1.05 MODELLING CO CONCENTRATIONS UNDER FREE-FLOWING AND CONGESTED TRAFFIC CONDITIONS IN IRELAND

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INTRODUCTION

The assessment and management of air quality is required under the EU Air Quality Framework Directive and its Daughter Directives (*CEC*, 1996, 1999, 2000) which specify the limits for certain pollutants, including carbon monoxide (CO). Air quality modelling is used to predict the future impact of road improvements, often as part of an Environmental Impact Assessment. The U.S. National Commission on Air Quality found in 1981 that such models may typically overpredict or underpredict actual concentrations by a factor of two. Even twenty years later the U.K. Department of the Environment Transport and the Regions (*UK DETR*, 2001) concurred that "If the prediction of an annual mean concentration lies within ±50% of the measurement, a user would not consider that the model has behaved badly." The Daughter Directive (*CEC*, 2000) concerned with CO allows 50% uncertainty in modelling of the eight-hour average concentration.

An assessment of CALINE4 was performed for two contrasting sites: a free-flowing motorway and a periodically-congested roundabout. Air quality was continuously monitored over a one-year period at both sites. The data collected was compared with model predictions based on local and regional meteorological data, site geometry and traffic volumes. The modelled and monitored results were compared through both graphical and statistical analysis (*Broderick B.M. et al.*, 2003).

METHOD

Sites

The motorway monitoring unit was located 20m north of the M4 at Leixlip, 16 km west of Dublin city centre. The motorway has two lanes in each direction, which run almost due east-west. The roundabout monitoring unit was located on the outskirts of Galway city, 25 m from a five-arm roundabout at the junction of the N6 and N84 routes. At both sites, the monitoring period was from 15th September 2001 to 15th September 2002.

Monitoring

CO concentrations were measured by infrared absorption using an API Model 300 analyser, at sampling intervals of one hour and of 15 minutes. In addition to air quality, meteorological variables such as wind speed and wind direction were recorded at both sites and at the National University of Ireland, Galway, 1.5 kilometres southwest of the roundabout. The national weather service, Met Eireann, provided hourly Pasquill stability class, cloud cover, wind speed and direction data from Casement Aerodrome, one kilometre south of the motorway monitoring site, from Dublin Airport, 18 kilometres northeast of the motorway site, and from Shannon Airport, 70 kilometres to the south of the roundabout site. The National Roads Authority (N.R.A.) provided hourly traffic flow data for the relevant section of the M4 motorway throughout the monitoring period. At the roundabout, one month of continuous traffic flow data for the main approach arm was supplemented by a one day survey (13 hour count), of all flows and turning movements on the roundabout.

Modelling

CALINE4 requires hourly traffic flows, meteorological parameters and a composite emission factor which represents the fleet profile of vehicle type, fuel and driving mode. It predicts the hourly concentration at receptors relative to the roadway line source (Benson, 1984). A composite emission factor of 6.62 g/mile CO was calculated for the vehicle fleet of 71% petrol cars, 21% diesel cars and 8% heavy goods vehicles (HGV). The motorway was modelled as one link, whereas the roundabout was modelled as five links meeting at the centre point of the roundabout.

RESULTS: TRAFFIC AND METEOROLOGY

Motorway

The average weekday and weekend diurnal traffic flow profiles are shown in Figure 1. The prevailing winds at the monitoring unit (receptor) were from the south east, south west and west, with a wind shadow cast by the building to the north east. The highest mean wind speeds of 3.5 m/s were for southerly winds. Stable conditions (Pasquill Stability Class E, F or G) were associated most frequently with east and northeasterly winds (c.60%) and least frequently with westerly winds (<20%). Conditions were never stable after 08:00 and before 16:00.

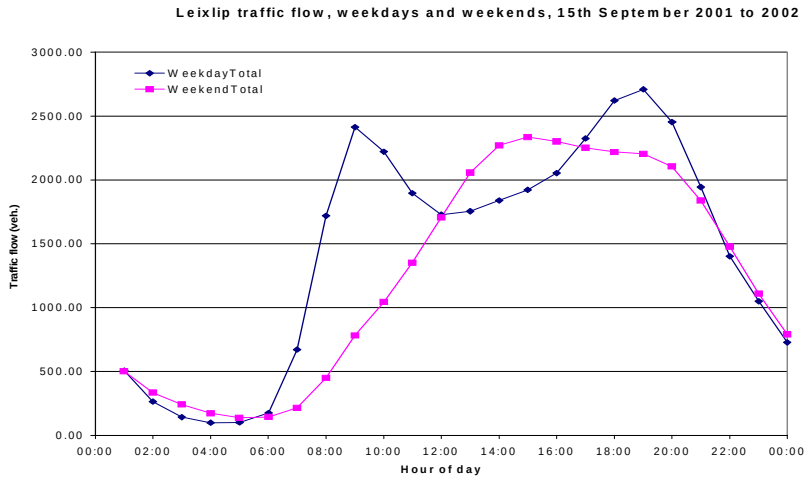

Figure 1. Diurnal variation in motorway traffic flow.

Roundabout

The roundabout is the second busiest roundabout in Galway city with the total number of cars peaking at 3900 vph. The peak weekday flow on the main N6 approach was just over 2000 vph, at 09:00 and 18:00 (Figure 2). The dominant wind direction was southwesterly, with average wind speeds of less than 2.5 m/s in all directions.

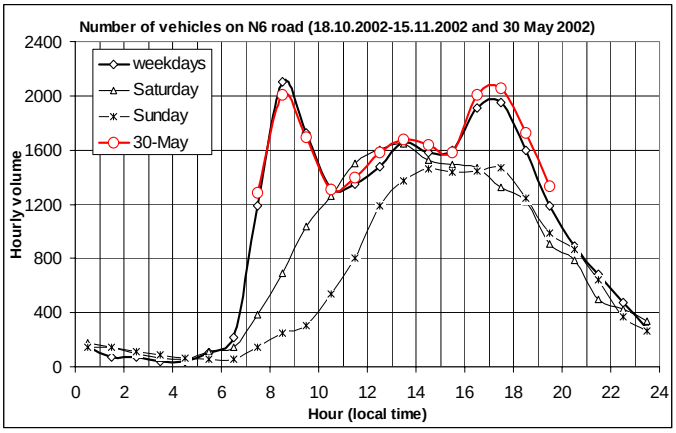

Figure 2. Diurnal variation in roundabout traffic flow.

RESULTS: MEASURED AND MODELLED CO

Diurnal annual average hourly concentrations

The average diurnal variations in the measured and modelled concentrations at the motorway site are compared in Figure 3. The CO concentration when the traffic source was at a minimum (in the early hours of the morning) was taken to represent the average background concentration. The peak annual average hourly CO concentration was 0.33 ppm at 23:00, whereas the modelled peak was 0.30 ppm at 20:00 (or 0.53 ppm when the background concentration is included). Both predictions lie within ± 50% of the measured concentration.

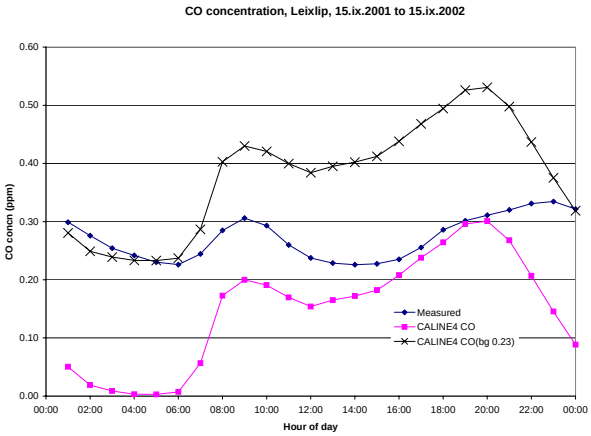

Figure 3. Average diurnal variations in CO concentration at the motorway site

Figure 4 compares the measured and modelled concentrations at the roundabout site. A constant background concentration of 0.18 ppm CO was assumed, on the same basis as the motorway site value. The highest average hourly CO concentration was measured as 0.75 ppm at 18:00, whereas the modelled peaks were 0.38 ppm at both 18:00 and 09:00. The modelled concentrations generally underpredict those measured, especially during the evening peak.

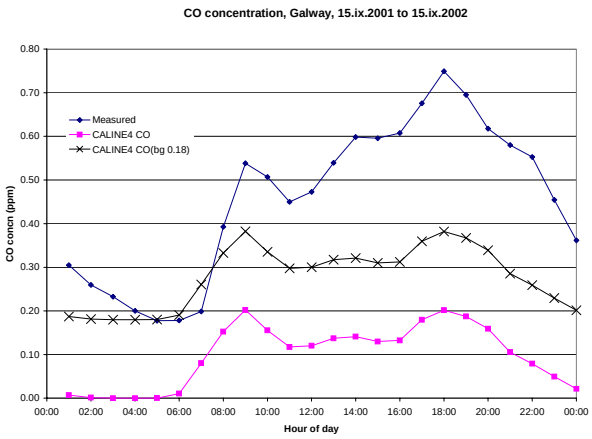

Figure 4. Average diurnal variations in CO concentration at the roundabout site

Annual statistics and model evaluation parameters

Table 1 compares the mean, maximum and 95th percentile values of the measured and modelled hourly concentrations at the motorway and roundabout sites. The mean and 95th percentile values were overestimated at the motorway, but underestimated at the roundabout. The maximum eight-hour running averages are underestimated at both sites, though at the motorway the predicted concentration is within 50% of that measured. These values can be compared with the EU limit value for the maximum eight-hour running average, which is 8.6 ppm, and with the Upper and Lower Assessment Thresholds (UAT and LAT) of 6.0 and 4.3 ppm, respectively. All measured and modelled values are well below the LAT.

Table 1. Predictions and measurements of CO concentrations at the motorway and roundabout.

CO (ppm)		**Mean**	**Max.**	**95th%ile**	**Max.8hr**
Motorway	Measured	0.27	2.6	0.6	2.15
(bg. 0.23)	Predicted	0.38	2.53	0.83	1.33
Roundabout	Measured	0.45	4.4	1.01	2.40
(bg. 0.18)	Predicted	0.28	1.98	0.58	0.86

Marmur and Marnane (2003) give a comprehensive explanation of the statistical parameters used in Table 2. The mean, Pearson's correlation coefficient (R), normalised mean square error (NMSE), factor of two (FAC2), fractional bias (FB) and fractional variance (FS) are calculated for the datasets of predicted and observed hourly concentrations. These parameters can be used to compare model performance with other assessment studies and to identify the conditions under which models best perform.

Table 2. Model evaluation parameters

	MEAN	R	NMSE	FAC2	FB	FS
Minimum	0	-1	0	0	-2	-2
Maximum	∞	1	∞	1	2	2
Ideal	1	0	0	1	0	0
Motorway	1.68	0.24	0.77	0.59	0.33	0.03
Roundabout	0.83	0.58	0.77	0.67	-0.48	-0.78

CONCLUSIONS

Diurnal variation

For both sites, the times of the predicted peaks coincide with those of the measured peaks. The model cannot predict the high CO concentrations observed at the motorway after 20:00, which may be due to stable conditions rather than the immediate traffic source. For the roundabout, the model did not predict the increase in magnitude of the evening peak from the morning peak, which may be due to diurnal variation in the background concentration, or an underestimation of the composite emission factor. At low speeds, CEFs for CO are highly sensitive to the assumed vehicle speed, and to the effects of queuing.

Statistics

The maximum 8-hour running average concentrations, which can be compared with the legislative limit values, were underestimated at both sites. At the motorway site, the prediction was within ±50% of the measured value, which satisfies the requirements of the EU Daughter Directive (*CEC*, 2000). The concentrations were underestimated for the roundabout. This may be due to the emission factor and link geometry used in modelling, but is of particular interest since roundabouts are common on Irish roads.

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