Analysis of the traffic management policy measures adopted in the central business district of Palermo

S. Amoroso, M. Migliore, S. Salerno & P. Zito
Department of Aeronautical and Transportation Engineering, Palermo University, Italy

Abstract

This research analyses the effects on air quality produced by the traffic management measures adopted in the Central Business District of Palermo (i.e. park price, the closure to traffic of Maqueda Road, etc.). Weather data series, pollutant concentrations data series (1997-2003) and the traffic data collected in 2003 were analysed by using different regression statistical models, to appraise the effectiveness of the traffic management policies adopted by City Council, understanding also the cause/effect relationships among the pollutant concentrations (CO, NO_2, O_3, C_6H_6 and PM_{10}) and the traffic flows variations over time.
Keywords: regression models, air pollution, traffic management measures, air quality

1 Introduction

The urban road transport has become the major source of environmental degradation in urban centres, where most of the people live and work. It produces negative externalities (i.e. pollution, congestion, delay, etc.), which are usually connected with the congestion of the traffic flows and the rise of queues on road network. The environmental damage produced by road traffic concerns the pollutant emissions, the noise and also the intrusive occupancy of urban spaces by parking vehicles. All those people, which live, work and for various reasons move in Central Business District of our city centres, are exposed to high pollutant concentration levels near to the road side. In the major of the cases, the regulation tools, introduced by local authorities, are focused to limit air pollution

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generated by road traffic in the urban areas, through: the traffic limitation on some arteries, the limited traffic areas, the park price, the road pricing, the park and ride strategy and so on.

Furthermore, almost all vehicle manufacturers introduce in the market new and less pollutant cars (i.e. low emission vehicles, hybrid and alternative fuel vehicles), which will replace the old cars, reducing the trend of the pollutant emissions and hence of the road side pollutant concentration levels as effectively observed. According to the current literature, the park pricing policy is an effective measure for restraining private trips. The car users can re-schedule off-peak departure time or change their routes, based on costs of their alternatives related to the departure time, eventually the mode change and the route, allowing so, an increase of the modal shift (public and pedestrian mode) and, in general, a reduction in the overall number of car trips.

In order to determine the underlying relationships among a set of input data (weather and traffic data) and targets (pollutant concentrations) and to predict pollutant concentrations, by recent literature, various approach have been used like: atmospheric dispersion models (Chiquetto et al [1], Karppinen et al [2], for a review on atmospheric plume see Middleton et al [3]); regression models (Shi and Harrison [4], Johnson et al [5]); and finally neural network models (Gadner et al [6], and Perez and Trier [7]).

Regression models are generally site dependent, because the pollutant concentrations depend on many factors as: traffic conditions, vehicle characteristics, weather conditions, and geographic and local site characteristics. The effects on air quality produced by the traffic management measures adopted in the Central Business District of Palermo (i.e. park price, the closure to traffic of Maqueda road, etc.) have been analysed, taking into account weather time series, pollutant concentrations time series (1997-2003) and the traffic data collected in 2003 and by using regression statistical models, to capture the cause/effect relationships among the pollutant concentrations and the traffic flows variations over time.

2 Regression models

The general relationship between concentration y and explanatory variables that affect it is:

$$y = F(x_1,\ldots\ldots,x_k) \tag{1}$$

where x_i $(i = 1,\ldots..,k)$ are explanatory variables. According to the form of function $F(.)$ we can have linear regression models expressed as follows:

$$y = \beta_0 + \beta_1 x_1 + \ldots\ldots + \beta_k x_k + e = \sum_{i=0}^{k} \beta_i x_i + e \tag{2}$$

where the random errors e are mutually independent, each with mean zero and variance σ^2 (assuming $x_0 = 1$) and β_i $(i = 0,\ldots..,k)$ are the parameters of model. Whereas the exponential regression models are expressed as follows:

$$y = \beta_0 \cdot x_1^{\beta 1} \cdot \ldots\ldots \cdot x_k^{\beta k} = \prod_{i=0}^{k} x_i^{\beta_i} \; . \tag{3}$$

By using logarithms for both sides of the equation (3), thus it becomes:

$$ln(y) = \beta_0^{'} + \beta_1 \, ln(x_1) + \ldots\ldots + \beta_k \, ln(x_k) \tag{4}$$

where $\beta_0^{'} = ln(\beta_0)$. In this way it is ever possible to use an ordinary least square regression model.

3 Analysis of the pollutants monitored in the CBD

Hourly weather and pollutant concentrations measurements have been collected over five years (1997-2003) at monitoring sites of Castelnuovo Square and Giulio Cesare Square (Palermo). The pollutant concentration data monitored every hour were: carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), benzene (C_6H_6) and particle matter (PM_{10}) expressed in $\mu g/m^3$. The hourly weather data were: rain (R), pressure (Pres), solar radiation (SR), temperature (T), moisture (M), wind speed (WS) and wind direction (WD). Whereas the traffic flow data have been collected since 2003, by loop sensors located close to the monitoring site of Castelnuovo Square in Libertà Street (flow FL1), Roma Street (flow FL2), and E. Amari Street (flow FL3), which outline the study area. Weather and pollutant concentrations data have been cleaned and synchronised with traffic flow data.

The traffic management policy measures adopted in the Central Business District of Palermo, essentially, are: the closure and the following aperture to traffic of Maqueda road (in 1998 and 2002 respectively) and the park price (in 2002). A pre/post survey on traffic flows and origin/destination trips, within the study area, has been carried out by using TModel software, to correlate the pollutant concentrations trend with the traffic management policy measures. The TModel has been used to update the private car origin/destination matrix (related to peak hour 8:00 – 9:00 and the average working day), by knowledge of traffic data monitored on some links of road network. This survey has highlighted that the average reduction of overall trips (produced by park price policy) is equal to 24% with destination the zones: 9 Ruggero Settimo Road, 22 Castelnuovo Square and 23 Politeama Square related to the study area (table 1).

Unfortunately, the monitoring of the benzene began since 2002, therefore the related time series has not permitted to obtain reliable outcomes. A Comparison between the means over 24 hour and peak hour ones (related to traffic flow 8:00-9:00) for each pollutant has been carried out and showed in the following sections. In order to develop suitable control strategies on the air quality in CBD of Palermo, it is hence necessary to identified which input variables can influence the formation process of pollutant concentrations over time, forecasting when acute episodes of air pollution can happen.

Table 1: Number of trips to destination, number of cars/hour for peak hour.

Zones	1996	1999	2003	Differences 1996-2003
9	325	347	265	-19%
22	565	510	460	-19%
23	313	241	196	-37%
Total	**1203**	**1098**	**921**	**-24%**

3.1 Carbon monoxide

Carbon monoxide is an exhaust gas mainly produced by combustion of fuel for domestic boiler and for vehicles in urban areas. The carbon monoxide, when emitted into atmosphere, has a stable behaviour. CO does not change its structure through chemical reactions with other pollutants or substances and it is directly correlated to the traffic flows. Figure 1 shows the yearly mean of CO over time (1997 – 2003).

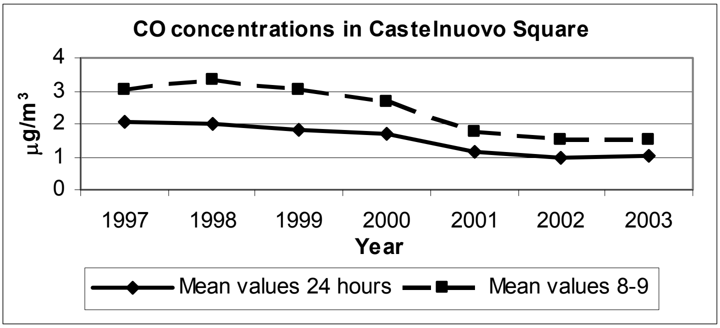

Figure 1: Yearly mean concentrations of carbon monoxide.

It should be noted two important aspects: the former is that, the yearly mean of CO concentration decreases over time; the latter is that, comparing the yearly mean CO concentrations over 24 hours with peak hour ones (8:00-9:00), these have ever higher values and similar trend as expected. The number of times that the warning threshold (regulated by law in force) has been exceeded is equal to 0.02% of whole cases.

Table 2: Results of CO exponential regression model April-December 2003.

Multiple R		0.731					
R Square		0.534					
Adjusted error		0.534					
Standard error		0.370					
ANOVA		DF	Sum of square			Mean Square	
Regression		5	545.067			109.013	
Residual		3454	474.735			0.137	
F = 793.141		Sign. F = 0.0000					
Variable	B	SE B	Beta	Toler.	VIF	T	Sign. T
ln(Const)	38.557	10.117				3.811	0.000
ln(Pres)	-14.407	3.360	-0.054	0.838	1.194	-4.287	0.000
ln(SR)	3.029E-02	0.007	0.068	0.578	1.731	4.446	0.000
ln(T)	-0.684	0.064	-0.138	0.803	1.246	-10.654	0.000
ln(WS)	-1.011	0.032	-0.487	0.577	1.733	-31.869	0.000
ln(FL2)	1.617	0.029	0.703	0.869	1.151	56.400	0.000

The linear regression model includes five most significant variables for CO concentrations: solar radiation, temperature, wind speed, wind direction, flow2 with R = 0.674 and R^2 = 0.454. Better results are obtained by using an exponential regression model with five variables: solar radiation, temperature, wind speed, pressure and flow FL2 (see table 2).

It is useful to underline as the flow FL2 explains the 42.9% of the CO concentration variation. Moreover the overall variance explained by model is R^2 = 53.4%.

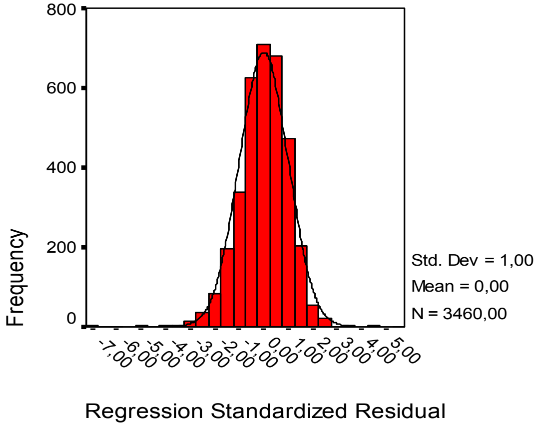

Figure 2: Normality test for the model residual of CO regression.

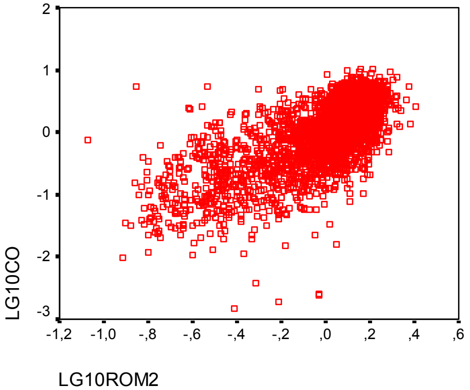

Figure 3: Plot of partial correlation CO concentration versus flow FL2.

3.2 Nitrogen oxides

Nitrogen dioxide NO_2 and nitrogen monoxide NO and are emitted mostly from vehicle exhausts. In comparison with CO, nitrogen monoxide (NO) reacts with ozone (O_3) to form nitrogen dioxide NO_2. NO_2 can revert to CO by sunlight. It has been shown that NO_2 causes adverse effects in pulmonary function when inhaled at high concentrations (Perez and Trier, [7]).

Ozone can cause health hazards and it is also a highly chemical reactive, capable of attacking surfaces, fabrics and rubber materials. The presence of O_3, in lower layers of the atmosphere, causes the rise of photochemical smog and it is the main cause of degrading of air quality in urban areas.

From the figure 4, it should be noted that NO_2 shows a decreasing trend and also the number of times that the warning threshold has been exceeded is equal to 0.14% of whole cases.

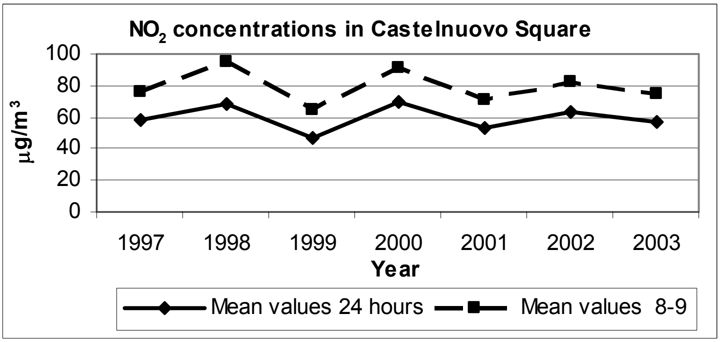

Figure 4: Yearly mean concentrations of nitrogen dioxide.

Table 3: Results of NO2 exponential regression model April-December 2003.

Multiple R		0.695					
R Square		0.483					
Adjusted error		0.481					
Standard error		0.211					
ANOVA		DF		Sum of square		Mean Square	
Regression		6		87.159		14.527	
Residual		2086		93.470		.045	
F = 324.192		Sign. F = 0.0000					
Variable	B	SE B	Beta	Toler.	VIF	T	Sign. T
ln(Const)	.257	.097				2.637	.008
ln(O_3)	-.138	.011	-.237	.717	1.395	-12.753	.000
ln(SR)	7.475E-02	.005	.298	.599	1.668	14.628	.000
ln(T)	-.406	.051	-.139	.826	1.211	-8.001	.000
ln(WS)	-.426	.025	-.377	.524	1.907	-17.344	.000
ln(WD)	-2.982E-02	.008	-.059	.920	1.086	-3.573	.000
ln(FL2)	.623	.022	.505	.807	1.240	28.787	.000

The analysis carried out by linear regression model presents an R = 0.67 and a determination coefficient R^2 = 0.451, considering the following most significant variables: ozone, solar radiation, temperature, wind speed, wind direction and flow FL2. Lightly better results are achieved by using exponential regression model (see table 3).

It should be noted that R = 0.695 and R^2 = 0.48 and moreover the flow FL2 explains the 20.6% whereas the ozone explains the 16.7% of the NO_2 concentration variation, being these the most important explanatory variables.

The trend of ozone mean concentration increases over time from 29.3 μg/m^3 in 1997 up to 36.8 μg/m^3 in 2003, moreover the number of times that the warning threshold has been exceeded is equal to 0.18% of whole cases. Also it should be noted as the mean values related to peak hour (8:00 – 9:00) are lower than ones over 24 hours, this is due to the fact that the O_3 is a secondary pollutant in whose formation the solar radiation plays a crucial role as expected.

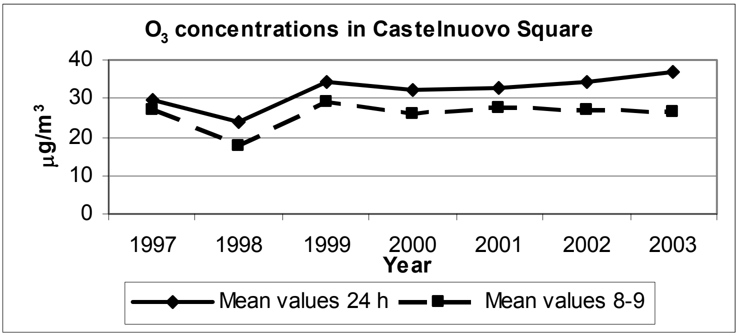

Figure 5: Yearly mean concentrations of ozone.

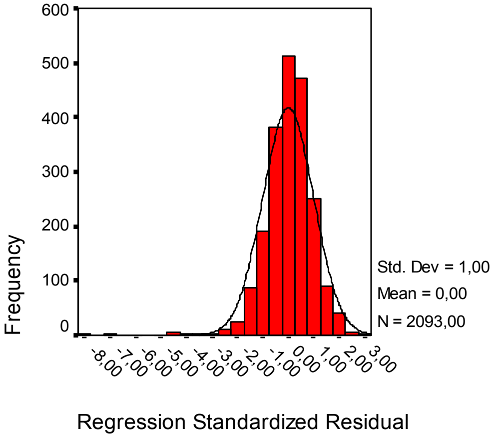

Figure 6: Normality test for the model residual of NO2 regression.

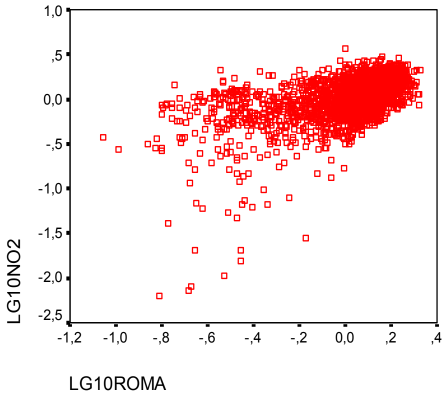

Figure 7: Plot of partial correlation NO2 concentration versus flow FL2.

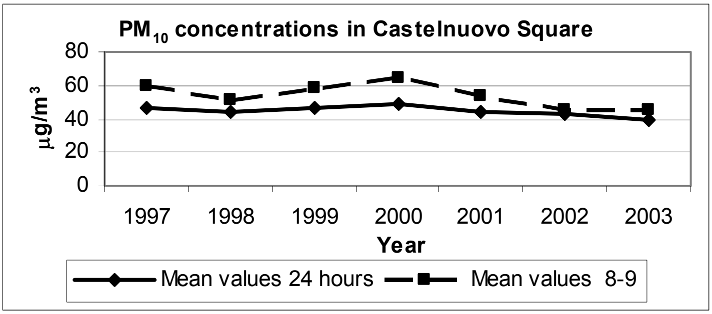

Figure 8: Yearly mean concentrations of particle matter.

3.3 Particle matter

Particle matter is a mixture of solid and liquid particles that have different size and composition. This mixture is composed by various chemical, organic and inorganic compounds. Particle matter is classified according to particles size the PM_{10} with diameter lower than 10 µm and $PM_{2.5}$ with diameter lower than 2.5 µm. Recent studies have underlined as the PM_{10} potentially poses the greatest health risk, since it has the capacity to be inhaled deep into the lungs, increasing the risk of cardiovascular and respiratory conditions and carrying toxins into body. The Italian law in force fixes the yearly threshold equal to 40 µg/m^3 as target of air quality. In the figure 8 highlights as the trend of pollutant concentrations exceeds the threshold of 40 µg/m^3 and the peak hour means are higher than ones over 24 hours.

Both linear and exponential regression model for PM_{10} do not show a good fit and do not provide reliable outcomes, because the determination coefficient is very low ($R = 0.351$ and $R^2 = 0.123$, considering the input variables: solar radiation, temperature, wind speed, wind direction and flow FL2). However these results highlight a correlation between PM_{10} concentrations and traffic flow. Probably this kind of statistical models are not able to explain a highly dynamic phenomenon.

3.4 Benzene

About 90% of benzene C_6H_6 is produced by exhaust vehicles, it is highly toxic for human health and has stable behaviour in atmosphere. Recent studies have showed as high exposure of this pollutant can cause cancer, leukaemia and genetic alterations.

How said previously, the monitoring of benzene began since 2002, therefore the time series is limited by only two years of observations (2002-2003). The number of times that the warning threshold has been exceeded is equal to 0.65% of whole cases. The trend of pollutant concentration means over 24 hours decreases, whereas the mean values related to the peak hour (8:00 – 9:00), instead are much higher and equal to 9 μg/m^3 (see fig. 9). Also both linear and exponential regression model for C_6H_6 do not provide reliable outcomes (R = 0.355 and R^2 = 0.126, considering as input variables: pressure, solar radiation and flow FL2). As well, for the C_6H_6 is present an evident correlation with traffic flows.

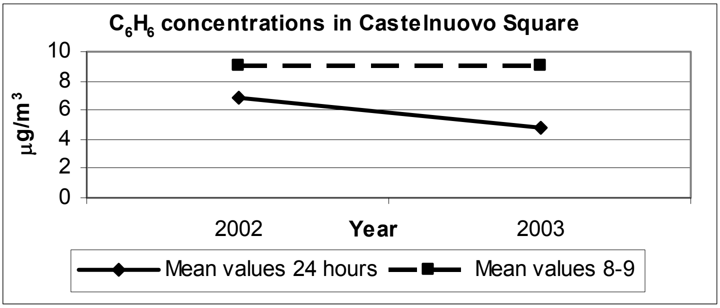

Figure 9: Yearly mean concentrations of benzene.

4 Conclusions

This analysis has highlighted as almost all pollutant concentrations decrease over time, except the ozone, and moreover in the year 2000 all pollutants present the highest mean values except the carbon monoxide. Also these trends are confirmed by data coming from the monitoring site of Giulio Cesare Square. All regression models show a strong correlation between pollutant concentrations and traffic flows. The figures 10 and 11 show a comparison among measured and estimated concentrations for a single day.

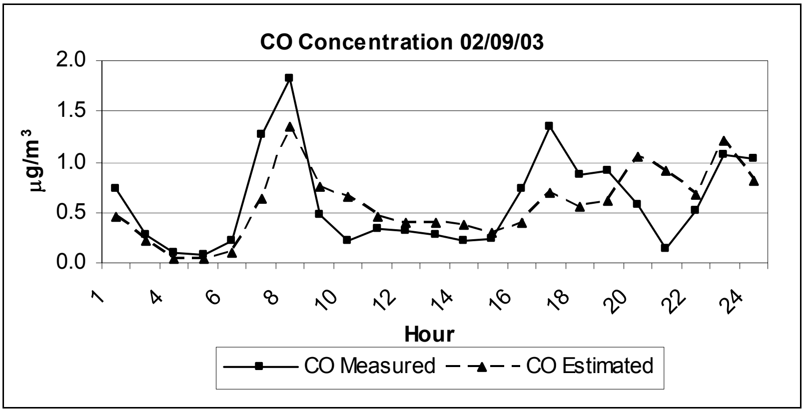

Figure 10: Comparison between measured and estimated values.

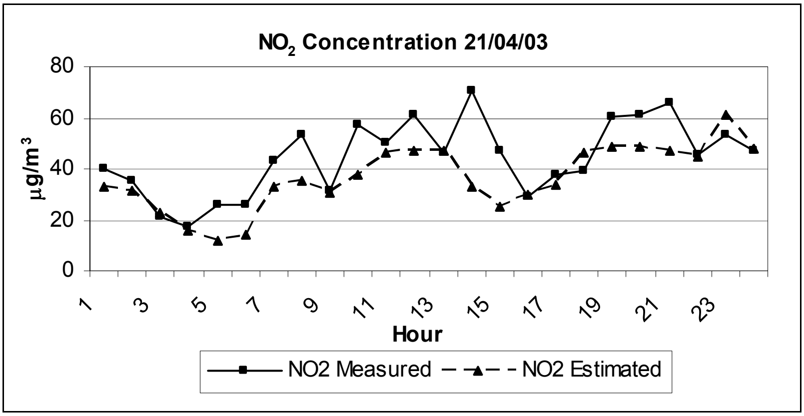

Figure 11: Comparison between measured and estimated values.

The survey on traffic flows related to peak hour and to the involved zones has highlighted a average reduction of overall trips equal to 24% in the study area, produced by park price policy (see table 1). Thus, such reduction of traffic flows in the interested area by park price has determined a consistent reduction of all pollutant concentrations, as effectively observed by data series analysed.

Therefore, it is reasonable to think as this traffic management policy has produced salutary effects on the urban environment in spite of the turn over of car fleet. Obviously, this traffic management measure has to be integrated by other policies (i.e. park and ride, pedestrian island and public transport). Of course, this research is the first step for a decisions support system able to identify the best traffic management policies in the urban area of Palermo.

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