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## **SIMULATION OF ILLEGAL DOUBLE PARKING: QUANTIFYING THE TRAFFIC AND POLLUTANT IMPACTS**

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### **ABSTRACT**

In many cities around the world illegal parking is a common occurrence, often caused by deliveries to shops alongside roadside parking and double parking near commercial activity. Case studies and research in Boston (USA), Parma (Italy), Rio de Janeiro (Brazil) investigated the frequency of occurrence of illegal parking behaviour depending on vehicle type. Illegal parking affects traffic flow especially in terms of causing congestion, increasing delays and creating queues. As a consequence it contributes to the elevation of pollutant concentrations in urban areas.

This paper reports on a study of the effects of illegal parking in an urban area of Palermo. A site where there is an high frequency of illegal double parking occurring was identified. A micro-simulation model was set-up, calibrated and validated using measured traffic parameters and available second by second emissions factors. Confident that the micro-simulation model was able to characterise double parking a set of different illegal double parking situations were designed, modelled and from the simulated outputs the environmental and traffic impacts were analysed.

This study demonstrated that the DRACULA (Dynamic Route Assignment Combining User Learning and microsimulAtion) successfully modelled Italian characteristics and the illegal double parking phenomenon through a statistical representation of the location along the road, the duration and frequency of occurrence of illegal parking incidents based on direct observation over a period of six months. It was clear that the illegal parking was governed by the commercial activities along the street. Impacts were quantified not only qualitatively but quantitatively and included impacts relating to traffic (such as length of queues, capacity) and the environment (in terms of vehicle emissions). The results showed how illegal double parking increasing congestion, delays and creating queues.

Finally, two short-term inexpensive and a medium to long term strategy that would reduce the occurrence of illegal parking and consequential effects, are presented.

*Keywords: illegal double parking micro-simulation, congestion effects, environmental impacts*

## 1. INTRODUCTION

In many cities around the world illegal parking is a common phenomenon often caused by deliveries alongside shops with roadside car parking arrangements and double parking near commercial activity. Studies and research carried out in Boston (USA), Parma (Italy), Rio de Janeiro (Brazil) has established the frequency of illegal behaviour for different vehicle types. The results of a survey in Parma demonstrated that respectively for light and heavy vehicles illegal double parking was found to be 53% and 47% (Zatti A. 2005). The survey differentiated the illegal parking behaviour into two different kinds:

- when the behaviour is dictated by a commercial vehicles, we are in presence of illegal double parking of lorries, trucks or heavy goods vehicles;
- when dictated by private car drivers it is associated with the driver fulfilling personal activity namely refreshment in a café, shopping, collecting a newspaper, etc.

The characteristics of these two kinds of illegal parking are quite different in some aspects. The former is characterised by long durations typically hours and at locations along specific roads with commerce. The durations are often governed by the volume of loading and unloading, a duration that can often be estimated with some degree of accuracy; the second is more difficult to quantify and to forecast because it is driven by the personal need for a certain activity and depends on other users of the road which governs the use of the legal on-street parking. Estimating the location and duration of such double parking activity is a real challenge. The only certainty is that this second kind of illegal parking occurs frequently mainly during the working hours (9:00am to 1:00pm and 4:00pm to 8:00pm).

## 2. ILLEGAL PARKING AND PREVIOUS STUDIES

Intuitively this phenomena influences traffic flow especially in terms of congestion, delays and queues, and therefore elevates pollutant concentrations in urban areas. Double parking is a key contributor to congestion on major corridors. Whilst local congestion is inevitable there is often a wide-ranging impact on the network. Simply lane blocking reduces the capacity of the street to handle the normal traffic flow and has particularly detrimental effects when the double parking occurs during peak commuting hours.

Illegal double parking creates other negative impacts:

- increased traffic on residential streets when motorists rat-run to avoid congestion on major corridors;
- degradation in the quality of bus services in the locality;
- increase accident risk for pedestrians when double-parked cars block sight lines especially when crossing the road;
- safety concerns for motorists and cyclists manoeuvring around double-parked cars;
- elevated pollution levels
- unnecessary use of fuel and elevated carbon emissions.

Until now studies of congestion have mainly considered recurrent events (eg football and event traffic - Tate J.E., Bell M.C., 2002) and that caused by incidents (Bell M.C., Wang W., Chen H., 2006) Whilst modelling of recurrent congestion is relatively straightforward it is more difficult for congestion resulting from illegal double

parking and a real challenge for incidents. (Cedar A., Livneh M., 1982 - Guiliano, G., 1989 - Kockelman K. M., Ma J., 2004). The important differences between the congestion resulting from incidents and illegal double parking are, above all the frequency of occurrence and the forecast of the location. In fact an incident can occur in theory whenever and wherever within an urban network and is not generally repeated in the short term. On the other hand an illegal parking event can occur frequently and at predictable locations such as in the vicinity of an attractor sites (florists, tobacconists, bar, news paper's, etc.) and in general more frequently.

A site in Palermo, where the illegal double parking occurs frequently, was chosen specifically for this work to study the various characteristics of the illegal double parking phenomenon.

### **3. METHODOLOGY**

A micro-simulation model was set-up, calibrated and validated using measured traffic parameters and available second by second emissions factors. Confident that the micro-simulation model was able to characterise double parking a set of different illegal double parking situations were designed, modelled and from the simulated outputs the environmental and traffic impacts were analysed.

The following methodological approach was adopted in this study:

- carry out several months of observations and characterise illegal double parking as distributions of time of occurrence, location and duration;
- set-up the micro-simulation model to enable the traffic parameters and emissions to be quantified;
- calibrate the model parameters to reflect the Italian driver behaviour;
- develop the mechanism and characterise double parking within the DRACULA model using reserved lane for dummy vehicles.
- create and formulate the illegal double parking scenarios and simulate the observed situations;
- carry out an analysis of the outputs and determine for each scenario a comparison with the base scenario without illegal parking. The effects were quantified in terms of congestion (queue length and capacity) and major emissions (N.B. emissions were calculated per vehicle and normalised to link length to enable comparison);

and finally

- short term solutions to address the illegal parking phenomena were formulated and the potential benefits investigated.

### **4. SITE DESCRIPTION**

The study region (Figure 1) chosen for this investigation of illegal parking behaviour was the Notarbartolo Street in the city of Palermo. This is a main road that has two lanes downstream and three lanes upstream with a co-ordinated fixed-time sequence of five signal controlled junctions. The two lane roadway has a bus lane shared with other vehicles, whilst in the opposite direction one of the three lanes downstream is a dedicated lane reserved for buses.

The flow profiles observed along this road showed no obvious peak periods evident during the working hours of each typical daily flow profiles defined using a statistical methodology developed by Grant and Bell (1983). The flow values observed between 08:00hrs and 20:00hrs were respectively, typically 1,200 veh/h and 900 veh/h in the downstream and upstream direction. One of the main reasons that encouraged us to investigate on the dynamics of the illegal double parking phenomena was the measured difference between the expected capacity and the real capacity of the main road. The difference was essentially due to the prevalence of congestion that was difficult to explain by other “traffic reasons” apart the driver behaviours. In the region chosen for this study is characterised by an high frequency of illegal double parking events, especially downstream after Morello street and upstream between Libertà road and Lo Jacono Street.

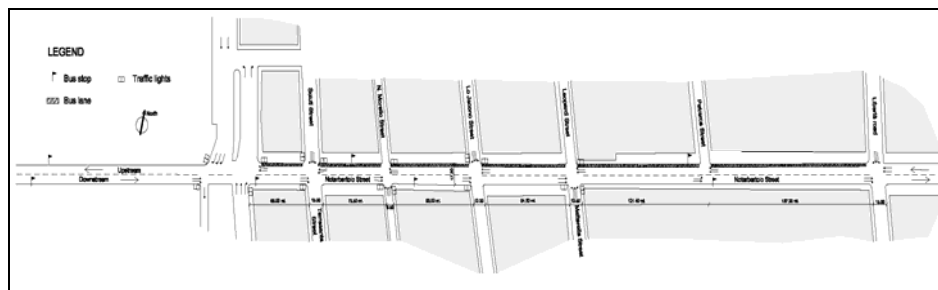


Figure 1 Study area

## 5. MODEL SET- UP

The traffic simulation model used in this work was DRACULA (Dynamic Route Assignment Combining User Learning And microsimulation) a dynamic network microsimulation framework developed in the Institute for Transport Studies (University of Leeds, UK), Liu (1994), Liu (2002).

The model attempts to represent the behaviour of individual drivers and vehicles in real-time as these move from day to day. This is coupled with a detailed within-day traffic simulation model of the second-by-second movements of individual vehicles according to car-following, lane-changing rules and traffic controls.

Moreover recently, Dr. J.E. Tate enhanced and calibrated an emission model for DRACULA based on the CMEM Emission Model. This has been used in this work.

The data needed to set up the DRACULA model relate to:

- the network (physical geometry, location of nodes, link widths, nos. of lanes, bus stops locations, car parking, traffic signal timings);
- traffic (Origin/Destination pair, turning movements and link counts, journey times node by node, delays, queue length (or nos of vehicles), saturation flows)

The Palermo network was set-up by conducting several types of survey including:

- manual (geometric parameters, turning movements etc);
- using GPS technologies to track and measure journey times along all roads in the study area;

- using video surveys from the junction corners and from the eighth floor of a building situated in the centre of the main road of the simulated network.

### 5.1 Manual

The manual surveys were used to measure geometrical and traffic details (bus stop locations, number of lanes, bus reserved lanes, link length and wide, junction structures, etc), traffic light characteristics (cycle time, stages, inter-green, offsets, etc.).

### 5.2 GPS on probe vehicle

The GPS technology was used to evaluate the average speed in each link of the network and to estimate the journey time in several O-D pairs and along each link during different hours of the day.

### 5.3 Video

Finally, the majority of data was captured from the video surveys which were used to evaluate the capacity of the roads, the saturation flows, the average speed along the main road of the network, to estimate the acceleration rates of vehicles away from at signalised junctions, the length of queues, illegal parking locations and durations etc.

## 6. MODEL CALIBRATION

The second biggest challenge of this work, and the one which required the most effort, was calibrate the DRACULA model to represent realistically “*Italian/Sicilian driver behaviour*”.

The parameters examined were:

- speed (desired speed factor, maximum, average, variance)
- acceleration (maximum, average, variance)
- deceleration (maximum, average, variance)
- reaction time (start after green)
- gap acceptance parameters (minimum safety distance, .....

The speeds and gap acceptance were observed from the video surveys at different times of the day to investigate any behavioural differences during different traffic conditions. The average speed in the proximity of a signalized junction was studied using the video recordings made from the eighth floor of a building situated at an intersection corner. This was achieved by dividing the screen in seven equal spaces and the speed and the gap between two consecutive vehicles was measured. These data were verified using the independent measure of speed derived from runs made by a probe vehicle.

With manual and video surveys allowed vehicle classification (motorcycle, car, van, HGV, bus).

The reaction time was measured both manually and from the videos which were particularly useful during high traffic flow conditions but not congested. This was due to masking of smaller by larger vehicles and counting the shear volume of vehicles became very difficult.

The video surveys were used also to quantify the saturation flow at junctions along the main road in each direction. This was calculated by counting the number of vehicles (delayed in a queue) that discharged during consecutive 6 second periods at the stop line each cycle and estimating the slope of the cumulative curve.

The capacity of the road was established in a previous study (Bell, Galatioto 2006) which investigated how the pollution concentration at the roadside was affected by the traffic flow monitored by four city council loop detectors located on the study region. This comparison showed that for all lanes in both direction the road capacity was 2,000 veh/h.

However, to calculate the road capacity in each direction separately was not straight forward because of the illegal double parking and the close proximity to a downstream of signalized intersections. In this work the capacity was estimated to be the ratio of the green duration to the cycle time multiplied by the saturation flow. The DRACULA model was used to output these values to estimate the capacity with and without illegal parking and for different locations of the illegal parking.

The research by Bruno, Rizzo 2004, showed that drivers, even if having the right of way, divide their crossing manoeuvre of an urban intersection into two different phases, the first slowing down: deceleration and speeding up: acceleration. From this previous study were taken measured driver deceleration as 0.8 - 2.1 m/sec<sup>2</sup> and acceleration 0.9 - 2.1 m/sec<sup>2</sup>; the driver on one occasion carried out this emergency manoeuvre but only on a few occasions and even then the maximum deceleration value has never exceeded 3.7 m/sec<sup>2</sup>.

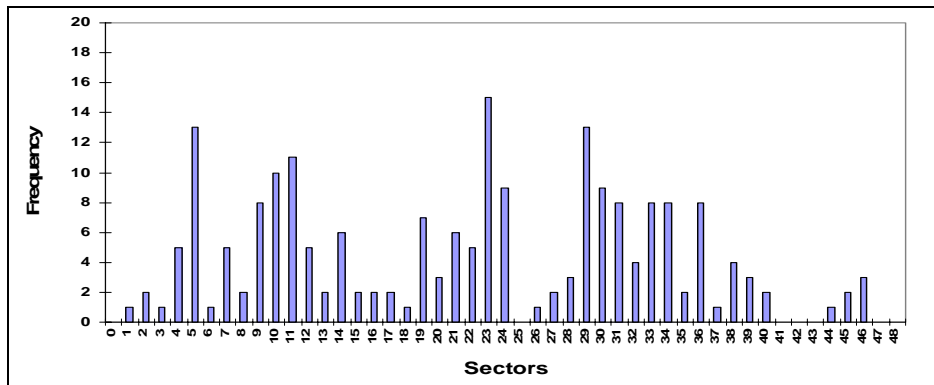
## 7. CHARACTERISATION OF ILLEGAL DOUBLE PARKING

Confident that the DRACULA model was validated for Italian/Sicilian drivers efforts were channelled into developing a way to model the phenomenon in DRACULA.

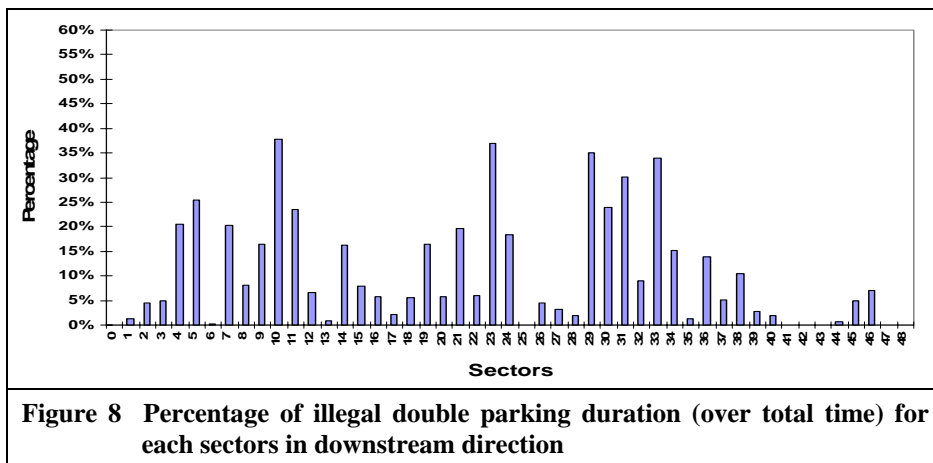
The first step was to carry out video surveys (from the 8<sup>th</sup> floor of a centre of the road building) of the illegal driver behaviour (with or without a ticket, both upstream and downstream) along a 550m section of Notarbartolo street (from Libertà road to Sciuti Street ) using / hours of video recordings collected over different periods of the day. The location, time of occurrence and duration of the illegal parking periods were noted., The geometry of the road was mapped (identifying the location of pedestrian crossing, bus stops, entrance/exit to/from garage or residential parking, etc. The street was divided into “sectors”, defined as approximately either two vehicle or two shop-window lengths (typically of length 7÷12 meters. Each sector was assigned a code or name, from A0 to A48 which was associated with building namely shops, banks, schools, offices, etc. The illegal parking was strongly related to commercial activities, the main offenders being the customer/client rather than shop deliveries and usually occurred each day throughout the week during the working/shopping hours (8:30 to 13:30hr and 16:00 to 20:00hr).

In order to establish the prevalence of the illegal double parking elsewhere in the city of Palermo and whether or not the same characteristic behaviour were exhibited, the surveys were extended over a wider area. In this way a unique database of illegal double parking in Palermo was developed. Interestingly, the analysis demonstrated that illegal parking was most likely to occur on 1-way roads with two lanes or more, and in most cases the reduction of effective width road is near 2/3.

An analysis of the survey data recorded over three morning periods, both with and without traffic restriction, for twelve hours each period and four afternoon for twelve hours of observation, provided the frequency of occurrence and the percentage of duration of illegal double parking downstream and upstream during the morning period (9:00 – 13:00hr). In the downstream direction the illegal double parking occurred evenly along the whole street whilst in the upstream direction the illegal parking was concentrated in four specific locations all sectors corresponded to jewellery, clothes shops, tobacconist and cafes. Figures 7, 9 and 8, 10 are respectively the frequency distribution for the occurrence in each coded sector and the percentage of illegal parking duration for the downstream and upstream road sections. This data formed the basis of the simulation in DRACULA.



**Figure 7** Illegal double parking frequency of occurrence for each sectors in downstream direction



**Figure 8** Percentage of illegal double parking duration (over total time) for each sectors in downstream direction

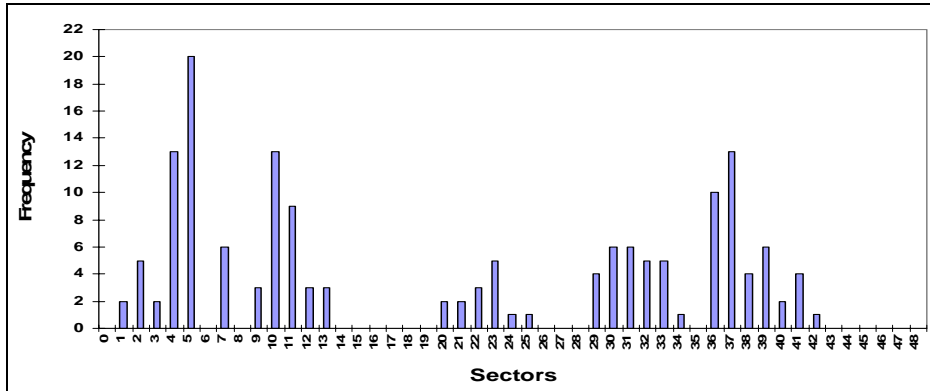


Figure 9 Illegal double parking frequency of occurrence for each sectors in upstream direction

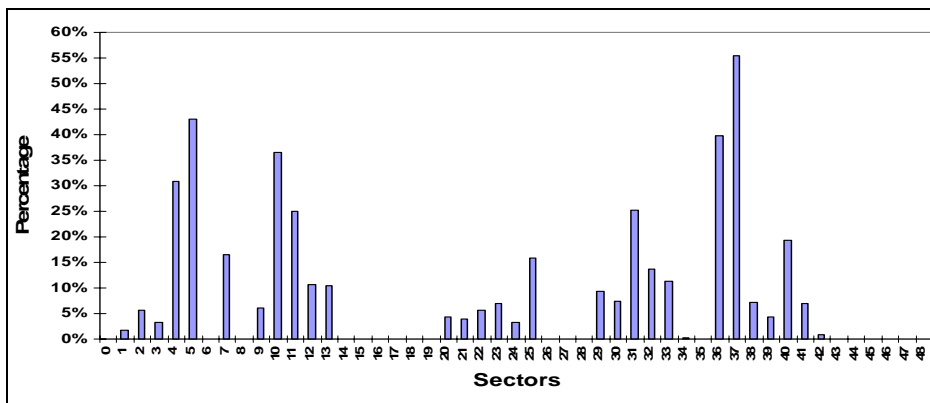


Figure 10 Percentage of illegal double parking duration (over total time) for each sectors in upstream direction

## 8. SIMULATION OF THE ILLEGAL DOUBLE PARKING

This paper reports the results of an unique application of the DRACULA to model illegal parking, a phenomenon which is uncommon in the UK. On advice of the author of DRACULA (Liu R.) two approaches to modelling the illegal double parking were identified.:

1. the first using the bus stop facility modifying public demand (number of passengers embarking and alighting the bus at each bus stop and the 'opening door time' as proxy for each 'illegal event'. However this approach did not work for three main reasons



- it was not possible to measure the stationary time of the illegal parking, because the bus stop duration is not predefined;
  - because the vehicles behind the bus stopped did not over take the bus but awaited its departure
  - because the bus acting as an illegally parked vehicle has associated with it a small but not negligible emission contribution as is the case for a parked vehicle.
2. the second approach used the so called dummy reserved lane feature in DRACULA. This function allows dummy vehicles to be stopped for a specified duration at a re-defined location, most importantly:
- the vehicles approaching must safely over take into the nearest lane
  - the dummy vehicle in the reserved lane can be identified as having zero emission.

Consequentially, the simulation using this second approach was shown to be more realistic .

### 8.1 Simulation of different scenario

In this research programme the DRACULA model was set up and comprehensively calibrated and validated to ensure that the approach adopted resulted in realistic representation of the actual phenomenon and that 15 runs of the model were necessary to gain parameters that were reasonably representative of reality.. Also, several scenarios, based on the direct observations were studied, these results of which have formed part of a successfully defended PhD Galatioto F., 2007. Due to constraints on paper length, the results of one scenario namely that occurring between two closely spaced signalised junctions, is reported here. The results of the verification and other scenarios will be reported in published journals in due course.

The simulation of the illegal parking between two closely traffic spaced signalised junctions was modelled for four different durations namely for 6, 12, 18, and 28 minutes and for three different origin destination matrices ~ 1200 veh/hr (congested), ~ 800 veh/hr (high), ~ 500 veh/hr (light). (*NB these values are referred to traffic flow in the downstream direction on main road*). In this way the different impacts on the congestion (in terms of queue length and capacity restriction) and varying the flow along the main road to understand in which conditions the illegal double parking generates the major negative impact can be studied. Each simulation was run for a main period of one hour.

## 9. RESULTS

The important contribution of this present work are essentially:

- for the first time the traffic microsimulator, DRACULA, was set and calibrated in a real network in Palermo, using driver behaviour and traffic parameters. This provides a useful tool to evaluate different effects of actual and future policies or traffic infrastructures, besides the evaluation of effects of illegal double parking analysed in this work;

- for the first time the effects of the illegal double parking event in terms of major emissions and increase of congestion (queue length and capacity restriction) have been assessed quantitatively and not only qualitatively.

### 9.1 Impacts on emission levels

The results are presented first in terms of major emissions, comparing the simulation outputs of different illegal parking scenario with the scenario without illegal parking. All the emissions for each link were normalised per unit length to allow comparison of the relative emissions upstream and downstream of the illegal parking in units of grams of CO per metre.

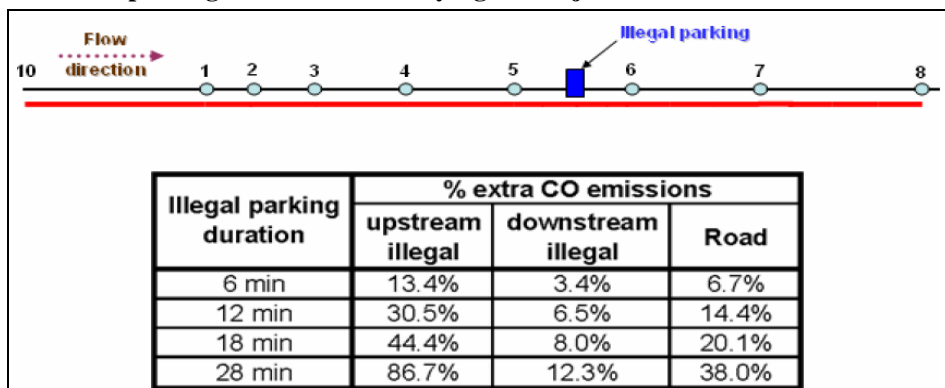
Principal considerations are:

- how levels of emissions vary along the road downstream and upstream of the illegal parking in a complex way;
- how emissions are reduced immediately downstream, for the flow reduction;
- to what extent the emissions gradually increase over time upstream and how much increase depended on the duration of illegal double parking;
- Whilst this is expected this work has been able to quantify these increases and decreases along the link;
- How the effects and propagation along the road are correlated with the position of illegal parking;
- In congested situation, the illegal parking impacts are minor, but increase the time in falling of congestion.

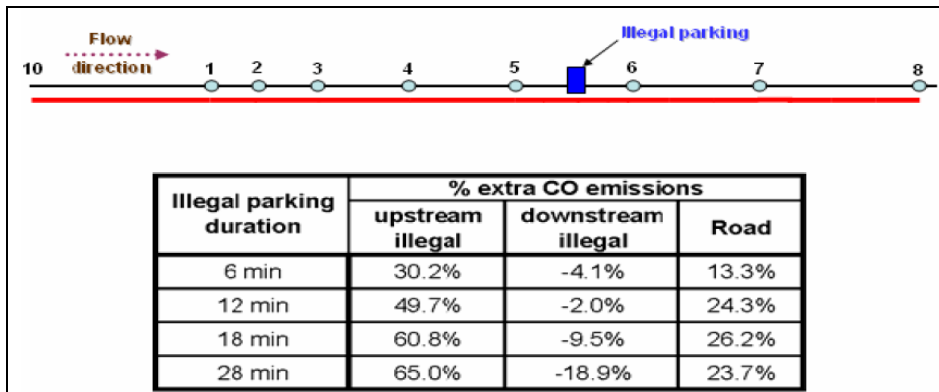
Tables 2 and 3 give the results for the difference of CO emissions produced on each link of Notarbartolo street between the illegal double parking scenario and the legal scenario. Results are presented in three kinds:

- emissions produced in all link downstream the illegal double parking event;
- emissions produced in all link upstream the illegal double parking event;
- emissions produced in all the main road;

**Table 2 Emission effects length normalised with a flow 800 veh/h and illegal parking between two closely signalised junctions**



**Table 3 Emission effects length normalised with a flow 1200 veh/h and illegal parking between two closely signalised junctions**



## 9.2 Congestion impacts

Another result of the comparison of different simulation outputs was the evaluation of the illegal parking impact in terms of congestion.

Principal considerations are:

- congestion levels increase generally over 50% with peaks of 200% in function of the illegal double parking duration;
- negative effects are quantify for illegal double parking durations over 5-6 minutes (in single events or cumulative);
- capacity reduces from 150 to 300 veh/h (15-30%).

In terms of length of queue:

- major absolute increments are observed just before the illegal parking events;
- along the links further upstream of the illegal parking event no queues occurred in the absence of illegal parking;
- the order of percentage of queue length increments is between 200% and 300%;
- for high flow (near congestion conditions) the negative effects tend to 0.

## 9. CONCLUSIONS

This work has demonstrated clearly how illegal parking can be modelled within a microsimulation model. It has derived the characteristics of the driver behaviour in terms of the time of occurrence, the duration and causes of the illegal parking event. In general the events are associated with commuters taking lunch in cafés and bars and shoppers making purchases at small retailers. The illegal parking in Palermo exhibited rather different characteristics to those associated with deliveries as observed in the USA (<http://www.cityofboston.gov/transportation>)

The duration of the parking was typically 12 minutes with a maximum duration over 1 hour for the case of incidences occurring between two signalised junctions. Whilst it is

acknowledged that this work has provided results for a specific event in Palermo and one could argue therefore, that the results are site specific, never the less the research has clearly demonstrated how the consequential congestion elevates emissions significantly.

In this study was estimated emissions increased by as much as 20-25% that could render an area, that otherwise would be compliant, as an ‘hot spot’

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