Using M/M/∞ Queueing Model in On-Street Parking Maneuvers

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Abstract: This paper quantifies the influence badly parked vehicles and on-street parking maneuvers have on average link journey times as a function of the duration of the events and the number of designated maneuvers and flow, by applying an M/M/∞ queueing model in which arrival and departure are all Poisson processes. The method has been validated using microsimulations calibrated by in-situ measurements taken in the streets of the city of Santander (Cantabria, Spain). The analysis on the delays shows a good fit for the M/M/∞ model for flows of 60–70% of capacity where the error is always lower than 5%. This demonstrates the efficiency of the M/M/∞ model for studying how on-street parking maneuvers and badly parked vehicles influence traffic flow and avoids the need to use generally more laborious microsimulation models. Microsimulations are used to calculate the reduction in link capacity for each case in the study and the increases in average journey times for the rest of the road users. This shows the effect that allowing on-street parking on arterial or main roads has on the rest of the traffic.

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CE Database subject headings: Parking facilities; Queueing; Traffic management; Traffic models.

Introduction and Objectives

Most cities in the world are experiencing severe problems caused by increased road traffic in terms of delays, fuel consumption, accidents, noise, and pollution.

The unchecked use and growth of the private vehicle and the great difficulties associated with altering urban infrastructure to keep pace create a very worrying panorama for decision makers trying to provide answers. The situation is made worse in individual locations by the delaying effect of a parking maneuver, or, even worse, the longer effects caused by badly parked vehicles.

Even greater problems appear when something happens to temporarily block a lane on these roads. These incidents could be anything that happens to temporarily reduce the capacity of the road, for example a traffic accident, spillages of dangerous materials, (Faradyne 2000) or, in the particular case covered by this article, badly parked vehicles and parking maneuvers.

The existing supply and usual saturation of parking places along urban streets increases superfluous traffic and reduces circulation times for cars in search of a free space as well as further delays for the rest of the traffic during the arrival and departure maneuvers.

This inevitably leads to a drop in road capacity, with an exponential increase in delays which are not normally considered in mobility studies, but could prove very important when planning timetables for urban public transport.

There are several published works in the worldwide literature which deal with reduced road capacity due to incidents. For example, Goolsby (1971) calculated capacity reduction and concluded that an incident which blocked one lane of three available reduces capacity by 50%; if the incident blocks 2 of 3 lanes, capacity drops by 79%, and, finally, if the shoulder lane is blocked traffic flow drops by 33%.

Mc Shane and Roess (1990) established that, depending on flow conditions and the duration of the incident, a 10% reduction in capacity can change the operating conditions of the road up to saturation.

Gordon et al. (1996) showed that blocking one lane causes a reduction of 65 and 51% for roads with 2 and 3 lanes, respectively. Smith et al. (2003) in a more recent investigation using data from the roads in the Hampton region (Virginia) modelled reduction in capacity by incidents as a random function variable with a Beta distribution. This was used to estimate a fall in capacity of 63 and 77% for 1 or 2 lanes blocked in a 3-lane road; the results were then compared with those of the Goolsby study.

The Highway Capacity Manual (TRB 2000) proposes some estimated values for reduction in capacity, depending on the number of lanes blocked and the number available in each direction.

More recently, Baykal-Gursoy et al. (2006) used microsimulations to compare delays caused by incidents with those obtained applying the M/M/∞ model with Markov modulated service rates which he himself had proposed in a previous article (Baykal-Gursoy and Xiao 2004) where arrival and departure are all Poisson’s processes.

Referring to the influence parking maneuvers and on-street parking in general have on reducing capacity and traffic congestion, Valleeley (1997) establishes a relationship between the number of parked vehicles and the reduction in street width and capacity. Chick (1996) obtains some capacity reduction factors as a function of the number of lanes and the number of parking maneuvers per hour, the results appear in HCM 2000. Younis and Purnawan (1999) analyze the delays caused by entering and de-
departure on-street parking maneuvers, differentiating between parallel and angle on-street parking, finding that entering maneuvers take more time than departure maneuvers, and that parallel parking is less problematic than angle parking.

In other lines of investigation, Box (2004) analyzes accidents caused by street parking and looks at how maneuvers influence congestion. Ukpong et al. (2005) compare pollution levels and journey times in streets with and without available parking.

Finally, Tanaka et al. (2006) analyze driver behavior in a similar situation to vehicles badly parked on the curb which occupy part of the adjacent lane, using a virtual reality machine to evaluate the routes taken by the vehicles, analyze the maneuvers when changing lanes and the perception of the drivers, etc.

This article assesses badly parked vehicles separately from incidents as such, because observation has shown that other vehicles behave differently in each case. When an incident takes place the phenomenon known as rubbernecking happens but is much less with a badly parked vehicle. Rubbernecking is the modification in driver behavior in the lanes adjacent to an incident, when passing next to the point where the incident has taken place they tend to reduce speed, for safety reasons and to have a look at what happened, creating an additional reduction in capacity. According to Smith and Ulmer (2003), this reduction could be up to 10% in each lane, the reduction in capacity caused by badly parked vehicles should be lower. From here on the badly parked vehicle will be termed an “event.”

So, on the one hand, this article will look at the influence both of parking maneuvers and badly parked vehicles (events) on average journey times and lane capacity and, on the other hand, a queue model will be applied to estimate delays, incorporating a tool which is easier to apply than microsimulation.

The bibliographic revision referred to articles which studied the reduction in capacity of a route and the delays caused by incidents and which also analyze the influence of parking maneuvers on traffic flow. However little investigation has been done on the influence of badly parked cars on route capacity and delays, where, as explained earlier, the effect of rubbernecking is reduced, this is one of the subjects covered in this article. :

- Apply an M/M/∞ queueing model to simulate the effect of parking on average link journey times.
- Calibrate a microsimulation model to evaluate the influence on capacity of badly parked vehicles and parking maneuvers, at the same time registering the delays that have been caused.
- Compare the results of the M/M/∞ queueing model with those of the microsimulations for their validation.

In the “Microsimulation Model” section this article describes the calibration process of the microsimulation model, then, it puts forward the M/M/∞ queueing model which will be applied in this study to estimate link journey times due to the presence of parking maneuvers. After that, there is an initial estimation of the reduction in capacity and average journey times as well as changes in velocity caused by badly parked vehicles. Later, the M/M/∞ queueing model is again applied to simulate journey times due to parking maneuvers. Finally, it puts forward the main conclusions that can be drawn from this investigation.

**Microsimulation Model**

The microscopic simulation model (see Fig. 1) was calibrated (Hourdakis et al. 2003) by measuring the variables most representative of the state of the traffic in different route sections in the study area (Barceló and Casas 2004). Data on traffic flow, velocity, density and headway were obtained from the traffic counters positioned by the technical department of Santander City Council for both rush hour and off peak for a representative week in autumn 2007. For discharge flows, owing to the small percentage of heavy vehicles inside the city and the typology of the intersections, it was decided to apply the TRL method (TRRL 1963).

These principal traffic characteristics represent the inputs for the microsimulation software AIMSUN (TSS 2006), which uses the vehicle behavior model (car-following and lane changing model) of Gipps (1986), and establishes that the objective velocity will be a function of the maximum desired velocity, the active speed limit and the limits imposed by the vehicle in front.

In turn, the lane changing model is represented by the decision diagram shown in Fig. 2. This model defines 3 zones during the period leading up to an event, in each of which the need to perform a maneuver increases as the vehicle approaches the event.

Therefore, the reality of situations of free flowing traffic and of traffic interrupted by events and parking maneuvers must be replicated during the calibration of the microsimulation model.

As stated previously, data obtained from traffic counters has been used in both cases for the measured lanes. Fig. 3 shows the fit between the speed/density and cumulative number of vehicles curves for a real traffic counter located in the study area and the equivalent counter used in the microsimulation corresponding to Section C of Fig. 4.

In order to model the behavior of vehicles when faced with the described situations, video recordings have been used. The main objective was to measure the distances in which drivers start to try to change lane once they realize there is an event or parking maneuver taking place as well as to measure the maximum give way times to perform this maneuver. Underestimating this latter parameter leads to overestimating waiting times, given that once a certain period has passed drivers will tend to force the critical gap which allows them to make their move.

Lengths of queues, number of vehicles in queues and average journey times have also been compared along with arrival patterns to check they fit a Poisson’s distribution (exponential).
The observed cases which were used for calibration are shown in Table 1. Next to the flow data is the peak hour factor (phf) which provides more information on how average flow changes depending on the time of day. Floating vehicles with GPS made the measurements of the real journey times (Jiang et al. 2006; Bishop 2004). Two vehicles travelled up and down the studied link several times for each of the situations presented in Table 1. Both were equipped for second by second storage of data.

Therefore, Table 2 shows, for each situation in Table 1, the journey time value, number of test runs, along with the standard deviation obtained for each situation, differentiating the results obtained when an event occurred from those obtained without event.

Average trip time ($TT$) in a section ($s$) is given by the expression

$$TT_{is} = \frac{\sum_{i=1}^{N} t_{ti}}{N}$$

where $t_{ti}$=time taken by vehicle $i$ to cover section $s$; and $N$ =total number of vehicles which have covered section $s$.

The delay suffered ($dT$) by a vehicle $i$ in crossing section $s$ will be

$$dT_{s} = TT_{is} - \left[ \frac{L_s}{\text{Min}(S_{max},S_{t},\theta_i)} + \frac{L_s}{\text{Min}(S_{max},S_{t},\theta_i)} \cdot \frac{S_{t}}{\text{L}_{s}} \right]$$

where $S_{s}$=speed limit of section $s$; $S_{t}$=turning speed; $\theta_{i}$=acceptance of the speed of vehicle $I$; $S_{max}$=maximum desired velocity of vehicle $I$; $L_{s}$=length of section $s$; and $L_{t}$=distance of turn $t$.
Logically, the average delay will be

\[ DT_s = \frac{\sum_{i=1}^{N} d_{tis}}{N} \]  

(3)

### M/M/∞ Queueing Model

Baykal-Gursoy et al. (2006) applied the M/M/∞ queueing model with Markov modulated service rates (Baykal-Gursoy and Xiao 2004) to simulate the effects incidents have on delays. In their work they considered that the space occupied by a vehicle in a section of road is a server that starts giving service when a vehicle enters the section of road and continues doing so while the vehicle travels to the end of the link.

The M/M/∞ queue is a model in which the arrivals and departures have a Poisson’s distribution. It assumes the existence of an infinite number of servers available to the system. It is used to make an approximation to the M/M/C model (Baykal-Gursoy and Duan 2006), with a sufficiently large number of servers.

To simulate the effects on congestion caused by incidents, the servers do not work or rather function at a below normal rate of service \( \mu’ \), normality returns once the incident is cleared. The model calculates the expected number of vehicles in the link using the following expression:

\[ E(X) = \frac{\lambda}{\mu} + \frac{\lambda \cdot f \cdot (\mu – \mu’)}{\mu^2 \cdot (r + f)} \cdot \left( 1 + \frac{(f + \mu) \cdot (\mu – \mu’)}{(r \cdot \mu + f \cdot \mu’ + \mu \cdot \mu’)} \right) \]  

(4)

Average trip time being

\[ W = \frac{E(X)}{\lambda} = \frac{1}{\mu} + \frac{f \cdot (\mu – \mu’)}{\mu^2 \cdot (r + f)} \cdot \left( 1 + \frac{(f + \mu) \cdot (\mu – \mu’)}{(r \cdot \mu + f \cdot \mu’ + \mu \cdot \mu’)} \right) \]  

(5)

To adapt Eqs. (4) and (5) to the characteristics of the link, the parameters must be transformed in the following way: capacity: \( L \cdot K_{max} \); rate of arrivals: \( \lambda = D/\text{veh/h} \); rate of service without incidents: \( \mu = v/L \); rate of service under incident conditions: \( \mu’ \).

### Table 1. Comparison of Results between the Real Data, the Queueing Models, and the Microsimulation

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Flow (veh/h)</th>
<th>phf</th>
<th>No. of maneuvers</th>
<th>Event</th>
<th>Probe vehicle sample size</th>
<th>Real data</th>
<th>Microsimulation</th>
<th>M/M/∞</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2,983</td>
<td>0.93</td>
<td>20</td>
<td>—</td>
<td>61</td>
<td>31.49</td>
<td>30.35</td>
<td>32.75</td>
</tr>
<tr>
<td>2</td>
<td>1,790</td>
<td>0.89</td>
<td>—</td>
<td>8 min</td>
<td>66</td>
<td>28.96</td>
<td>28.84</td>
<td>29.47</td>
</tr>
<tr>
<td>3</td>
<td>1,437</td>
<td>0.87</td>
<td>11</td>
<td>—</td>
<td>68</td>
<td>28.81</td>
<td>28.92</td>
<td>28.73</td>
</tr>
<tr>
<td>4</td>
<td>3,989</td>
<td>0.97</td>
<td>—</td>
<td>15 min</td>
<td>57</td>
<td>56.44</td>
<td>57.38</td>
<td>41.2</td>
</tr>
</tbody>
</table>

The time interval considered for data collection was 10 min, rather than the more traditionally minimum recommended 15 min. This value has been shown by (Smith and Ulmer 2003) to be enough for evaluating a stationary situation in traffic conditions.

Fig. 5 shows that the capacity of the lane containing the event goes down as the section under consideration gets nearer to the event. Once the event is passed traffic always returns to the stable side. The free lane also suffers worsening traffic conditions owing to the incident.
to the lane changes, although, logically, this is not as bad as in the lane with the event, and the free lane’s capacity is slightly surpassed.

Table 3 provides a summary of the results obtained and shows that a vehicle which is badly parked for only 15 min implies a 14% reduction in the hourly flow of vehicles in a 2-lane road. This implies an important modification of the flow-delay curve, because the delays increase exponentially with respect to the event free situation, as with McShane and Roess (1990). In fact, with 50% capacity flows on the link, a vehicle stationary for 15 min produces a 57% increase in average journey times, and up to 107% when the event lasts 30 min.

The reduction in flow and the increase in average journey times are, logically, greater the longer the event goes on for, obtaining saturation-delay curves which tend to be asymptotic to the value of the new capacity registered, capacity drops to 53% when the event lasts a complete hour. As explained earlier this reduction is less than found in other studies because of the lesser influence of “rubbernecking” in an event of these characteristics.

Applying the M/M/∞ model produces a good fit for lower degrees of congestion with maximum flows of 2,000–2,500 vph, representing 60–70% of capacity (Fig. 6). This is within what was to be expected, given that in cases of high congestion there are other distributions which fit better, such as a Binomial distribution or the Generalized Poisson distribution, besides, the congestion of the downstream links (spill-back) means that the delays are not exclusively due to what is occurring on the link in the study and, finally, the hypothesis of infinite servers cannot be assumed for very high flows, which would have a M/M/C queueing model (Baykal-Gursoy and Duan 2006).

Table 3. Flow and Delays for Different Event Durations Obtained from the Microsimulation

<table>
<thead>
<tr>
<th>Flow (veh/h)</th>
<th>2 lanes</th>
<th>No event</th>
<th>15'</th>
<th>30'</th>
<th>45'</th>
<th>60'</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>500</td>
<td>0.106</td>
<td>0</td>
<td>510</td>
<td>0.109</td>
<td>0</td>
</tr>
<tr>
<td>1,000</td>
<td>993</td>
<td>0.211</td>
<td>0.25</td>
<td>999</td>
<td>0.213</td>
<td>0.50</td>
</tr>
<tr>
<td>1,500</td>
<td>1,497</td>
<td>0.319</td>
<td>0.25</td>
<td>1,515</td>
<td>0.322</td>
<td>1.83</td>
</tr>
<tr>
<td>2,000</td>
<td>1,765</td>
<td>0.376</td>
<td>0.15</td>
<td>1,753</td>
<td>0.373</td>
<td>3.50</td>
</tr>
<tr>
<td>2,250</td>
<td>2,252</td>
<td>0.479</td>
<td>0.45</td>
<td>2,238</td>
<td>0.476</td>
<td>14.25</td>
</tr>
<tr>
<td>2,500</td>
<td>2,496</td>
<td>0.531</td>
<td>0.45</td>
<td>2,473</td>
<td>0.526</td>
<td>25.42</td>
</tr>
<tr>
<td>2,750</td>
<td>2,765</td>
<td>0.588</td>
<td>0.5</td>
<td>2,760</td>
<td>0.588</td>
<td>30.02</td>
</tr>
<tr>
<td>3,000</td>
<td>2,982</td>
<td>0.634</td>
<td>0.6</td>
<td>2,973</td>
<td>0.581</td>
<td>34.98</td>
</tr>
<tr>
<td>3,250</td>
<td>3,288</td>
<td>0.700</td>
<td>0.75</td>
<td>3,286</td>
<td>0.609</td>
<td>40.12</td>
</tr>
<tr>
<td>3,500</td>
<td>3,508</td>
<td>0.746</td>
<td>0.9</td>
<td>3,508</td>
<td>0.746</td>
<td>37.96</td>
</tr>
<tr>
<td>3,750</td>
<td>3,779</td>
<td>0.804</td>
<td>1.45</td>
<td>3,779</td>
<td>0.804</td>
<td>48.23</td>
</tr>
<tr>
<td>4,000</td>
<td>4,004</td>
<td>0.852</td>
<td>2.58</td>
<td>4,021</td>
<td>0.856</td>
<td>65.15</td>
</tr>
<tr>
<td>4,250</td>
<td>4,238</td>
<td>0.902</td>
<td>3.25</td>
<td>4,297</td>
<td>0.902</td>
<td>64.65</td>
</tr>
<tr>
<td>4,500</td>
<td>4,477</td>
<td>0.953</td>
<td>6.00</td>
<td>4,973</td>
<td>0.953</td>
<td>64.65</td>
</tr>
<tr>
<td>4,750</td>
<td>4,692</td>
<td>0.998</td>
<td>9.04</td>
<td>4,973</td>
<td>0.998</td>
<td>64.65</td>
</tr>
</tbody>
</table>

Fig. 5. (Color) Representation of flow-speed, flow-density, and speed-density diagrams for an event lasting 30 min
On this occasion parking maneuvers are introduced as high frequency short duration events. According to the data collected, the average parking time introduced is 30 s, at frequencies of 10, 20, and 30 maneuvers/h. That data was obtained by measuring more than 240 maneuvers on several streets of Santander, providing the duration of the events and their distribution in time.

The number of parking maneuvers was varied as previously indicated by using 10, 20, and 30 maneuvers/h. For each of the cases studied 200 replications were made to validate and compare the results of both models.

During a parking maneuver the lane is temporarily cut at one point. Depending on the traffic intensity in the adjacent lane the vehicles try to change lane to avoid the obstacle. Until this maneuver is completed the speed is reduced and often comes to a complete stop if the maneuver wasn’t possible. For certain traffic intensities lane changes imply a reduction in traffic flow in the free lane. The measurement of velocities registered during the parking event is the input data for the model as the value of parameter $\mu$. This behavior appears in Fig. 7 showing the temporal variations in lane speed and occupancy for the different traffic intensities.

Table 4 shows the results and the comparison of the queue model with the microsimulations. Capacity reductions of 6, 10, and 16% can be seen for 10, 20, and 30 maneuvers, respectively. Average journey times increase by 15, 24, and 39%, which demonstrates the huge influence of allowing parking on arterial and busy roads on traffic flow.

The comparison of journey times reflects a good fit for the queue model and the microsimulations (Fig. 8), especially when flows are 60–70% of capacity, where the error is always lower than 5%, from this range on the differences in estimation stay below 14% (Fig. 9).

Conclusions

This paper has shown the validity of the $M/M/\infty$ queueing model with Poisson distribution arrivals and departures for simulating the effect of parking (both maneuvers and badly parked vehicles) on link journey times on two lane roads and for amplifying its field of application.

The journey times obtained in the microsimulations show increases for the rest of the link users of 57 and 107% for vehicles badly parked for 15 and 30 min, respectively, with reductions in roadway capacity of 13 and 27%. The reduction in capacity found on the same road when the event lasted 60 min reached 55%. This is lower than found in the other studies mentioned when dealing with the effects of incidents due to the reduced amount of “rubbernecking.”

For parking maneuvers the microsimulations showed reductions in road capacity of 6, 10, and 16% for 10, 20, and 30 maneuvers, respectively, with average journey time for the rest of the users up by 15, 24, and 39%, thereby demonstrating the influence that allowing parking on arterial or main roads in cities has on the rest of the traffic.

The comparative analysis on average journey times between the microsimulations and the queue model assumes a degree of error which is always lower than 5% when the link is at 60–70% capacity. After this value the results depend on traffic conditions (flow, duration of event, number of maneuvers), being under 14% for all the cases of the number of maneuvers studied.

The efficiency of the $M/M/\infty$ queueing model has been shown for studying the influence of on-street parking maneuvers and badly parked vehicles on traffic and avoids the need to use microsimulation models which are generally much more labour intensive.
Table 4. Flow and Journey Times as Function of Number of Parking Maneuvers; Comparison of Results between the Queue Model and the Microsimulation

<table>
<thead>
<tr>
<th>2 lanes flow (veh/h)</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow</td>
<td>ATT (s)</td>
<td>Flow</td>
<td>ATT (s)</td>
</tr>
<tr>
<td>500</td>
<td>0.106</td>
<td>27.60</td>
<td>0.103</td>
<td>27.72</td>
</tr>
<tr>
<td>1,000</td>
<td>0.211</td>
<td>27.60</td>
<td>0.217</td>
<td>27.77</td>
</tr>
<tr>
<td>1,500</td>
<td>0.319</td>
<td>27.85</td>
<td>0.320</td>
<td>28.32</td>
</tr>
<tr>
<td>2,000</td>
<td>0.427</td>
<td>27.90</td>
<td>0.430</td>
<td>28.74</td>
</tr>
<tr>
<td>2,500</td>
<td>0.531</td>
<td>28.05</td>
<td>0.535</td>
<td>29.07</td>
</tr>
<tr>
<td>3,000</td>
<td>0.632</td>
<td>28.10</td>
<td>0.634</td>
<td>29.07</td>
</tr>
<tr>
<td>3,500</td>
<td>0.745</td>
<td>28.20</td>
<td>0.746</td>
<td>29.07</td>
</tr>
<tr>
<td>4,000</td>
<td>0.853</td>
<td>28.30</td>
<td>0.852</td>
<td>29.07</td>
</tr>
</tbody>
</table>

Fig. 7. Diagrams for speed/time and occupancy/time for a location with 20 maneuvers/h obtained from the microsimulation.
Fig. 8. Microsimulation–$M/M/$ fit for journey times depending on flow and number of maneuvers

Fig. 9. (Color) Relative errors: Microsimulation–$M/M/$ according to duration of event and number of maneuvers

References


