 4 1;
11 7 13 5 14 10 16 10 2 10 4 10 6 10 7 10 4 2;

```

```

&ID_INPUT_SEC ID_PATH1 PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8
PROB_9 ID_PATH2
PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8 PROB_9 ID_PATH3 PROB_1
PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8 PROB_9;
1;
1 0.4808 0.9756 0.4762 0.3953 0 0 1.0417 0 2.6738;
2 0.9615 1.4634 1.4286 1.9763 0.9709 1.3453 1.0417 1.0256 0.5348;
3 98.5577 97.561 98.0952 97.6285 99.0291 98.6547 97.9167 98.9744 96.7914;
2;
4 61.194 56.0224 54.7872 60.8374 54.1114 53.528 50.8108 51.7426 47.6316;
5 38.806 43.9776 45.2128 39.1626 45.8886 46.472 49.1892 48.2574 52.3684;
3;
6 61.0119 55.7103 54.6419 60.688 54.1114 53.528 50.5376 51.7426 47.013;
7 38.6905 43.7326 45.0928 39.0663 45.8886 46.472 48.9247 48.2574 51.6883;
8 0.2976 0.5571 0.2653 0.2457 0 0 0.5376 0 1.2987;
4;
9 97.7444 96.9136 97.7011 96.3636 98.8571 98.4536 97.8495 98.9011 97.0732;
10 0.7519 1.2346 0.5747 0.6061 0 0 1.0753 0 2.439;
11 1.5038 1.8519 1.7241 3.0303 1.1429 1.5464 1.0753 1.0989 0.4878;

```

**Section 6: Roundabout 2 data**

```

&ID_INT NO_LIGHTS IN_SEC INTER_SEC OUT_SEC PATH LIGHT ROUNDABOUT;
2 0 4 16 4 12 0 1;

```

```

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

```

```

&ID_IN_SEC NO_PATHS TIME_SERV INTERSECTION ;
1 3 1.2 1 2;
2 3 2.4 1 4;
3 3 2 1 5;
4 3 1.8 1 3;

```

```

&ID_OUT_SEC TIME_SERV IN_SEC_LINK LINK_ROAD_OUT ;
1 1 3 15;
2 1 7 17;
3 1 11 9;
4 1 15 14;

```

```

&ID_PATH PATH_LENGTH S_1 P_1 S_2 P_2 S_3 P_3 S_4 P_4 S_5 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 7 10 8 10 1 2;

```

3 6 1 5 2 10 4 10 6 10 9 10 11 10 1 3;  
 4 3 5 5 7 10 8 10 2 2;  
 5 4 5 5 6 10 9 10 11 10 2 3;  
 6 6 5 5 6 10 9 10 12 10 14 10 15 10 2 4;  
 7 2 10 5 11 10 3 3;  
 8 4 10 5 12 10 14 10 15 10 3 4;  
 9 6 10 5 12 10 14 10 16 10 2 10 3 10 3 1;  
 10 3 13 5 14 10 15 10 4 4;  
 11 5 13 5 14 10 16 10 2 10 3 10 4 1;  
 12 7 13 5 14 10 16 10 2 10 4 10 7 10 8 10 4 2;

```
&ID_INPUT_SEC ID_PATH1 PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8
PROB_9 ID_PATH2
PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8 PROB_9 ID_PATH3 PROB_1
PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8 PROB_9;
1;
1 25.731 21.2928 18.2336 21.4854 26.936 25.3333 25.8687 31.9749 25.3165;
2 23.3918 30.4183 32.7635 26.5252 30.9764 24.6667 23.5521 22.5705 28.481;
3 50.8772 48.289 49.0028 51.9894 42.0875 50 50.5792 45.4545 46.2025;
2;
4 26.3158 32.6531 31.3351 26.5957 31.1864 24.9158 23.7354 23.4528 30.1003;
5 57.2368 51.8367 46.8665 52.1277 42.3729 50.5051 50.9728 47.2313 48.8294;
6 16.4474 15.5102 21.7984 21.2766 26.4407 24.5791 25.2918 29.316 21.0702;
3;
7 55.7692 57.4661 54.4304 54.902 44.1696 50.1672 49.8099 43.0267 50.519;
8 16.0256 17.1946 25.3165 22.409 27.5618 24.4147 24.7148 26.7062 21.7993;
9 28.2051 25.3394 20.2532 22.6891 28.2686 25.4181 25.4753 30.2671 27.6817;
4;
10 22.9358 21.8391 30.888 30.6513 31.2 32.7354 33.6788 34.0909 27.0386;
11 40.367 32.1839 24.7104 31.0345 32 34.0807 34.715 38.6364 34.3348;
12 36.6972 45.977 44.4015 38.3142 36.8 33.1839 31.6062 27.2727 38.6266;
```

### Section 7: Roundabout 3 data

```
&ID_INT NO_LIGHTS IN_SEC INTER_SEC OUT_SEC PATH LIGHT ROUNDABOUT;
3 0 3 12 3 6 0 1;
```

```
&ID_INTER_SEC TIME_SERVICE NO_VEHICLES ;
1 1 1;
2 1.8 3;
3 1 1;
4 1.2 2;
5 1 1;
6 3.6 6;
7 1 1;
8 1.8 3;
9 1 1;
10 6 10;
11 1 1;
12 1.2 2;
```

```
&ID_IN_SEC NO_PATHS TIME_SERV INTERSECTION ;
1 2 1.2 1 2;
2 2 1.8 1 3;
3 2 1.2 1 2;
```

```
&ID_OUT_SEC TIME_SERV IN_SEC_LINK LINK_ROAD_OUT ;
1 1 3 10;
2 1 7 11;
```

```

3 1 11 7;

&ID_PATH PATH_LENGTH S_1 P_1 S_2 P_2 S_3 P_3 S_4 P_4 S_5 P_5
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 3 5 5 6 10 7 10 2 2;
4 5 5 5 6 10 8 10 10 11 10 2 3;
5 3 9 5 10 10 11 10 3 3;
6 5 9 5 10 10 12 10 2 10 3 10 3 1;

&ID_INPUT_SEC ID_PATH1 PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8
PROB_9 ID_PATH2
PROB_1 PROB_2 PROB_3 PROB_4 PROB_5 PROB_6 PROB_7 PROB_8 PROB_9;
1;
1 50.2439 48.5 51.4563 46.9636 37.2549 51.3636 52.1277 50.7772 53.0387;
2 49.7561 51.5 48.5437 53.0364 62.7451 48.6364 47.8723 49.2228 46.9613;
2;
3 43.4043 39.9225 32.4675 34.2932 42.953 34.5161 34.0909 31.8792 31.5985;
4 56.5957 60.0775 67.5325 65.7068 57.047 65.4839 65.9091 68.1208 68.4015;
3;
5 56.3559 61.5079 66.242 68.3924 69.1057 64.2405 63.9706 67.4419 65.7143;
6 43.6441 38.4921 33.758 31.6076 30.8943 35.7595 36.0294 32.5581 34.2857;

```

## 8. Comparison of the two systems

In this Section, we analyze the congestion levels for the two vehicular traffic systems during the time bands considered. The behavior of the two models is compared by analyzing the results traced by the simulators of the two systems. The procedures for tracing the evolution of the traffic in the system during the simulation have been written in the QNAP2 [3] programming language and will be the subject of a future publication. These procedures are periodically executed during a simulation run. They record, in some dedicated text files, the number of vehicles found inside various devices of our model.

After the simulation, a specific application analyzes the content of the files written by the tracing procedure and graphically detects the existence of congestion events that can occur within the system. These events are determined by the occurrence of queues due to the exceeding of the acceptance capabilities of the model internal devices. For this purpose, we analyze and describe the queues identified in the simulations of the two traffic systems. The time bands with the most traffic during the whole day are the following: 07:30–09:00, 12:00–13:30, 17:50–19:20. We compared the two models in an attempt to identify the different traffic behaviors during the same time band, which will be described in details.

### *Time band 07:30–09:00*

For this time band, we can say that no significant congestion events occurred in any of the models. No queue of any type built up in the model with three roundabouts. Some queues formed in the model relating to the Current System, starting from 08:00 and until 08:55. We noted that Section 13 of Roundabout 1, meaning the Chiantigiana national road section on the Stellino side linking



Roundabout 2 to Roundabout 1, was the critical point of the system as regards the congestion issues. There are in fact six different times with queues for this section.

• 8:01

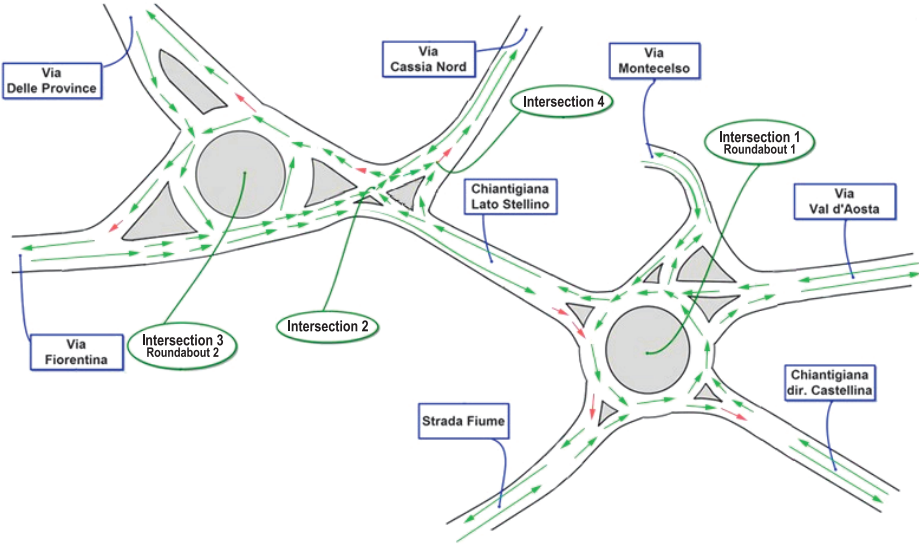


Figure 27. Model with two roundabouts – 08:01

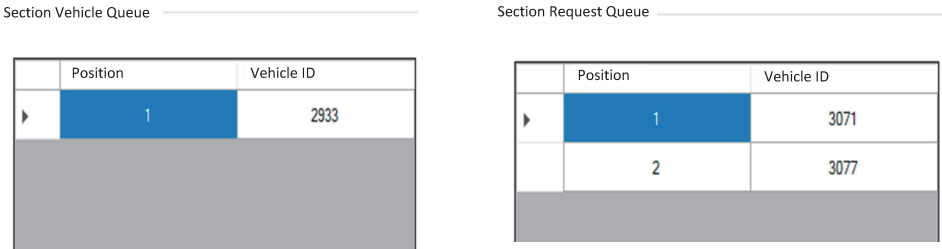


Figure 28. Queue at the point of entrance to Section 13 of Roundabout 1

Queue at the point of entrance to Section 13 of Roundabout 1, meaning the first internal section of Roundabout 1, involving vehicles coming from the Chiantigiana national road, the Stellino side. In this case, the section has the capacity to contain one vehicle, but the queue of the requests for entrance to the section contains two requests as shown in the Tables 1–2.

• 8:10

In this case, there are two traffic slowdowns on the same Roundabout. The two tables in Figure 31 relate in fact to the slowdown indicated by the two red arrows at the entrance to Roundabout 1 of the Chiantigiana national road, the

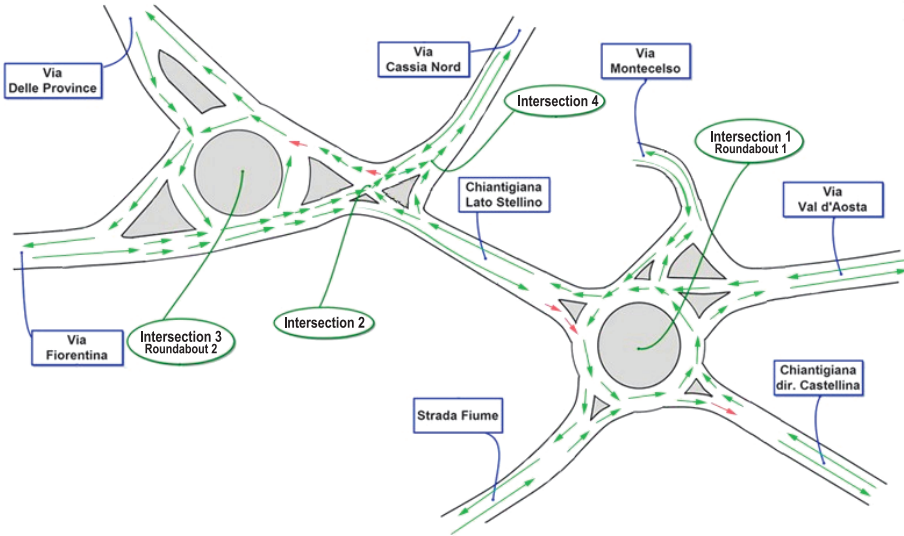


Figure 29. Model with two roundabouts – 08:10

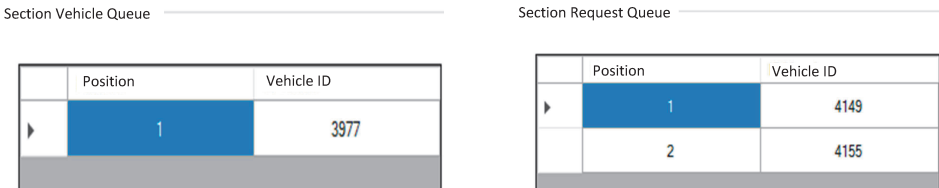


Figure 30. Status of exit 5 in Roundabout 1

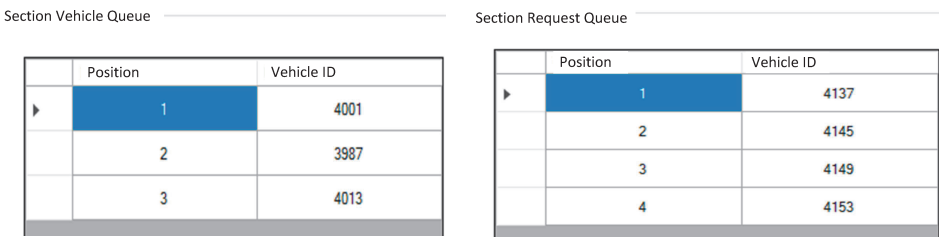


Figure 31. Status of input section 4 in Roundabout 1

Stellino side, with three queuing vehicles. Moreover, there is a queue of one vehicle at the point of exit from the roundabout towards the Chiantigiana national road, the Castellina in Chianti side, see Figure 30.

- 8:18. Roundabout 2, Exit 4 (exit from the roundabout Entering the Chiantigiana national road, the Stellino side, going towards Roundabout 1): one queuing vehicle.
- 08:21. Roundabout 1 Section 13: one queuing vehicle.

- 08:29. Roundabout 1 Section 13: one queuing vehicle.
- 08:35. Roundabout 2 Exit 4: one queuing vehicle.
- 08:37. Intersection 2 Exit 2 (vehicles that travel towards Roundabout 2 from Cassia Nord): one queuing vehicle.
- 08:40. Intersection 2 Exit 2: one queuing vehicle.
- 08:47. Roundabout 1 Section 13: one queuing vehicle.

• **8:51**

Several traffic slowdowns detected during this period.

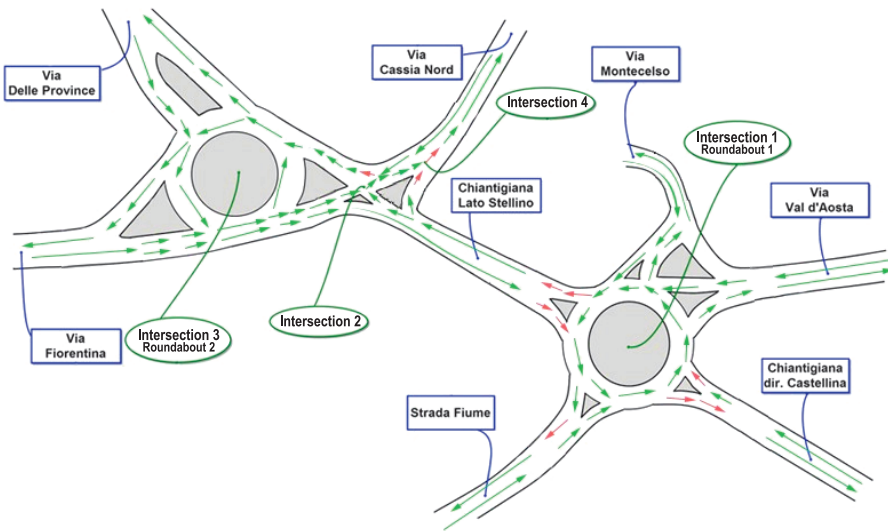


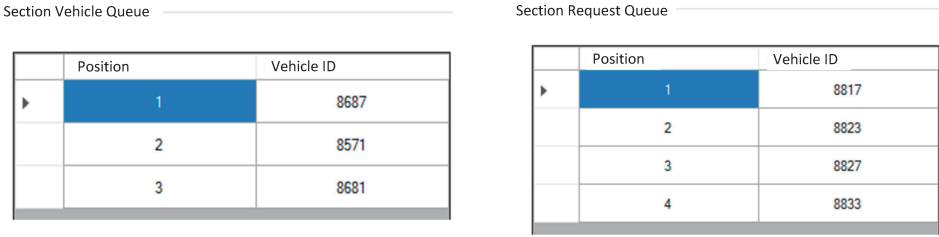
Figure 32. Model with two roundabouts – 08:51

Section Vehicle Queue		Section Request Queue	
Position	Vehicle ID	Position	Vehicle ID
▶ 1	8717	▶ 1	8835
		2	8833

Figure 33. Status of Input Section 1 in Intersection 4

Section Vehicle Queue		Section Request Queue	
Position	Vehicle ID	Position	Vehicle ID
▶ 1	8649	▶ 1	8829
		2	8835

Figure 34. Status of Internal Section 13 in Roundabout 1



**Figure 35.** Status of Input Section 4 in Roundabout 1

1. Intersection 4: Input Section 1 (vehicles from Roundabout 1 going towards Cassia Nord) – one queuing vehicle. See Figure 33.
  2. Roundabout 1: Section 13 (is the first internal section crossed by vehicles entering from Input Section 4) – one queuing vehicle, see Figure 34. This queue causes the following slowdown.
  3. Roundabout 1: Entrance 4 – three queuing vehicles.
- 08:55. Intersection 4: Exit 1 (vehicles from Roundabout 1 going towards Cassia Nord) – one queuing vehicle.

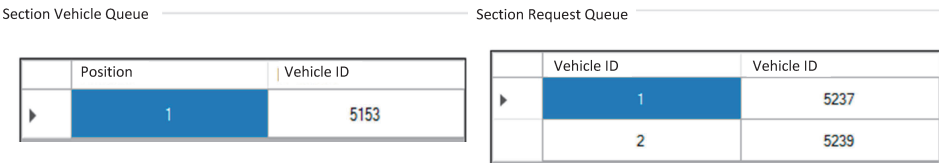
**Time band 12:00–13:30**

No traffic congestions were detected during this time band for any of the models. As for the previous time band, the simulation of the model with three roundabouts did not show any queues. The simulation of the current model indicated some traffic slowdown.

In the model, traffic slowdown occurrences start at approximately 12:55. Therefore, they affect a smaller time band when compared with the simulation model for the first time band. In this case, a problem occurs at Section 1 of Roundabout 2, the incoming traffic section for vehicle flows entering Roundabout 2 from Cassia Nord and the Chiantigiana national road, the Stellino side. There are in fact six different times with queues for this section.

● **12:31**

And it is indeed at this point of the model that slowdowns in this time band start. This is represented in the figure by the red arrows, which correspond to some sections of Road Intersection 2.



**Figure 37.** Status of Exit 3 in Roundabout 2

- 12:39. Intersection 2: Section 1 (vehicles leaving Roundabout 2 going towards Cassia Nord) – one queuing vehicle.

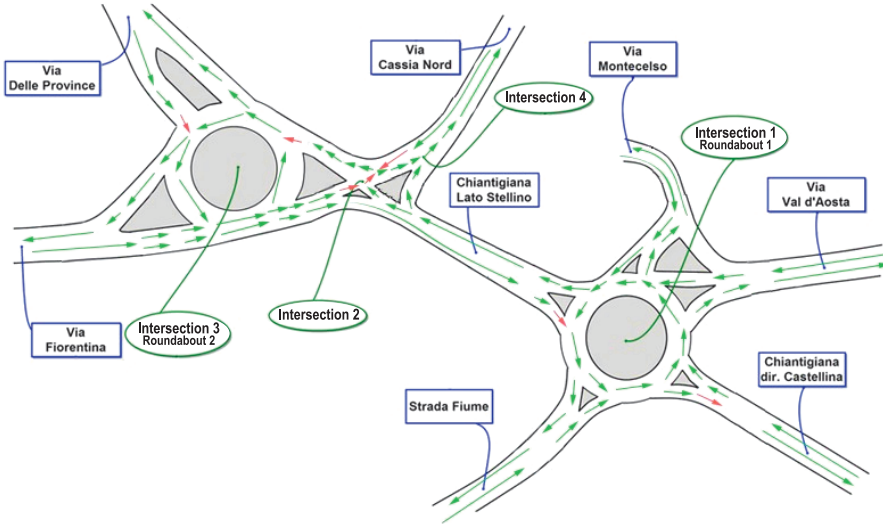


Figure 36. Model with two roundabouts – 12:31

- 12:45. Intersection 2: Section 1 – one queuing vehicle.
- 12:46. Intersection 2: Section 1 – one queuing vehicle.
- 12:52 Roundabout 2: Exit 3 (exit from the roundabout entering Road 19 going towards Intersection 2, see Figures 3 and 7) – one queuing vehicle.

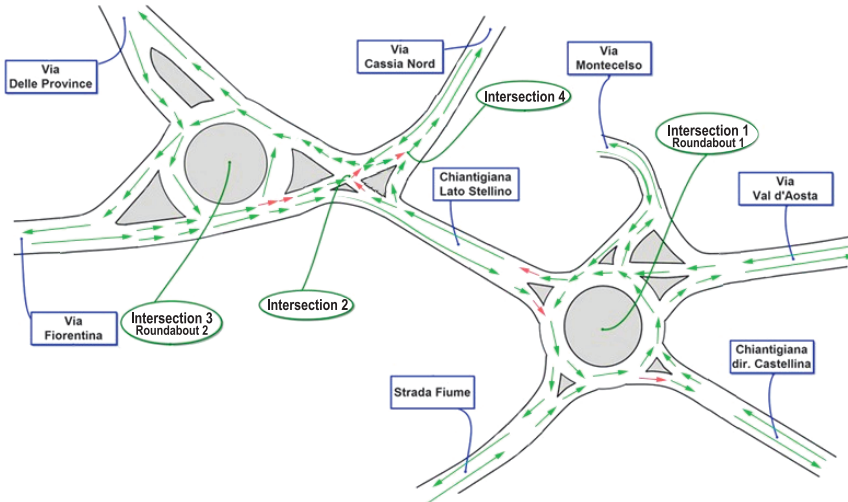
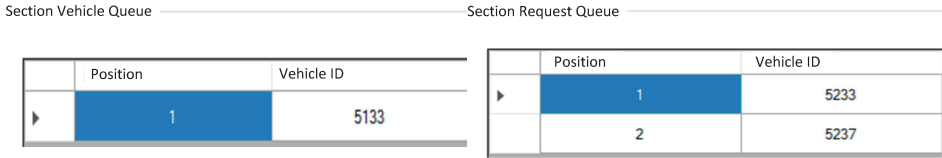


Figure 38. Model with two roundabouts – 12:52

Intersection 2: Section 1 (vehicles leaving Roundabout 2 going towards Cassia Nord) – one queuing vehicle.



**Figure 39.** Status of Internal Section 1 in Intersection 2

- 13:01. Intersection 4: Section 1 (vehicles going towards Via Cassia Nord) – one queuing vehicle.
- 13:05. Roundabout 2: Section 1 (the point of entrance to the roundabout for vehicles coming from Via Cassia Nord and the Chiantigiana national road, the Stellino side) – one queuing vehicle
- 13:10. Intersection 2: Section 1 – one queuing vehicle.

***Time band 17:50–19:20***

The simulations of the two traffic models show that during this time band the traffic flows behave substantially differently as far as congestion issues are considered.

In both case studies we can identify some traffic slowdowns from the very first minutes. However, we can also see significant congestion for the model with two roundabouts, affecting the traffic flow of the Chiantigiana national road, the Stellino side.

During the simulations, several queues were identified, distributed across both systems during all intervals. However, the traffic of the model with three roundabouts is visually much more flowing when compared with the Current System with two roundabouts. The most significant examples of the simulations during the 17:50–19:20 time band are shown below.

**17:52 – Model with two roundabouts**

Starting from this time, the system experiences queues every minute, initially concentrated at Intersection 2 of the system, and then expanding to every entrance and exit point of both roundabouts; in this specific case, we note the presence of a queue in Section 2 of Intersection 2, through which vehicles coming from Via Cassia Nord can enter Roundabout 2.

**17:53 – Model with three roundabouts**

In this case, the first queue seems to appear approximately one minute later. However, it does not affect Intersection 2, but rather Intersection 1 Section 13, meaning the point where vehicles coming from the Strada Fiume road link cross Roundabout 1. At the same time, a further queue develops at the next exit, the Chiantigiana national road, the Castellina side.

**18:08 – Model with two roundabouts**

As minutes go by, we can see gradual saturation of the road system. However, this saturation is not total, but tends to cause the formation of queues

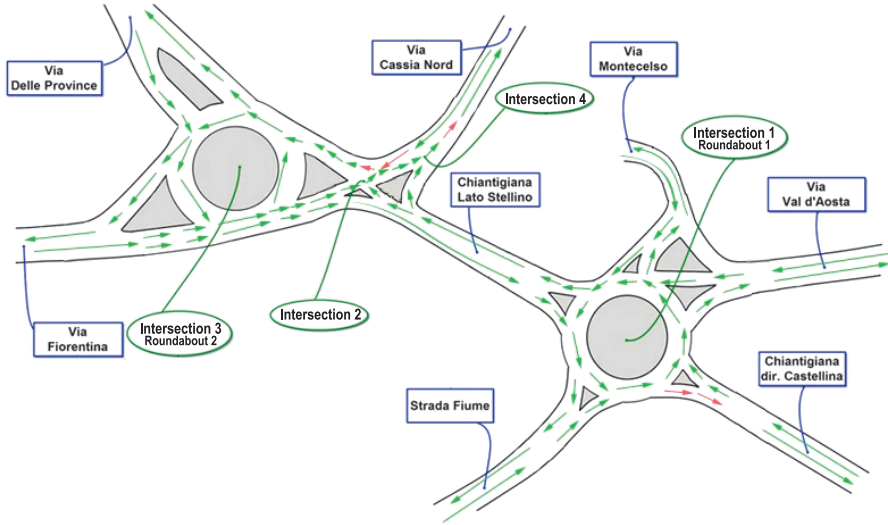


Figure 40. Model with two roundabouts – 17:52

mainly along the Chiantigiana national road, the Stellino side. Such queues eventually become constant during the whole simulation, and obviously along the lane connecting Via Fiorentina to the above. Other queues develop occasionally at various entrance and exit points of the intersections. In more detail, we can see queues at the following:

- Roundabout 2 Entrance 4 (vehicle flow from Via Fiorentina to Roundabout 2) – one queuing vehicle;
- Roundabout 2 Exit 4 (vehicle flow from Roundabout 2 to the Chiantigiana national road, the Stellino side) – queuing vehicles;
- Roundabout 1 Entrance 4 – queuing vehicles from the Chiantigiana national road, the Stellino side, to Roundabout 1, the road is saturated by queuing vehicles;
- Roundabout 2 Entrance 1 – one queuing vehicle from Via Cassia Nord to Roundabout 2;
- Roundabout 2 Internal Section 11 is saturated by queuing vehicles from Via Fiorentina directed to Exit 4;
- Roundabout 2 Internal Section 13 is saturated by queuing vehicles directed to Exit 4;
- Roundabout 2 Internal Section 15 is saturated by queuing vehicles directed to Exit 4.

**18:05 – Model with three roundabouts**

Also, here we note a constant increase in the number of queues as time goes by, although less significant when compared with the model with two roundabouts and mainly concentrated around Via Fiorentina.

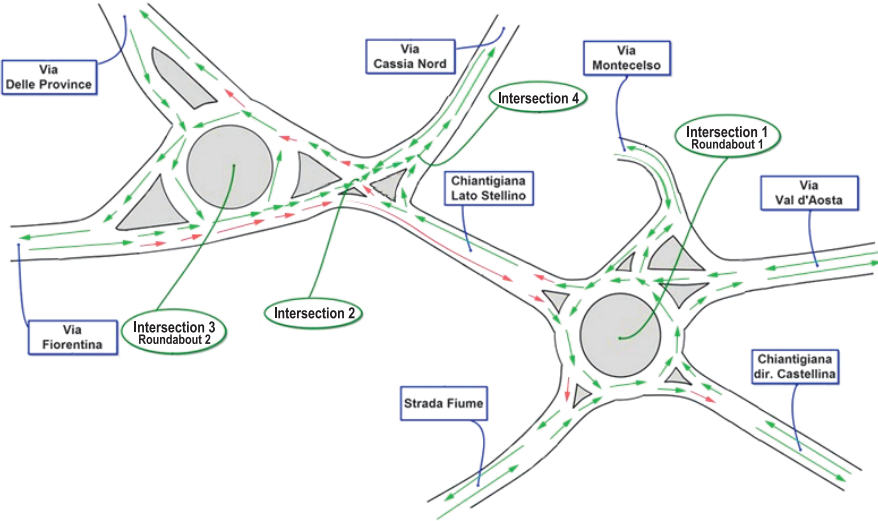


Figure 41. Model with two roundabouts - 18:08

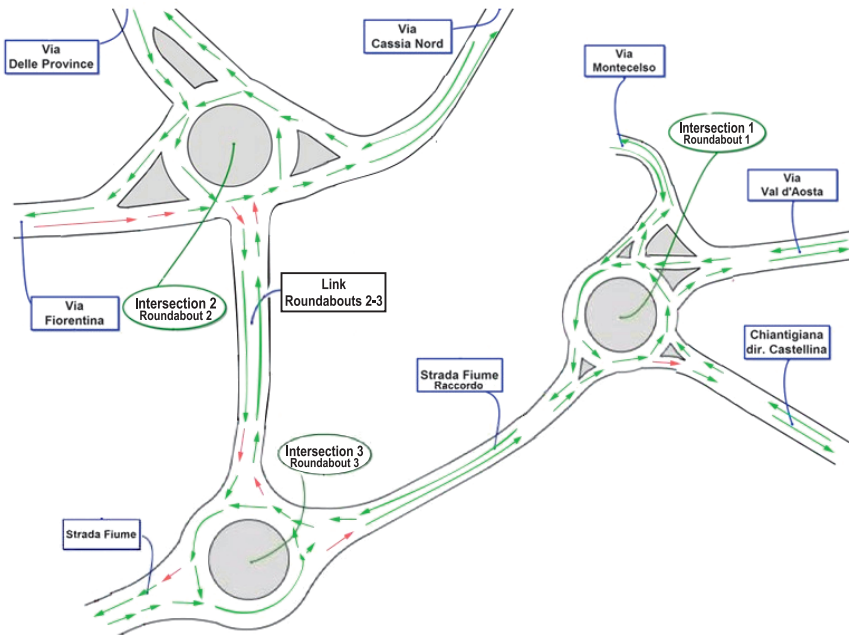


Figure 42. Model with three roundabouts - 18:05

During this specific time band, we can identify only one queue at Intersection 2 Entrance 3: the point of entrance to Roundabout 2 for vehicles coming from Via Fiorentina, from which subsequent slowdowns will follow in cascade.



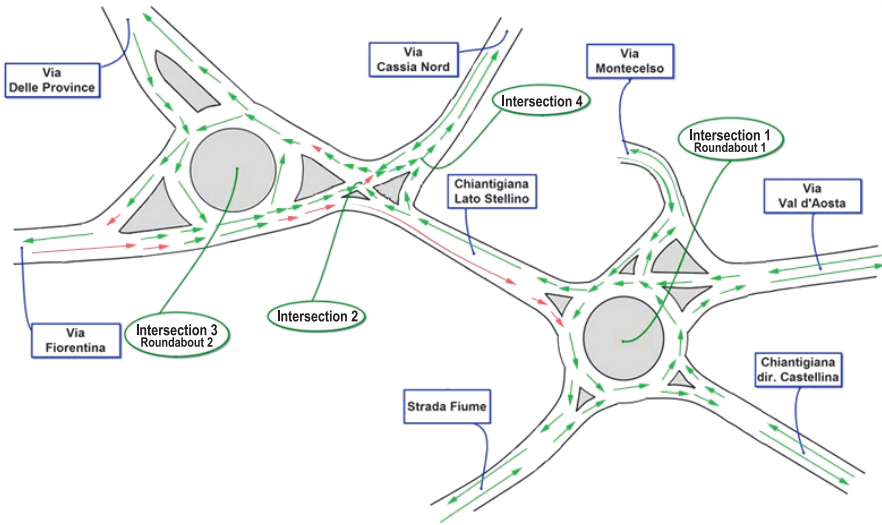


Figure 43. Model with two roundabouts – 18:40

**18:40 – Model with two roundabouts**

At this point the system reaches the maximum concentration of queues, which can be seen along the whole path going from Via Fiorentina to Roundabout 1, passing through the Chiantigiana national road, the Stellino side, as well as some scattered queues affecting Intersections 2 and 4. In detail:

- Roundabout 2 Entrance 4 – two queuing vehicles from Via Fiorentina to Roundabout 2;
- Roundabout 2 Exit 3 – one queuing vehicle from Roundabout 2 to Intersection 2 (internal lane);
- Roundabout 2 exit 4 – one queuing vehicle from Roundabout 2 to the Chiantigiana state road, the Stellino side (external lane);
- Roundabout 1 Entrance 4 – one queuing vehicle from the Chiantigiana national road, the Stellino side, the road is saturated by queuing vehicles;
- Roundabout 2 Entrance 1 – one queuing vehicle from Cassia Nord or the Chiantigiana national road, the Stellino side;
- Roundabout 2 Internal Section 11 – one queuing vehicle;
- Roundabout 2 Sections 13 and 15 – are saturated by queuing vehicles.

**18:05–18:09 Model with three roundabouts**

As previously indicated, this time interval is particularly critical due to the generation of queues in a sequence. The queue starts due to Roundabout 2, Internal Section 10, which then causes congestion of Road 18, see the models shown in Figures 20 and 24.

Everything then moves to the link road between Roundabouts 2 and 3. This is repeated during the whole period analyzed, with the cycle just described at alternating intervals. More precisely:

- Roundabout 2 Internal Section 10 – from Via Fiorentina to the internal sections of Roundabout 2;
- Roundabout 2 Entrance 3 – from Via Fiorentina, entrance to Roundabout 2;
- Road 18 – Via Fiorentina access towards Roundabout 2.

### 19:17 – Model with two roundabouts

After the interval with the highest traffic concentration, at the end of the simulation a short period of time follows during which queues gradually decrease, until the traffic starts flowing without too many problems.

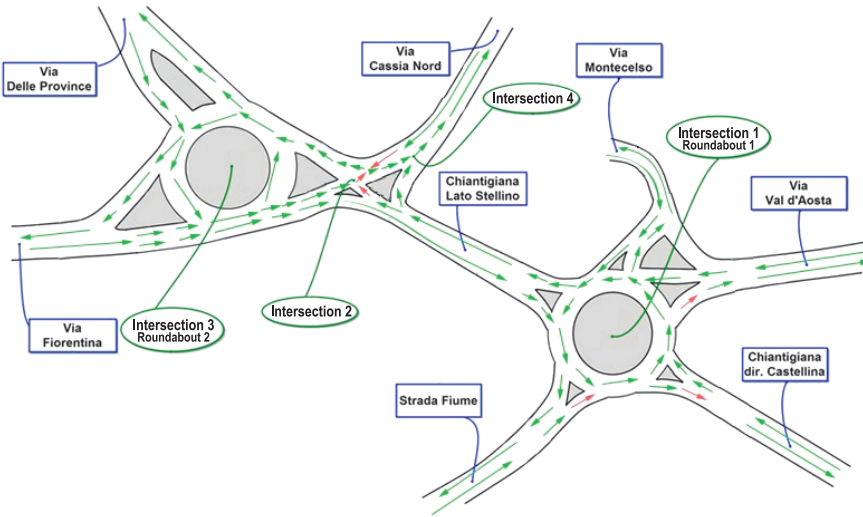


Figure 48. Model with two roundabouts – 19:17

### 19:14 – Model with three roundabouts

Its counterpart reaches a situation of flowing traffic some minutes in advance, with only some insignificant traffic slowdown events.

## 9. Conclusions

In this study, we have considered two separate architectural models for the management of a city road network. The first model considers the current situation of the system, while the second takes into account the system structure envisaged in the new City Development Plan. We have created a simulator for both models, using a technology developed through the use of complex queue networks, which is described in some previously published works [4, 1, 2, 5–7].

The results of the study, obtained through the use of the two simulators, make it possible for us to confirm that the new vehicle traffic system contemplated in the City Development Plan will result in much less congestion than in the current system. For all the time bands considered during the study, the new

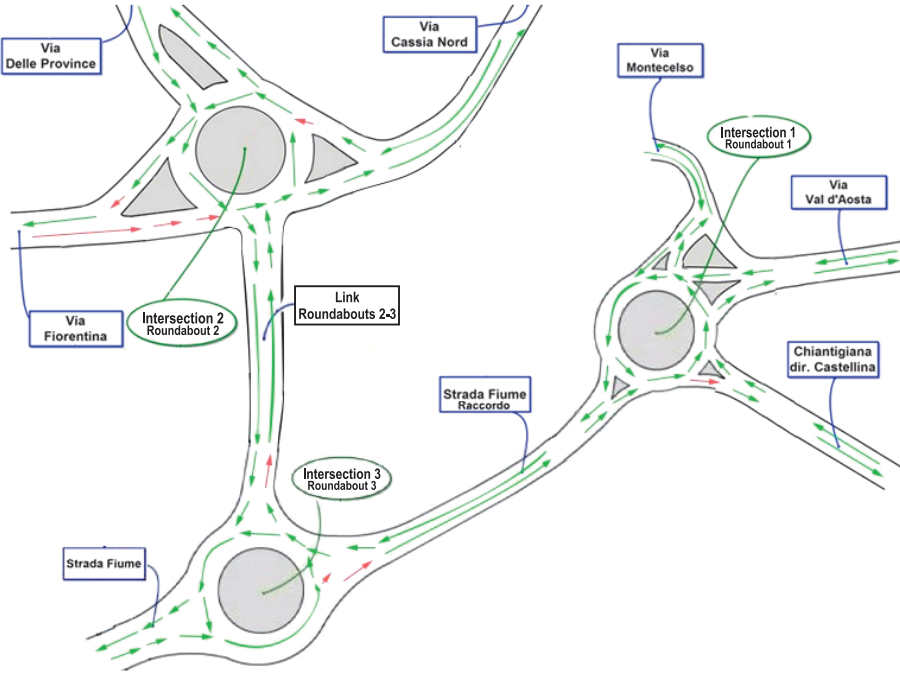


Figure 44. Model with three roundabouts – 18:05

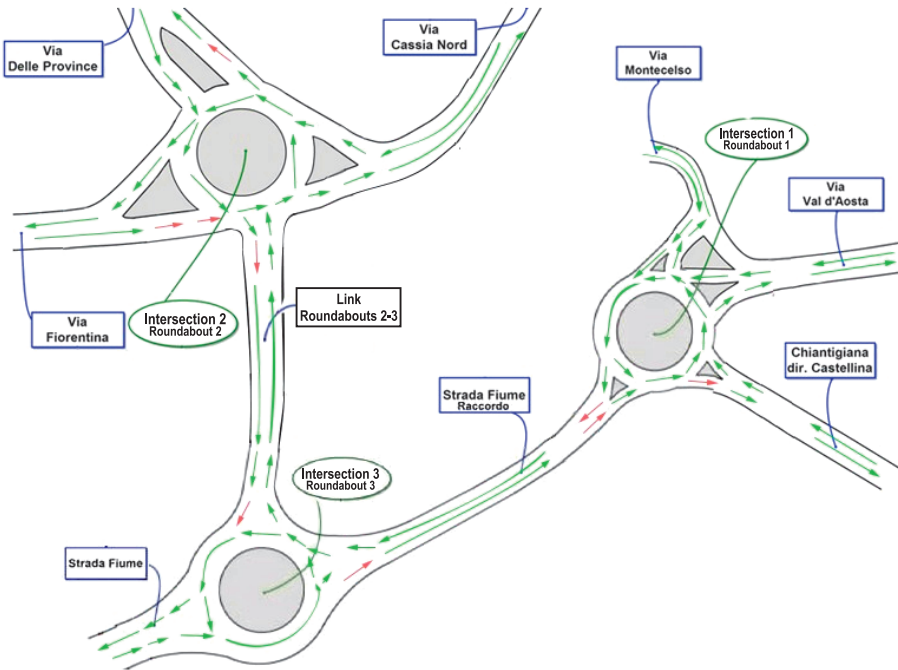


Figure 45. Model with three roundabouts – 18:06

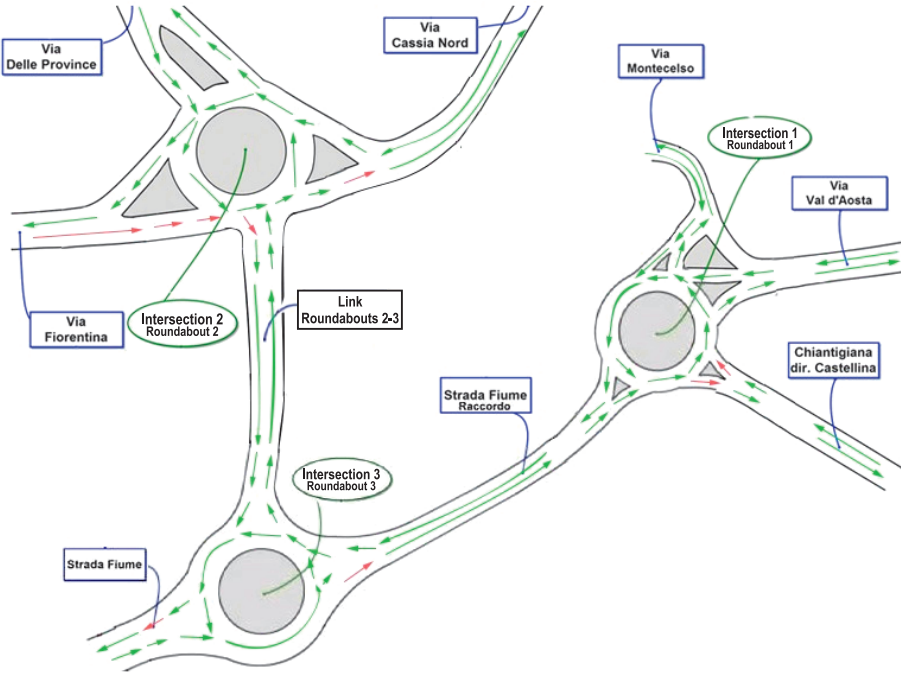


Figure 46. Model with three roundabouts – 18:08

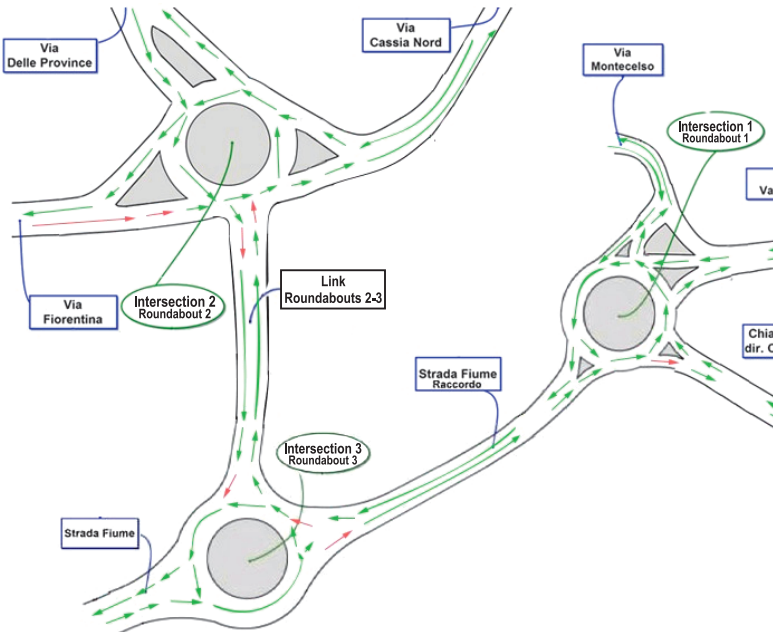


Figure 47. Model with three roundabouts – 18:09

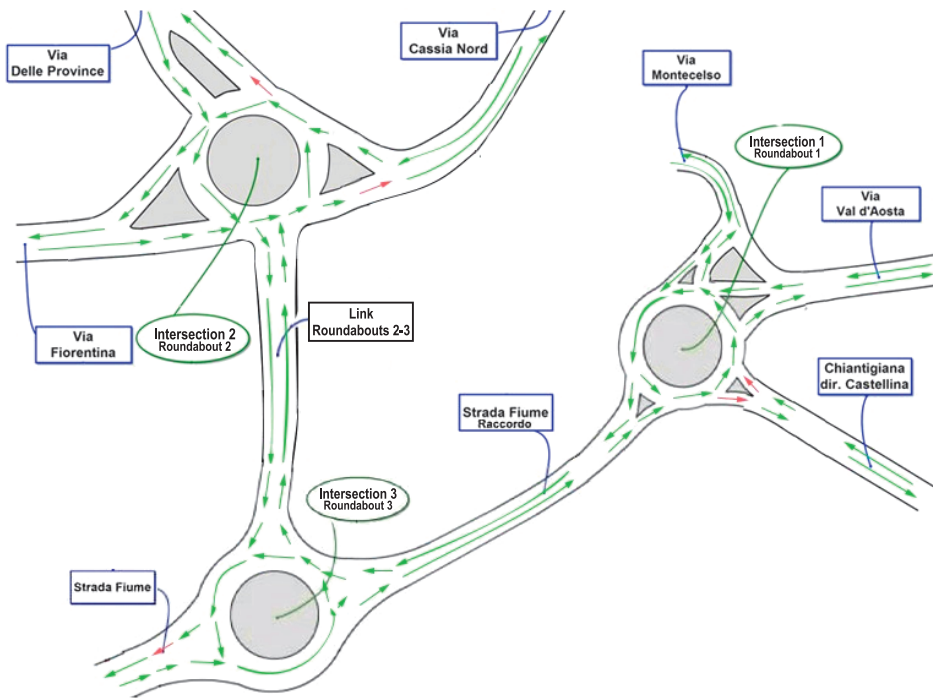


Figure 49. Model with three roundabouts – 19:14

system, characterized by the presence of three roundabouts, appears exempt from any significant traffic congestion occurrences. As far as the current system is considered, queues develop frequently in all the time bands. In particular, the last time band considered suffers significant congestions affecting the traffic flow entering Roundabout 2 from Via Fiorentina and going towards Roundabout 1 through the Chiantigiana national road, the Stellino side.

## References

- [1] Pasini L and Sabatini S 2016 *TASK Quart.* **20** (1) 9
- [2] Pasini L and Feliziani S 2013 *TASK Quart.* **17** (3) 155
- [3] Simulog QNAP2 V9 Reference Manual
- [4] Pasini L, Rietti F M and Allegretto F 2016 *TASK Quart.* **20** (3) 273
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- [7] D’Ambrogio A, Iazeolla G, Pasini L and Pieroni A 2009 *Simulation Modelling Practice and Theory* **17** (4) 625

