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Simulating the effects of pedestrianisation on urban freight deliveries

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Abstract

The city of Seville is currently developing a land-use reorganisation policy aimed at increasing the number of pedestrian spaces. This paper contains the microscopic simulation built to assess one of those pedestrianisation initiatives from the point of view of its effects on traffic flows and, more specifically, freight deliveries. Two different alternatives are compared with the current scenario from the point of view of traffic congestion, parking space occupation and route times. Due to the complexity of the freight delivery practices involved, the use of a standard traffic simulation package was not appropriate, and the simulations were carried out using the commercial package Arena, which enabled the representation of all that complexity with a specifically built simulation model.

Keywords: city logistics, urban transport, microscopic simulation, pedestrianisation.

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1. Introduction

The pedestrianisation of urban areas is often a controversial issue, and policies aiming at transforming the city into a more sustainable environment often have to face the rejection of citizens who work, live or shop in the area. However, of all the stakeholders involved in urban mobility, the strongest opposition to pedestrianisation policies often comes from the commercial sector, including shop owners and delivery companies. The former normally fear that obstructing the access of customers to their premises can result in a descent in sales, even though the case is normally the opposite, due to the enhanced attractiveness of pedestrian areas in the eyes of buyers (Chiquetto, 1997; Yiu, 2011). The latter, on the other hand, fear the increase in time, cost and difficulties encountered when delivering goods into pedestrian areas. Even though these fears do not seem to be justified, given the beneficial outcomes reported in many case studies (Whitehead et al, 2006), on a closer look the short-term effects of pedestrianisation schemes may not be so clear (Hass-Klau, 1993).

The case study contemplated here is the pedestrianisation of Asunción, one of the most commercially dense streets in Seville, which has been an ongoing objective of the local authorities for a long time, within a general framework aimed at increasing the

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number of pedestrian areas in the city. Seville is the largest city in the south of Spain with 700,000 inhabitants, and in the last two decades has undergone an exponential growth of its metropolitan area, with the subsequent affluence of vehicles into the city on a daily basis. The answer of the local authorities to this affluence, striving for the sustainability and liveability of the city, includes a progressive increase in the number of pedestrian areas, expelling vehicles from central commercial areas.

The case of Asunción Street was under the spotlight for several years, given that it was subject both to a great pedestrian affluence, due to the number of retail premises located in it, and to a great flow of traffic, being one of the main exit links from the most densely populated neighbourhood in the city. Adding to the picture was the case of persons who went to shop to the street in their cars and double-parked in front of the stores, despite the installation of parking meters in the street. The enforcement campaigns of the local authorities often resulted in the police giving tickets or towing away cars on one end of the street while, not having other parking spaces available, cars kept double-parking on the other end. The high incidence of double parking and the intense load/unload activity of Asunción Street on a normal weekday before pedestrianisation can be seen in Figure 1.

Figure 1: View of Asunción Street before pedestrianisation.

This paper describes the use of microsimulation as a decision-making tool to forecast the effect of different pedestrianisation policies for Asunción Street contemplated by the local authorities. More specifically, special attention was paid to freight delivery operations, since the commercial density of the area requires intensive load/unload operations during work days. These operations are significantly affected by traffic congestion and parking availability, and also by any pedestrianisation initiative (Muñuzuri et al, 2005). The process followed started with the analysis of traffic and freight deliveries in the street as they were taking place, and then used microsimulation to represent the final scenarios after pedestrianisation.

The rest of the paper shows a revision of different examples of the study of urban freight deliveries using microscopic simulation in Section 2, the description of the area contemplated and the pedestrianisation policies in Section 3, the different modules combined in the simulation process in Section 4, the results produced by the simulations and the conclusions obtained from them.

2. An overview of urban freight simulation

Even though several optimisation models have been formulated in order to draw an analytical picture of freight deliveries in urban areas, the complexity and dynamic conditions of urban traffic have resulted in a strong bias towards simulation models. The simulation of freight deliveries in urban areas has often been designed with a macro approach, aiming to estimate vehicle flows (Boerkamps and Van Binsbergen, 1999; Sonntag and Tullius, 1998; Muñuzuri et al, 2012) and their environmental impacts (Ambrosini and Routhier, 2004), or from an economic, supply-chain point of view (Hensher and Puckett, 2005), or used to assess the overall effect of infrastructure provisions or mobility regulations (Yannis et al, 2006).

However, when the analysis is not referred to a whole city or metropolitan area but rather to a specific street or neighbourhood, the required level of detail is often much more precise (Wigan and Southworth, 2006). In these cases, the mere macro simulation of freight vehicle flows is not sufficient to gain an adequate insight on issues like congestion effects, parking availability or delivery practices. The closer look provided by microsimulation is then required.

The introduction of freight issues in traffic microsimulation packages has only been accomplished in very recent years, and in any case it is still relatively limited (Lawson, 2006). Some recent applications of the capabilities of commercial packages include the determination of delivery routes in an urban environment (Ferguson et al, 2012) or the analysis of the disturbances caused by large vehicles in urban traffic flows (Hancock and Lu, 2006; Lake et al, 2002). More detailed simulations, combining traffic issues with specific freight delivery practices, nevertheless require the building of dedicated models using general simulation packages (Sinarimbo et al, 2003). The introduction of ad-hoc simulation tools has also been used to represent the interaction between freight vehicles and traffic (Hosoya et al, 2003) or dynamic decision making depending on congestion (Wang et al, 2002; Xu et al, 2003). Other recent examples of the use of microsimulation include the determination of vehicle tours as a previous step for the application of macroscopic models (Stefan and McMillan, 2005; Wisetjindawat and Sano, 2003) or the influence of goods transport on land use (Moeckel et al, 2002).

Here we address the building of a specific, ad-hoc simulation tool, with the objective of representing as accurately as possible the complex environment of Asunción Street, including the fact that passenger cars often parked in load/unload zones in the area, causing delivery vehicles to double park or park illegally on the sidewalk in certain spots where it was possible to do so. Besides, if those spots were occupied by other delivery vehicles, they had to search for the next available one, etc. The representation of this complexity, required for the in-depth analysis of the effect of pedestrianisation on deliveries in the area, meant the development of a dedicated simulation process, using the Rockwell Arena software package. Although initially intended for simulating production processes, this simulation environment was easily adapted to traffic scenarios, with equal flexibility.

3. Area description

The area studied in this case corresponds to Asunción Street, more specifically its section between Plaza de Cuba and Virgen de Luján, also considering the traversing streets and neighbouring area (see Figure 2). The streets Juan Sebastián Elcano and Monte Carmelo are also included in the analysis, as an alternative for the diversion of the traffic flows originally passing through Asunción.

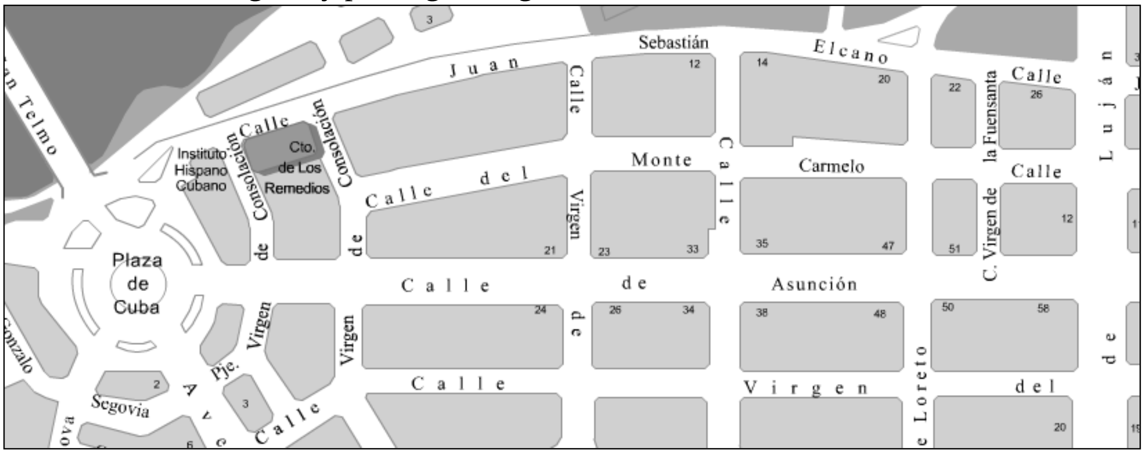

Figure 2: Area considered in the simulations.

The model we built was used for the comparison of the original traffic situation with two potential scenarios. These two scenarios correspond to pedestrianisation proposals elaborated by the Traffic and Transport Delegation of the Seville City Council, with the intention of using one of the two alternatives for the new planning of the area. In order to decide which alternative is best, once the two potential scenarios were simulated, their effects were compared with the original one in terms of congestion levels, freight delivery practices and use of parking spaces. The two scenarios can be briefly described as follows:

a) Partial pedestrianisation: the complete pedestrianisation of the street was discarded, due to the accessibility problems that would be caused in the neighbouring streets. Nevertheless, the partial pedestrianisation proposed addressed the main objectives, increasing the space for pedestrians in the area and eliminating the through traffic passing through Asunción. The proposal consisted in allowing general traffic to cross the street through adjacent streets and traversing ways, while converting the rest of Asunción in a pedestrian area. Load/unload operations would be transferred to adjacent streets, and bus and taxi stops would be taken out.
b) Increasing the sidewalks, leaving a single lane for traffic and no parking spaces along the street. Even though this proposal could not be considered a full pedestrianisation scheme, the space for pedestrians would have been significantly increased, and the through traffic penalized. Load/unload operations would also have been transferred to adjacent streets, and bus and taxi stops taken out.

The simulation model was built and validated with respect to the original scenario, with normal traffic along the streets, taxi and bus stops, load/unload operations, etc.

From there, the two modified scenarios were also built and analyzed, considering the changes in congestion levels, parking space occupation, etc. A significant amount of field work was required for the modelling of the original situation, including data collection and model validation. This field work consisted of:

- A classification of shops in sectors according to their type of activity, as defined by the local Chamber of Commerce following the Economic Activity Tax census. The different sectors considered in the analysis are displayed in Table 1.
- Surveys passed to shop owners and drivers of delivery vehicles, in order to find out their practices, frequencies, etc. The retailer survey was passed to 75 retailers, including the following questions: frequency of deliveries received, usual delivery schedule, type of transport company, type of vehicle used, usual parking space used and time required for the delivery. The driver survey was passed to 40 drivers with questions about their usual route and parking spaces used, the route frequency and duration and the average time required for each unloading operation.
- Traffic flow measurements in 19 points spread through the analyzed zone, corresponding to the 7 sections into which the simulated area was divided (see Figure 3). Vehicle flows were counted daily in five-minute intervals distributed through the morning hours of a whole week.
- A census of delivery parking spaces in the area, both legal and illegal: double-parking or parking spaces on sidewalks were also considered for loading and unloading in the original scenario, according to the observed daily practices. Indeed, these illegal parking practices are not exclusive of the case analyzed here (Danielis et al, 2010)
- Measurement of traffic light cycles, of bus stop times and of the average time spent by taxis at the taxi stop located in Asunción.

Sector	Description	Sector	Description	Sector	Description
1	Supermarkets	12	Photograph	23	Hotels
2	Bakeries	13	Herbal dietetics	24	Lingerie
3	Banks	14	Toys	25	Drugstores
4	Bathroom equipment	15	Large Furniture	26	Music stores
5	Bars / Cafés	16	Small furniture	27	Opticians
6	Bingo	17	Hairdressers	28	Home textiles
7	Education	18	Perfumes	29	Boutiques
8	Art galleries	19	Transport agencies	30	Clothes
9	Pharmacies	20	Gifts	31	Shoes
10	Hardware	21	Clothing accessories	32	Dry cleaners
11	Flowers	22	Decoration	33	Clocks and watches

Table 1: Activity sectors considered in the analysis.

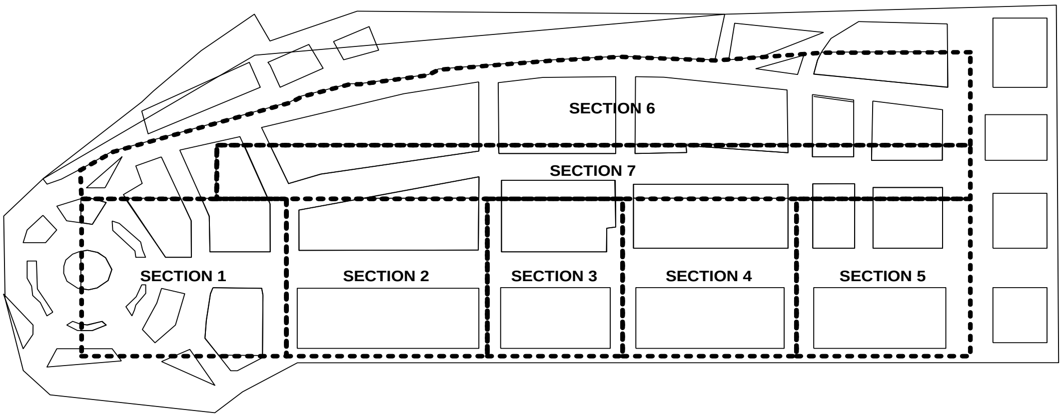

Figure 3: Sections into which the simulated area was divided.

4. Simulation

With all the collected information, we modelled the original scenario in Asunción Street, using the Arena software package. As mentioned before, this package, although not specifically designed for traffic modelling, proved perfectly suitable for this type of task, adapting production-oriented features to the modelling of streets, intersections and parking spaces, and allowing us to represent the specific features of city distribution practices.

4.1 Dynamic entities.

The dynamic entities used in the model were the different types of vehicles driving in the area, including passenger cars, taxis, buses and delivery vehicles (see Figure 4). With respect to delivery vehicles, we considered three types of vehicles:

- Freight providers (full truckload carriers): carrying goods for a specific sector (i.e., drinks for bars and restaurants, supplies for supermarkets, etc.). 33 different providers were identified in the survey. Depending on the type of delivery, providers used both vans (under 3.5 tons) and trucks (over 3.5 tons), and followed regular routes, with an observed weekly frequency and at fixed intervals during the day.
- Freight operators (less-than-truckload carriers): we identified 6 main operators, carrying less-than-truckload shipments to retailers belonging to different sectors (clothing, stationery hardware…), using mainly vans. The number of operators (6 in the simulations) was taken from observation, and the introduction of a delivery van in the simulation took place when a certain number of requests had been made by the retailers in the area, according to the ordering frequencies revealed by them in the surveys.
- Other freight vehicles: those that did not stop in the simulated area, and were therefore considered as normal passenger vehicles with respect to traffic congestion.

The movement of vehicles through the streets was modelled with constant speed conveyors. The fact that vehicles thus could not pass each other or modify their speed was proven not to be an obstacle when modelling urban traffic in the chosen area, since vehicles usually stayed in line through the whole street, driving at a more or less constant speed. The simulation period chosen corresponded to the shops' opening hours in the morning, that is, from 9.00 to 14.00 hours, since that period is when traffic densities were higher in the area.

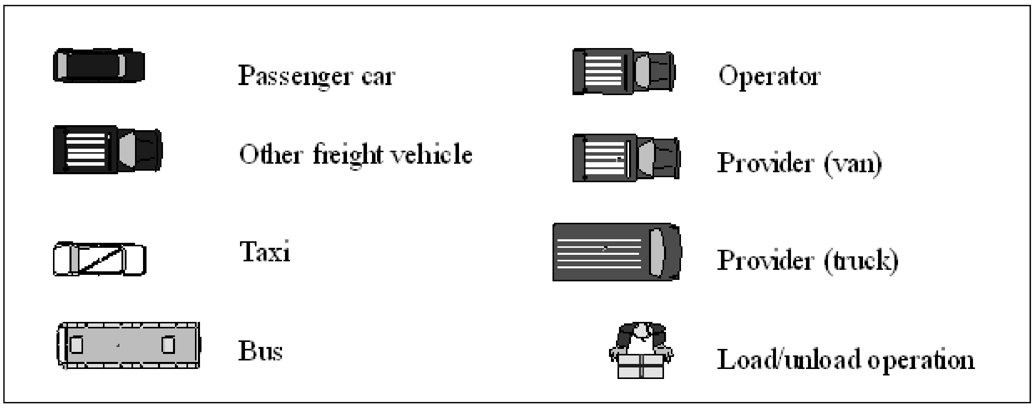

Figure 4: Types of dynamic entities considered in the simulation.

4.2 Simulation features.

The representation of traffic in the area was simulated using a combination of Arena modules. The main modules used in the microsimulation are described in this section.

a) Entry of vehicles: This module generated the dynamic entities different from delivery vehicles (passenger cars, taxis, buses and other freight vehicles) in the simulation. These generations were modelled by Create modules, which generated vehicles in all access streets at a rate similar to the one observed from reality.

b) Generation of operators' vehicles: The generation of delivery vehicles corresponding to transport operators was modelled by a double process. In the first part of it, represented in Figure 5, a Create module was assigned to each one of the retail premises present in the area, which generated orders for deliveries. Depending on the probability of each retailer of placing an order on a given day (equal to the inverse of the number of deliveries received daily, obtained in the survey), this order may be discarded or assigned to a transport operator. The operator was selected randomly from the list of operators which served this particular shop on a regular basis. If no vehicle for that operator had been generated when the order was to be assigned, it was held until a vehicle was available.

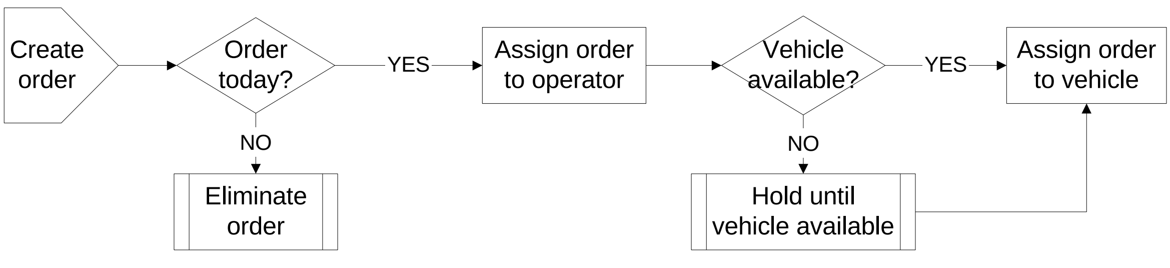

Figure 5: Generation of orders corresponding to retail establishments.

Delivery vehicles were generated by a Create module in the second part of the process, shown in Figure 6. When the number of orders reached a certain level, corresponding to the average number of deliveries that operators' vehicles made in the area, the vehicle was sent to the starting point of the first conveyor in its route. This route was then governed by Decide modules located in all accesses, intersections and exits, and the parking spaces where it needed to stop to make a given delivery were determined by Convey modules. At the same time, a new vehicle was generated to incorporate the new orders generated by retailers.

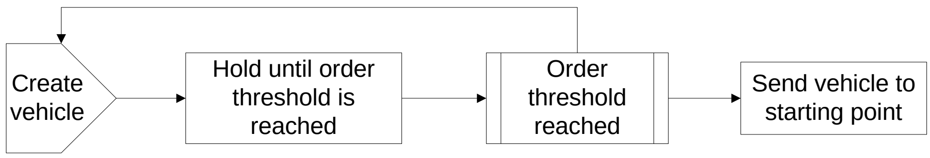

Figure 6: Generation of operators' vehicles.

c) Generation of providers' vehicles: These were easier to model, since they followed fixed routes depending on the location of retailers belonging to their specific sector. Therefore, a simple Create module, with a specified frequency determined from the surveys, was sufficient to generate the vehicles. Depending on the probability of their specific sector receiving deliveries on a given day, they were then eliminated or introduced in the simulation. In this case, they moved from one conveyor to another and parked in the same manner as operators' vehicles. The process is represented in Figure 7.

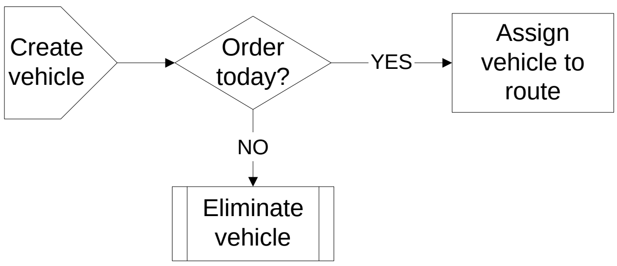

Figure 7: Generation of operators' vehicles.

d) Exit of vehicles: Exit modules were located at all exit streets, eliminating all types of vehicles from the simulation after they had completed their route.

e) Traffic lights: They were modelled by a closed loop (see Figure 8) where single entities (vehicles) followed the loop during the whole simulation. An additional entity created in each iteration of the loop by a Separate module was used for graphic animation of the traffic light in the model. The different traffic lights in the model were interrelated, in order to take into account the synchronizations observed from reality.

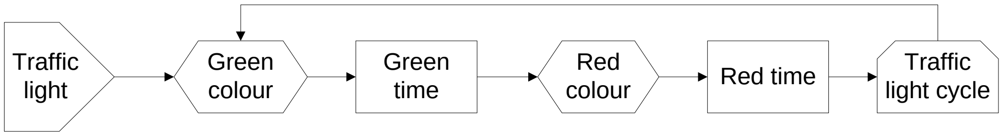

Figure 8: Simulation of the traffic light cycle.

f) Give way intersections: Intersections were modelled using production Stations, which could only be occupied by one entity (vehicle) at a time. Priority conditions were used to simulated "Give Way" signalling and traffic light queues, making use in this case of Accumulating conveyors, where the distance between the entities located on the conveyor could vary if the exit of the conveyor was blocked. First, the vehicle reached a Hold (Scan for Condition) module, which guaranteed that no vehicle entered the intersection until it was free, or allowed access only when the corresponding traffic light was green. The intersection corresponded to a Process module, which allowed representing the estimated time needed by a vehicle to cross the intersection, according to observations. Finally, depending on the vehicle's route, it chose the corresponding conveyor to continue after the intersection. The process sequence is represented in Figure 9.

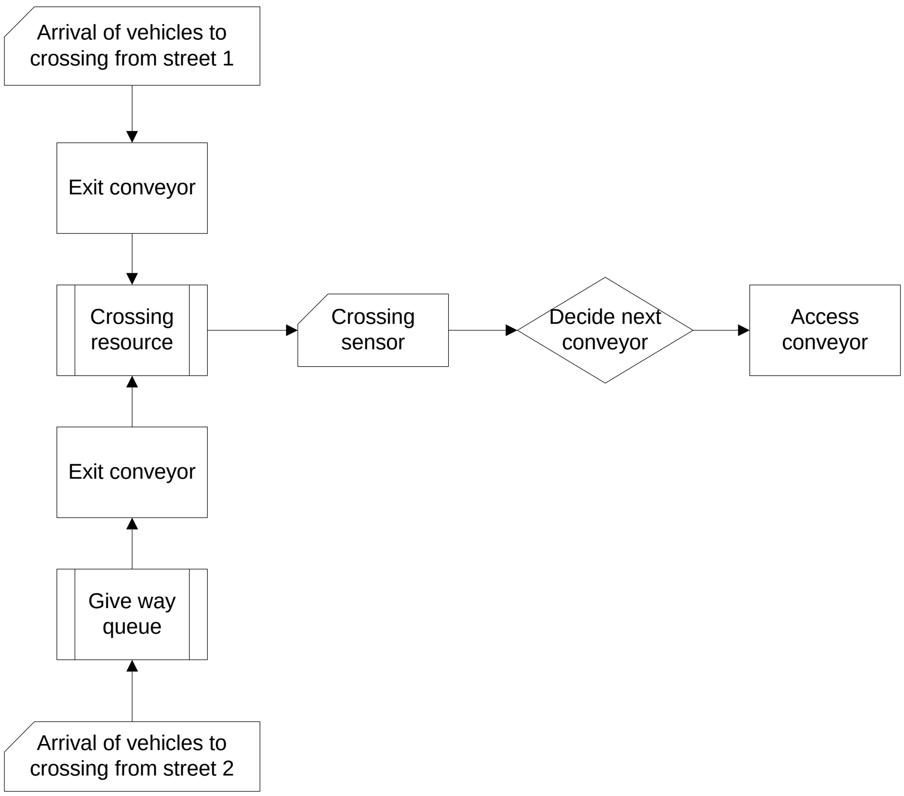

Figure 9: Representation of the modelling of intersections.

g) Load/unload process: The delivery parking places contemplated in the model included all the spots, legal or not, identified during the field work, where freight vehicles parked to make deliveries. Each one of these parking places was simulated by a

Station with a given capacity, accessible from the corresponding conveyor. The association of parking places to retailers, represented by vectors of retailers' codes, was also taken from the field work observations.

When a delivery vehicle reached a given parking place, the remaining destinations to be visited by the vehicle were compared with the retailers associated to the place. If there was available capacity, the parking process was simulated with a Seize module, after stopping traffic during the parking time. The time taken for the delivery was defined by a Delay module, and the vehicle entered the conveyor again. The process is described in Figure 10.

The case of providers was again easier, given that the list of parking places where they needed to park was fixed when the vehicle was generated. If the parking place was occupied, the vehicle continued until the next one.

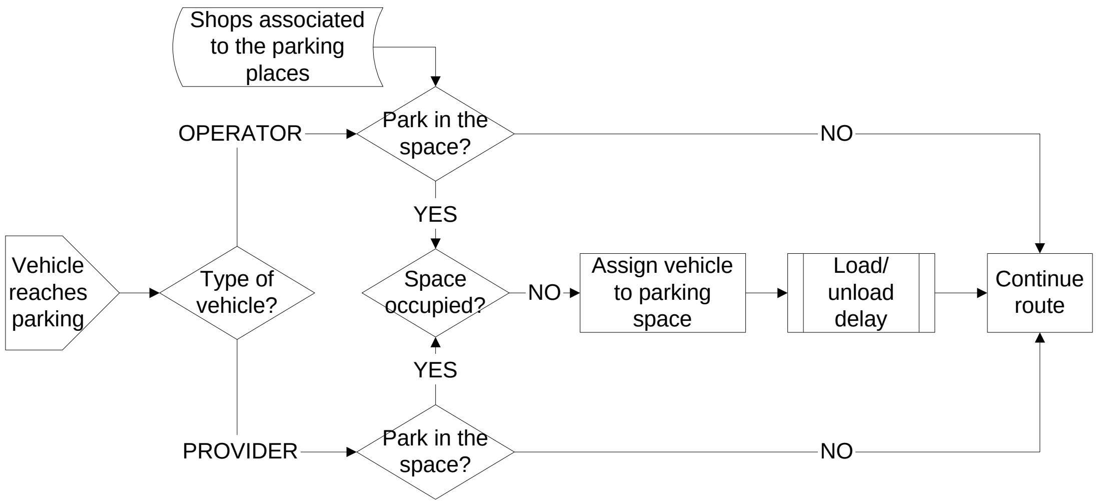

Figure 10: Load/unload process for delivery vehicles.

h) Bus and taxi stops: Bus stops may have been implemented with a Delay module, but a Process module was again used in order to animate the flow of passengers getting on and off the bus. As for Taxi stops, they were modelled by Stations which could only be accessed by taxis, with a certain capacity.

Figs. 11 and 12 show a representation of the general simulation scenario, generated with the graphic tools of Arena, and a more detailed view of the movement of vehicles along Asunción Street.

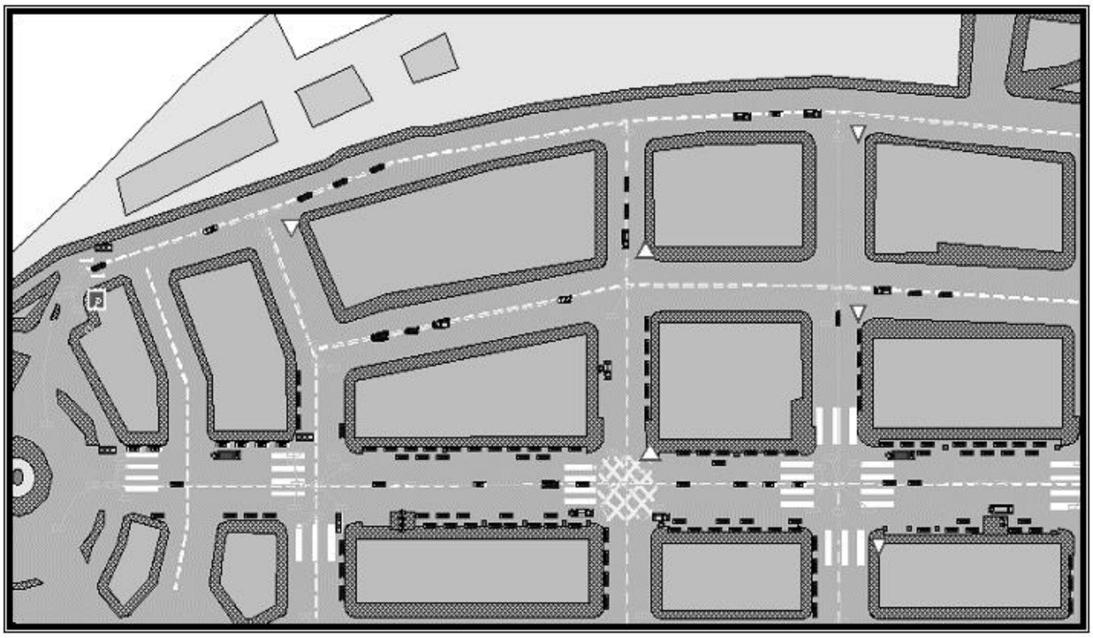

Figure 11: General overview of the simulation model animation.

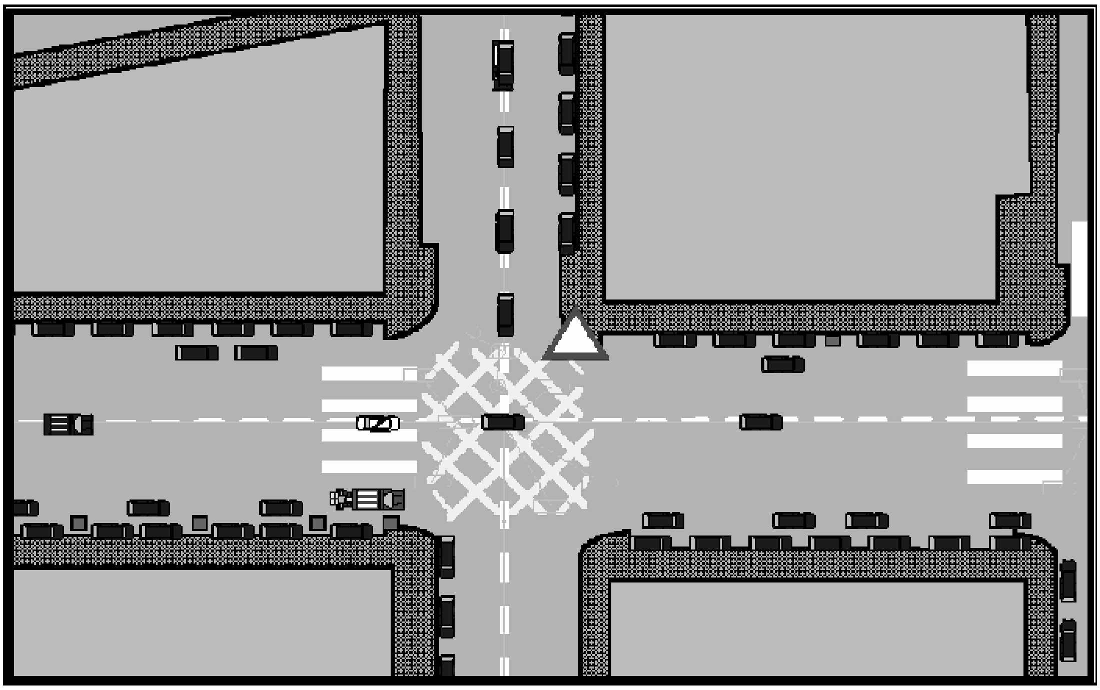

Figure 12: Detail of the simulated area.

5. Results

In order to retrieve the results of the simulations, we used the capabilities of Arena for generating reports. The reports generated were (a) the degree of occupation of the load-unload parking spaces in the area, as a measure of the difficulty for parking for delivery vehicles; (b) the average number of vehicles in each street section at a given instant, as a measure of the degree of congestion; and (c) the average route time for each type of vehicle (see also Table 1), also as an indicator or the degree of congestion. The comparison of these indicators for the three scenarios considered is shown in Figs. 13, 14 and 15. After pedestrianisation, the vehicles that were passing through sections 2 and 4 have now moved to section 6, but the other adjacent sections (1, 3, 5 and 7) do not show significant variations. With respect to parking spaces for delivery vehicles, the pedestrianisation scheme has caused a reduction in the requirement of spaces in sections 1, 2 and 3, whereas the spaces located in section 4 are close to saturation. The differences in the route times for delivery vehicles shown in Fig. 15 are due to the different paths they need to follow in the pedestrianised scenarios, to the actual location of their final destinations and to the availability of parking spaces.

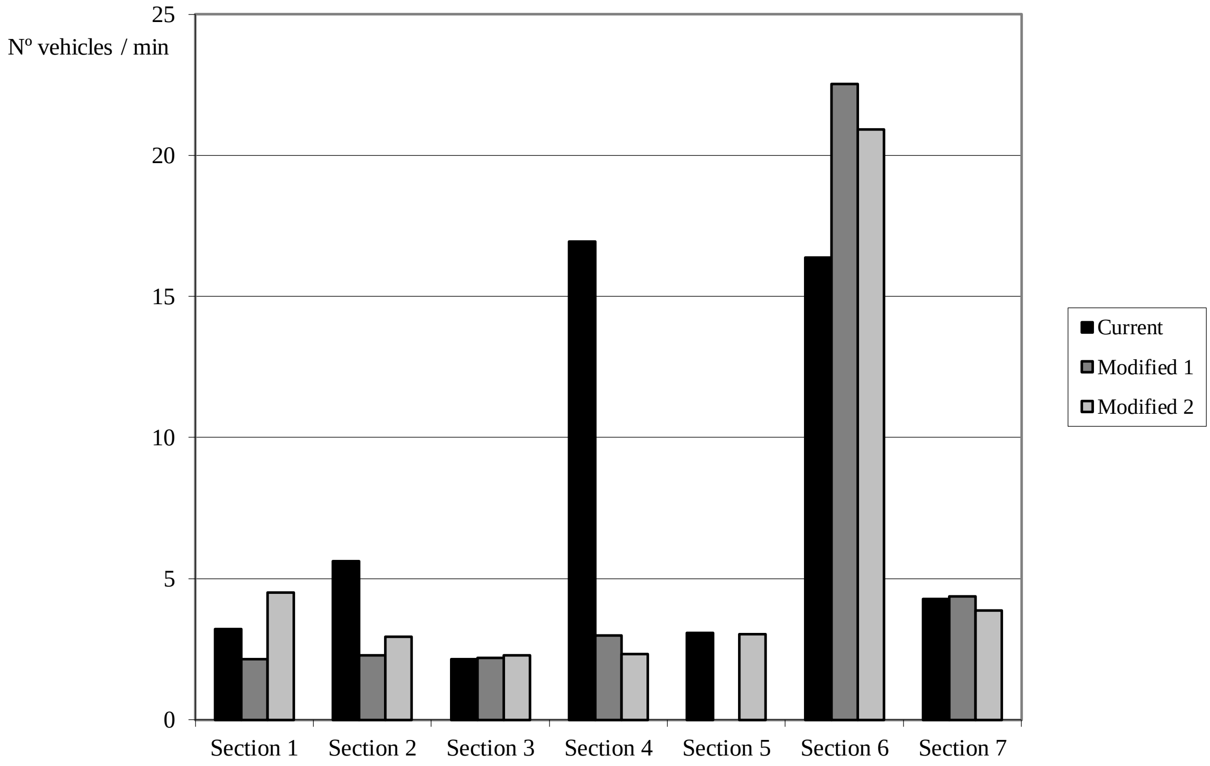

Figure 13: Traffic congestion in the different sections of the simulation for the considered scenarios (section 5 does not hold traffic in the first modified scenario).

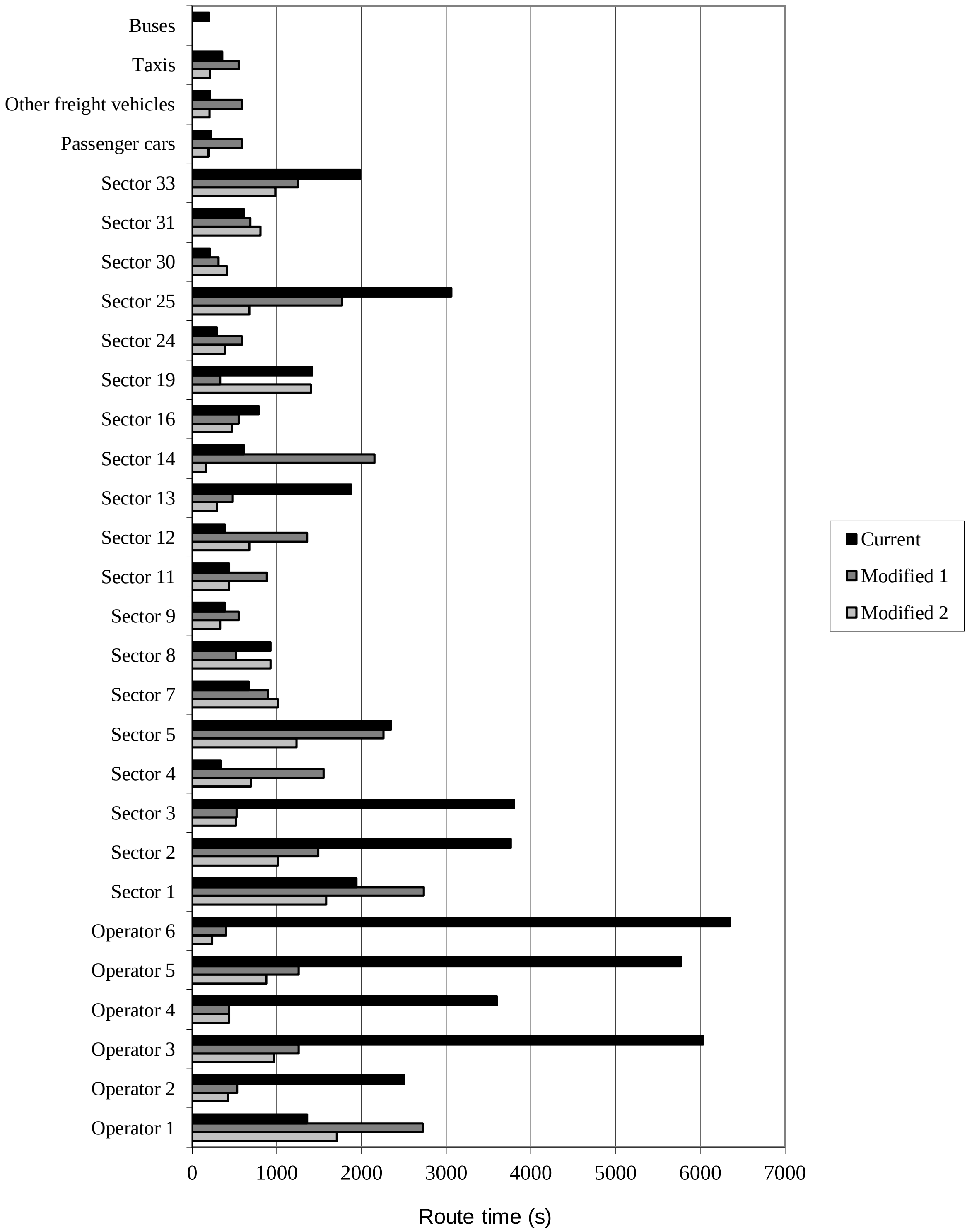

Figure 14: Comparison between the average route times of the different types of vehicles in the considered scenarios.

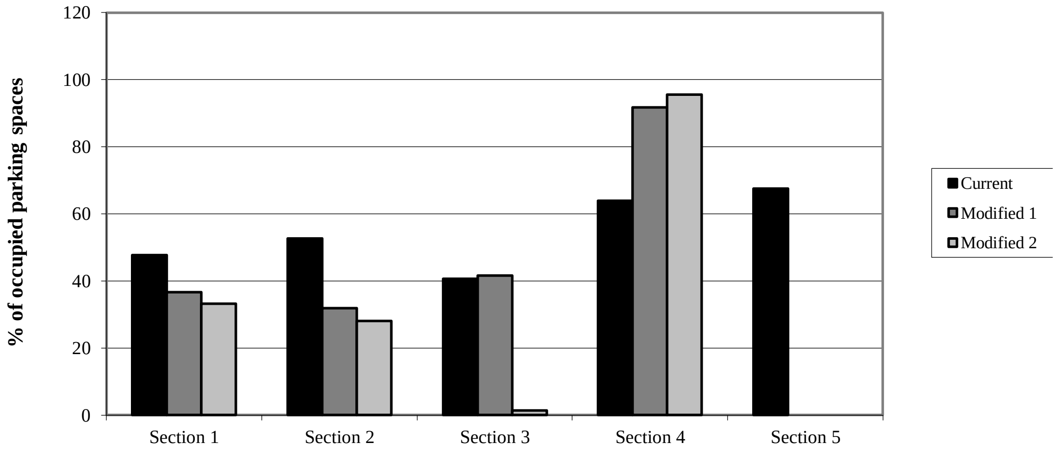

Figure 15: Comparison of the different degrees of parking space occupation for delivery vehicles in the considered scenarios (sections 6 and 7 do not hold any parking spaces, and neither does section 5 in the modified scenarios).

5.1 Original scenario

The results obtained from the simulation of the original scenario reproduced the same problems in the area with respect to general traffic and freight delivery operations that had been identified by the field work. For instance, there were certain bottlenecks in the circulation of passenger vehicles, concentrated in the sections of Asunción where double parking was more frequent, and in the traffic light queues.

The coexistence of public and private vehicles with double parking proved to be the main cause of congestion in the street. The street originally had two lanes, but most of it was modelled with one single conveyor, representing one single lane, since double parking often blocked completely the other one. Finally, the authorized load zones appeared to be clearly insufficient for the delivery vehicles operating in the area, which were often forced to use illegal parking spaces.

The results obtained for the current scenario validated the simulation model, which was then used to build the modified scenarios.

5.2 Partial pedestrianisation

The first modified scenario, corresponding to a partial pedestrianisation of the Asunción Street, contributed to the reduction of the congestion levels in the Asunción area, which would in turn contribute to enhance commercial activity in the street. However, since all the through traffic was redistributed down side streets, congestion in Juan Sebastián Elcano increased significantly.

Assuming that passenger cars were enforced out of load zones, route times were found to be generally lower for operators, due to the higher availability of parking spaces and reduced congestion levels. However, those for providers increased significantly, since their delivery routes, usually comprising more than one destination in the street, were much longer now.

Nevertheless, even though the simulation was only concerned with the dynamic aspects of the new configuration (traffic flows, use of parking spaces…), the analysis should also have taken into account some other issues, not observable in the simulations. An example of this is the reduction in the number of parking spaces for passenger cars, which had to face opposition from certain retailer sectors.

5.3 Increase sidewalk width

On the other hand, the second modified scenario corresponded to the increased width of sidewalks along Asunción Street, causing smaller congestion levels in the street, since there was no double parking or waiting behind stopped buses. Also, in contrast with the first modified scenario, Juan Sebastian Elcano was not so congested with this option, since a fraction of the total through traffic would still continue passing through Asunción.

The total route times for operators also decreased and those for providers also increased, but with lower rates than those found in the first modified scenario. Finally, the location of load zones was identical to the one present in the first modified scenario, and therefore the reduction of the number of parking spaces for passenger cars was similar.

5.4 Result comparison

Both modified scenarios presented similar results in terms of overall congestion levels and modification of route times, with slightly better results in the case of the first one (partial pedestrianisation). As it usually happens when modifying street configuration, the largest effects took place in nearby streets, being in this case Juan Sebastian Elcano the one that received all the through traffic flows expelled from Asunción (see Fig. 13). The simulations showed that an increase in the green times of the traffic light located at the end of Juan Sebastian Elcano would be required in order to relieve the saturation of the street. This might cause traffic interferences in the crossing street, Virgen de Luján, which is also an important avenue, and the question remained whether this would be acceptable. However, enabling the left turn before the end of Juan Sebastián Elcano (along the continuation of Loreto) would allow the release of the vehicle flow without affecting the crossing with Virgen de Luján (see Fig. 2).

Another important drawback of the modified scenarios was the reduction of parking spaces, opposed by residents and workers in the area, and by shop owners. However, other pedestrianisation initiatives accomplished in other areas of the city had started off with similar opposition but finally proved to be very effective. Shopping in the area is an activity mainly carried out by residents of this densely populated area, so the restrictions to the use of private cars were not too relevant from that point of view. Thus, the enhancement of commercial activity through a greater affluence of pedestrians was likely to compensate the reduction of customers arriving in their cars from other areas of the city.

From the point of view of accessibility, it was maintained in either of the contemplated scenarios, and the route times of delivery vehicles would not increase significantly with respect to the original situation: in fact, they would be reduced in most cases, due to the reduction of congestion around Asunción, as shown in Fig. 14.

6. Conclusions

The paper has presented a microscopic simulation of traffic and freight transport used to assess the effect of two different pedestrianisation policies. The simulation model built was validated using current data collected from the field and then used to compare the two alternatives proposed by the City Council.

In general, both modified scenarios appeared beneficial with respect to the original situation in terms of traffic indicators, and their drawbacks were similar. Implementing restrictions to vehicle movements in any given area is always likely to move congestion effects to adjacent streets, but in this case the increase in vehicle flows in sections 6 and 7 of the modified models remain within acceptable bounds. Also, even though we have not analyzed environmental effects here, previous simulation analyses show that they are likely to present only small isolated increases on streets adjacent to the pedestrianisation scheme (Chiquetto, 1997). Besides, the route time values shown in Figure 14 confirm that freight carriers were wrong to fear an increase in delivery times, and therefore in costs. Average route times are at most similar after pedestrianisation, which means that supply-chain-related practices, frequencies and schedules are not affected by it.

This is why, given the interest of the local authorities towards the increase in the number of pedestrian areas in the city, the first modified scenario, corresponding to the partial pedestrianisation of Asunción, was implemented. The slightly better results of this scenario with respect to the increase of sidewalk width in terms of route times and congestion levels were accompanied by the increase in the attractiveness of the area. Figures 16 and 17 show the current design of Asunción, which is now the first pedestrian area outside the historical city centre of Seville while maintaining accessibility for residents and delivery vehicles.

Figure 16: Current view of Asunción street, after the implementation of the Partial Pedestrianisation scheme.

Figure 17: Load/unload zone in one of the streets adjacent to Asunción.

Although the quantitative results of the likely outcomes of the modified scenarios were estimated, it is clear that the presence of many different stakeholder groups in the area (residents, shop owners, workers, drivers, delivery companies, buses, taxis, etc.) made it appropriate to complement the simulations with evaluation techniques aimed at estimating a general score from the opinions of all stakeholders. Nevertheless, the results after the first year of a pedestrianised Asunción street have confirmed the simulation forecasts, and the new design of the street and the new mobility patterns in the area are now accepted by all the stakeholder groups involved. Further research goals include the quantitative evaluation of this type of policies in a multi-actor environment, following the example of Taniguchi and Tamagawa (2005).

Finally, with respect to the simulation process itself, the operation of delivery vehicles in the area required the use of a general-purpose package like Arena. Its flexibility enabled us to accurately simulate the complex transport environments in the area, with acceptable representative results. However, since we used a generic simulation package and not a specific traffic simulator, we had to face the drawback of building the simulation model almost from scratch for each analysis.

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