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Vehicular Pollution in Car Parks

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A FEATURE of redeveloped city centres is multi-storey car parks which have been erected in an attempt to control roadside parking and aid traffic flow. These car parks have been erected on sites either peripheral to the city centre or as part of redevelopments either under, as part of, or on top of shopping precincts.

Regulations or codes of practice have been issued by the Department of the Environment (DoE) for the design and construction of multistorey carparks as Building Regulations 1965, in particular Part E (Structural Fire Precautions). Multistorey carparks fall within purpose group VIII (storage and general) as defined in regulation E2. Circular 17/68 (Ministry of Housing and Local Government) further develops this area. These regulations are directed primarily to safeguarding construction and fire hazard standards. The problem of pollution from motor vehicles in confined spaces does not appear to be considered.

Our attention has been drawn to the problems of pollution in carparks which occur at certain times, these times generally being associated with traffic congestion within and/or without the carpark. The public has sensed gross pollution conditions within the carparks, and voiced its concern.

Our studies have been conducted at a variety of carparks of widely differing design, in different towns and cities over a range of 300 miles in England. We do not identify the carparks, since we feel this to be a national problem which should not be sensationalized locally. Further, following our work, some measures have been taken to reduce the pollution levels in the carparks worst affected.

Initially we were concerned with carbon monoxide concentrations within the carparks, but later interest developed in the lead concentrations of the carpark atmospheres and in the blood of carpark employees.

RESULTS

CARBON MONOXIDE was measured using a Draeger-Normalair hand pump with tube No. 25601 5/c, range 0-150 or 0-700 ppm according to the number of strokes of the pump. The model number of the tube used has been tested against standardized gas mixture and found to be accurate.[1] A recent report has shown the main source of error when using these tubes to be that of the operator in reading the position of developed stain.[2] A standard procedure was adhered to for reading the length of stain, and thus the pollutant concentration. Transient carbon monoxide values were measured using an 'Ecolyser' apparatus calibrated with standard gas mixtures. Lead concentrations were measured inside the pay kiosk using a Charles Austen Duplex 2F pump drawing an average 1·5m³ of air per hour. The samples were drawn through a 47mm diameter Whatman GF/F glass fibre retained in a Bulkley White open filter holder. The intake funnel of the plastic sampling tube was sited at head level approximately 0·5m from the car-park attendant. Lead on the filter papers were determined using standard techniques by the County Analyst of Leicestershire.

We look at the carparks investigated in terms of their configurations.

Carpark 'A'

Carpark A is the most interesting case of those investigated. Designed and built to comply with the regulations described in the introduction, it measures at maximum dimension 130×130m approx. with a head clearance of slightly over 2m. The carpark is situated on top of a redeveloped shopping centre which essentially occupies a whole city block and is comprised of two floors. The lower floor of the carpark has an extremely reticulated and obstructed configuration because of skylights, plant rooms, offices, service shafts and walls which protrude through from the redevelopment below. The upper floor of the carpark is the roof of the redevelopment complex and is completely open. The lower floor can thus be envisaged as a very thin sandwich, 130×130m and 2m high, almost all of which is covered.

A survey over one week was undertaken, in detail for a very busy day and in contrast for a "quiet" weekday. Two points or areas of high pollution and associated high vehicular congestion were identified. The first occurred at an internal traffic junction with several conflicting traffic flows. Carbon monoxide levels are given in Table I for a congested traffic period at this point. (We define congestion as occurring during a period of traffic immobility or very limited mobility, the latter being less than 5m/min.) Levels of carbon monoxide were recorded up to 120 ppm at this point. Background values were regarded as those recorded at the edge of the carpark, overlooking a main thoroughfare at a height of 15m approx. In the absence of traffic

TABLE I

Carbon Monoxide Concentrations Within Carpark A

	Saturday		Tuesday	
Time	1st Point	2nd Point	1st Point	2nd Point
07.15	1/2	0/0	0/1·5	0·5/0·5
08.15	6/0·5	2/0·5	0·5/1	1/0
09.30	12/0·5	3/0·5	1/1	5/0
10.30	40/1·5	6/0	2/1	7/0
11.30	50/1	75/0	6/0·5	10/0·5
12.30	120/2	125/0	—	—
13.00	—	—	8/1·5	15/0
13.30	45/1·5	8/0	—	—
14.00	—	—	15/1·5	10/0·5
14.30	35/2	75/0	—	—
15.00	—	—	20/1·5	14/0·5
15.45	55/2	110/0	—	—
16.00	—	—	18/1·5	10/0
16.45	60/2	180/0	—	—
17.00	—	210/0	4/1·5	3/0
17.05	—	160/0	—	—
17.10	—	190/0	—	—
17.15	—	130/0	—	—
17.20	—	160/0	—	—
18.00	3/1	4/0	8/1·5	6/0
19.00	2/1	7/0	1/0·5	2/0
20.00	2/1·5	3/0	—	—
21.00	1/1	1/0	0·5/0·5	3/0
22.00	1/1·5	3/0	6/1	7/0
23.00	5/2·5	2/0	3/1·5	0/0
24.00	0/1·5	0/0·5	4/1	0/0·5

Values are expressed as ppm CO/wind speed in ms^{-1}.

TABLE II

Carbon Monoxide and Lead Concentration in Carpark B1 Kiosks

Day	Period	Lead, μgm^{-3}	Carbon Monoxide, ppm Kiosk 1	Carbon Monoxide, ppm Kiosk 2
Tuesday	24 hours	0·45	—	
Wednesday	24 hours	2·08	—	
Thursday	24 hours	1·22	—	
Friday	24 hours	1·39	—	
Saturday	09.00	0·49	5	
	10.00	3·20	20	
	11.00	16·62	80	
	12.00	7·07	130	
	13·00	11·88	90	
	14.00	12·71	70	
	15.00	7·78	70	130
	16.00	9·86	30	130
	17.00	4·31	50	110
	18.00	6·32	50	200
	19.00	10·82	1	8
	22.00	0·97	—	—

congestion high levels of carbon monoxide did not occur, Table I.

A second point of high pollution potential was found on the exit ramp of the carpark which takes the form of an intertwined double helix of entrance and exist ramps, enclosed in a totally glazed rotunda. Egress from the exit ramp at peak times was substantially hindered, and frequently stopped completely, by traffic congestion in the city centre streets. The exit ramp then effectively comprises a small enclosed space with stationary vehicles running their engines, generally with their chokes operative. A typical set of values for carbon monoxide levels found are given in Table I and comparison is made with a "quiet" day in that table and also in Figure 1. Peak values of 210 ppm carbon monoxide are found, with transient values going up to 450 ppm. Further observations have found values up to 280 ppm at other peak times.

The values of 210 and 280 ppm quoted above is the average over a period of 2–3 minutes, the time necessary for the analytical procedure and gives the more concern because these values are inhaled by people sitting in vehicles which are relatively immobilized for periods of up to 35–40 minutes. In extreme circumstances, much longer periods of exposure can occur. The longest time for congestion causing delays to vehicles leaving a city centre carpark known to the authors is 105 minutes (but not from the carpark under discussion) in the shopping period just prior to Christmas.

Measurement of carbon monoxide inside the cash kiosks showed levels ranging between 50 and 80 ppm, which is in excess of the recommended TLV values.

Carpark B1

This carpark is constructed of a ground floor and four decks, mainly open at the edges, for the upper levels, overall dimensions being 70×38m, with an average height of 3·1m. In comparison with carpark A, this carpark has a relatively open deck structure, being completely open on one or both sides at most points, the maximum depth from any open side being 38m. Only at the exit gap from the first deck were values of 150 ppm carbon monoxide found for a continuously moving traffic stream. The rate determining factor for egress of vehicles from the carpark was the payment procedure at the cash kiosks, the road on to which the vehicles move from the carpark being able to accommodate the flow even in peak hours. Investigations were concentrated into periods of maximum traffic movement out of the carpark. As this carpark is relatively open and congestion within it of low probability, it does not pose a serious hazard to its users.

On the other hand, the cash kiosks were found to have very high carbon monoxide levels at 250–300 ppm and continuous monitoring was carried out for both kiosks to assess the hazard of atmospheric lead and carbon monoxide to the attendants.

The position of the kiosks in this carpark is interesting and probably critical, being in a wide, low tunnel which forms both the entrance and exit to the carpark. Continuous monitoring for lead was carried out during the carpark opening hours, 07.00 to 21.00, Monday to Friday. Saturday was the day of maximum usage for the carpark and sampling was carried out for successive periods of one hour duration from 07.00 to 19.00. Use of the carpark had virtually ceased by 19.00 and the final sampling period was 19.00–21.00. The levels measured as a result of the 24 hours monitoring during the week were not excessive, being 2·08cmg/m³ maximum for lead. The hourly measurements for the Saturday indicated a progressive increase in lead concentration which coincided with usage of the carpark. A peak value of 16·62μg/m³ was found for the period 10.00–11.00, with slightly lower values for other periods. The average for the period 08.00–19.00 was 8·09μg/m³ lead. Concurrent measurements of carbon monoxide were made and are shown in Figure 2. Additional measurements of carbon monoxide were made outside the kiosks showed that concentrations could vary significantly within short periods of time, as shown in Table II.

The volume of vehicles using the carpark was negligible until 09.00, after which the volume increased rapidly such that there was continuous movement both in and out of the carpark. For long periods of time there was an unbroken queue of cars waiting to leave and for shorter but significant periods a queue waiting to enter. During such periods cars left the carpark at an average rate of one every 2½ minutes.

The monitoring exercise for this carpark confirms that during periods of peak usage concentrations of vehicular pollutants rise to levels considerably in excess of those recommended. It is accepted that one-hourly monitoring shows only peak levels but the consistently high readings for both carbon monoxide and lead over the period 10.00–19.00 hours suggests that the peaks are not untypical for each hour.

Carpark B2

The design of this carpark is similar to that of B1 but is even more open and is also sited well clear of other buildings such that these two factors together create a substantial through draught for all but the most stable weather conditions. The location of the carpark is away from the city centre and is not as intensively used as the other carparks. The carpark also exits on to a gyratory traffic system through an open roadway. Any build-up of traffic occurs on the roadway prior to joining the traffic system which itself disperses traffic rapidly in peak periods. The maximum value of carbon monoxide recorded was 30 ppm, in the vicinity of two cars waiting to exit at the pay kiosk. The carpark has a low probability of causing pollution hazard to people using it and to its attendants.

Carpark B3

This carpark is similar in design to B1 and B2 but occupies the space over an extensive car showroom and workshop development occupying a whole block. The carpark lowest floor is thus raised about 10m above the major road to which it fronts and is well exposed to winds. The various decks of the carpark are open and a depth composed only of two carparking spaces and a roadway each side, with large gaps for traffic circulation providing a through draught. The carparking decks are of sufficient area and height to allow good dilution and dispersal of vehicle exhaust gases, the upper decks being in the main open upon all sides.

Carpark B4

This carpark is in the town centre of a recently developed area and is one of five carparks built within a central ring containing the shopping centre. The carpark comprises a ground floor and three upper decks, in a long, open configuration. The carpark is two roadways and four carparking spaces wide and egress from the carpark is by automatic barriers for a standard charge, the barriers being operated by ground pressure sensors. The barriers are situated in an open area and vehicles proceed via a short length of roadway on to the central ring road, which is able to disperse traffic

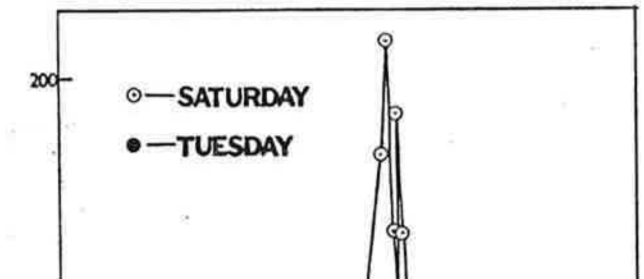

Figure 1. Variation of Carbon Monoxide with time on exit ramp of car park 'A' for a Saturday (○) and Tuesday (●).

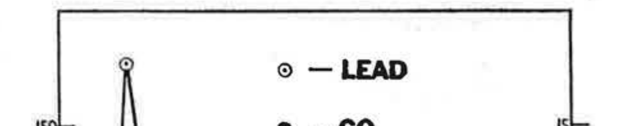

Figure 2. Hourly Variations of Carbon Monoxide (●) and Lead (○) in kiosk of carpark B1.

rapidly at peak periods. The maximum level of carbon monoxide recorded was 33 ppm, at the vehicle exit from the carpark at a steady vehicle exit rate of 200 per hour.

Carpark C1

A common type of carpark is represented by type C1, a continuous ramp with, in this case, six turns. The continuous deck is 15m wide and is open at the outer edge but for a retaining wall. The only enclosed part is at the lowest levels where the carpark is enveloped in an associated redevelopment of shops and a public house. This carpark is close to a city centre and exits into a traffic area which is liable to congestion and which has only one route leading away from it. The enclosed lowest level of the ramp and the reasonable liability to traffic congestion leads to some concern over the incipient hazard posed by this carpark.

The pay kiosk is again found to have internal levels of carbon monoxide at 110–130 ppm over significant periods of time during periods of continuous use. It is pertinent to note that at the times of measurement the attendants had been on duty for eight hours and shifts of over twelve hours are common.

Carpark C2

An interesting comparison is with a carpark constructed of two intertwined continuous ramps. The site is much larger than in carpark C1 with a large airspace in a central well. The entrance and exit for each ramp form a confined tunnel in which the pay kiosks are situated. The highest carbon monoxide concentrations recorded were 50 ppm, adjacent to the cash kiosk during a period of continuous use. Low values were found on the parking decks of the carpark itself, the ramps being quite open apart from the retaining wall. The carpark is situated on a large site with low level development around it within a circular traffic system, well away from developments of a similar size. The traffic system around the carpark rapidly disperses traffic at peak times and this factor, together with the open structure of the carpark, indicates a low probability of a pollution hazard to its users.

Carpark D

This carpark is completely different from any of the carparks described previously. It occupies a ravine used previously as a railway station and may be divided into two separate areas. The major area lies on the bottom of the ravine and measures 400×80m approx, with a headroom of 3·5m and comprises one floor only. The carpark is used for the extensive shopping centre above and also for the tenants of apartments built above the shopping centre. Two points are of particular interest, first the carpark is positively ventilated by air drawn from above and extensively and thoroughly distributed throughout the carpark by a ducting system to give 6 air changes each hour. Second, the movement of vehicles out of the carpark at peak times is purposively managed by several attendants *as part of their duties*, an important feature found lacking in other carparks. These two features, together with a willingness to open additional pay kiosks at peak times, control a potentially severe hazard. At peak times carbon monoxide values of up to 105 ppm were recorded in the area immediately in front of the pay kiosks. However, the rate of vehicles leaving the carpark was such that any queues developed at peak times were kept to two lines, well separated, of five vehicles each. Thus, the levels of pollutant were contained and the time of exposure for the population kept to a minimum. Vehicles exit into a traffic system which was able to disperse traffic in peak hours.

On the other hand, a closely associated carpark has the form of a medium size multistorey structure but sunk into the ground with only one edge open to the ravine. The lowest level is continuous with that previously described. Vehicles exit from this carpark by circulating through the various decks and approach the pay kiosks at the end of a steeply inclined ramp. Due to the complex configuration of this carpark the ventilation was not as effective as in the other carpark. At peak times a substantial queue of vehicles was observed wending throughout the levels of the carpark. Peak levels of 450 and 400 ppm carbon monoxide were observed under these conditions for lower levels of the carpark, which together with a recorded exit time of 25 minutes noted for a succession of certain vehicles, over a period of at least 45 minutes poses a serious hazard to the users of the carpark. Values of 100–170 ppm were noted on the steep exit ramp for carbon monoxide whilst values of 200–270 ppm were recorded by the pay kiosks.

DISCUSSION

THE RESULTS presented show a large variation in the hazards posed by carparks towards their users. There is a close relationship between congestion of vehicles within the carpark and localized carbon monoxide concentrations, which may be extended to include lead concentrations, within the carpark. The carpark attendants are particularly exposed to high concentrations of carbon monoxide and lead for significant time periods. The time exposure of carpark attendants is different from that of the general population using the carparks but then also is the allowable response/exposure of these two groups. By being at work, a carpark attendant is presumed to be both fit and adult. A cross-section of the general population contains in addition unfit adults, babies, young children and elderly people. The whole question of TLV and continuous exposure limits for the general population and the working population is confused, as has been discussed recently.[3] In addition there are clear differences of philosophy and emphasis between Western Europe and the USA on one hand and that of Eastern Europe on the other.

The carparks investigated in this work show a complex combination of factors in determining the levels of pollution to which their users are exposed. The levels of internal carbon monoxide appears to depend to an inter-related first approximation on first, the congestion within a carpark and second, the physical configuration of that carpark. The term "physical configuration" gathers together several factors under one heading to describe the ability of the carpark to disperse traffic fumes from an internal point furthest away from an outside edge.

Surveying the examples described it is clear that the design of a carpark can have a profound effect on the circulation of air—the natural ventilation—within the structure. An associated factor is the open character of the site which may affect the impact of ambient air movements on the air masses within the carpark. We define a simple measure of these complex factors as the "porosity" of the structure, measured as the lowest ventilating wind velocity at a point within the carpark divided by the wind speed measured on the carpark roof. Thus, in example A, the lowest values of wind speed within the first level of the carpark were found to be approximately one third that of the values on the open and unobstructed top deck, only two metres above in physical terms. In defining such a simplistic term it must be emphasised that its derivation should be made with caution. In many carparks the porosity of the structure, as defined, will almost certainly vary with wind direction. As we are concerned with public health, the lowest reading should be used, to give the most pessimistic value of the carparks ability to ventilate itself naturally.

Congestion of a carpark is difficult to define, particularly in the context of its liability to congestion at peak periods. To simplify the arguments, we assume the following. First, that 80 per cent of a carparks capacity should be expected to leave within a thirty-minute period. Second, the number of exits which are physically distinct should be recognized. In this way, for instance, two lanes and kiosks which exit into one constrained exit lane should be counted as one lane. Two exit lanes either together or separate, count as two lanes. The number of vehicles wishing to exit, for the purposes of calculating congestion, is 80 per cent of total capacity divided by the number of physically distinct exit lanes. Thus, a carpark of 500 vehicles capacity with two exit lanes and kiosks but only one constrained (i.e. long and narrow) final exit would give a value of 400 vehicles per 30 minutes. This outward flow is then compared with the maximum vehicular flow per 30 minutes of the road system into which the carpark exits. The maximum outflow may therefore be expressed as a fraction of the immediately local traffic flow.

A final factor is the management of the carpark, an extremely subjective area. In our experience, carparks which have a standard charge for use can process vehicles out through the exit lanes more quickly than those for which a ticket has to be presented and a charge calculated. There is also the area of responsiveness to sudden flows of vehicles wishing to leave the carpark. A typical example of this would be a carpark situated close to a theatre. When the evening performance is over, a sudden rush of several hundred cars can severely overload the capacity of the kiosks to process the charges. In one case, that of carpark 'A', congestion can cause up to 40 minutes delay in the region of 22.00 hours, a situation caused in the main by the lack of response of the carpark management to open a second kiosk that is readily available, even though the vehicles exit into a traffic system which is operating at well below maximum capacity at that time. The rate determining step for egress of the vehicles from the carpark is solely the financial charging process, clearly inadequate in this case for dealing with a sudden increase in traffic flow.

Finally, there is the quality of the carpark management, a very variable quantity. The importance of a purposeful, interventionist, carpark management cannot be overemphasized. It is a basic observation of this work that, given several exit routes, carpark users will place and/or so conduct their vehicles as to minimize the capacity of those exit routes. It is assumed that the function of management in this context should be to counteract this tendency and purposively intervene to so arrange maximum traffic flow. One carpark management described does this in a competent and well instructed manner, an action which together with forced ventilation due to the construction of the carpark, is decisive in keeping pollution levels low. On the other hand, in another carpark, employees other than the kiosk staff and supervisory management (the latter generally having responsibility for other carparks as well and therefore not present continuously during even office hours) were clearly acting without coherent instructions in the event of traffic congestion within the carpark. The management of a carpark can affect the congestion within the structure in a manner quite separate from the factors described previously.

The results reported here show that whilst the majority of carparks do not pose health hazards to their users, some carparks by virtue of their design, site configuration, position and poor quality of management, do pose such a hazard. The major cause of the hazard is pollution from the congested motor vehicles seeking egress which builds up faster than it can be dispersed. The attendants within the carpark are exposed to high levels of carbon monoxide, which exceed the TLV concept limit, and also to high levels of particulate lead, the latter being probably more important.

APPENDIX

THE THREE areas that we have described as affecting the levels of pollution within carparks, viz: the porosity, the capacity of the surrounding traffic system to absorb the outward flow from the carpark and the quality of the carpark management, together determine the hazard to the carpark users. It should be possible to quantify these factors so as to build up an index with which to assess the pollution potential of a carpark. From the examples cited, it is difficult to assign greater weight to one factor than to another; therefore we assign equal weight to each factor and calculate each factors contribution as follows:—

1. *The Porosity or Natural Ventilation Factor*

The calculation of this factor is quite straightforward. The natural draught within the carpark is divided by the windspeed around the carpark, as measured by that recorded on the roof of the carpark. The lowest recorded value is used, with respect to wind direction. The contribution of this factor may therefore be expressed as:—Lowest internal wind speed/external (roof) wind speed ×33⅓.

2. *The Outflow/Traffic Dispersal Capacity Factor*

The capacity of the carpark is calculated at the 80 per cent level and then divided by the number of physically distinct exit lanes or channels to give the effective outward flow per 30 minutes. This vehicle flow is then divided by the capacity of the traffic system into which the carpark empties, ×33⅓.

3. *The Management Factor*

This factor is the least quantitative and most subjective of the three. As several subfactors contribute, these are treated separately. First, the charging process is rated on a scale of 1–11. A standard charge for all vehicles, irrespective of time parked, collected automatically would be rated 11 whilst a charge system which needs calculation and is collected automatically without any manual help or supervision would be rated at 1. A calculated charge collected manually would be intermediate at 6. The second sub-factor is that of the responsiveness of the carpark management to sudden changes in traffic flow, e.g. by opening a second kiosk and exit lanes, or additional such facilities. This a subjective assessment to be made also on a scale of 1–11. Finally, there is the quality of the management of the carpark employees in managing the internal flow of traffic within the carpark and with particular reference to maintaining maximum flow to the cash kiosks, again scored 1–11.

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Until recently one of the main and accepted goals of treatment for alcohol abuse was total abstinence. This has come under increasing scrutiny by sociologists, psychologists and other professionals working in treatment programmes. The results of controlled drinking obtained by Sobell and Sobell[6] appear very encouraging, though they are localized and therefore any treatment with the goal of controlled drinking would benefit by further research evaluation.

On a wider level alcohol abuse has an impact on society and society has a responsibility towards the prevention of alcohol abuse and the strategies available could be far reaching and widespread. At the tertiary level of prevention further co-operation is required, either on an area and or regional basis, between general psychiatric units, addiction units, Social Services Departments, the Probation Service and voluntary organisations in order to comprehensively service the population who are already receiving help or will be receiving help in the near future. On the secondary level there is an opportunity for new programmes on alcohol abuse to be started, such as the involvement of General Practitioners to diagnose problematic drinking amongst their patients for possible early referral to agencies for help, or for people to be helped as Out-Patients at surgeries or clinics with the help of trained personnel in alcohol abuse. Further, industry could take a crucial role in helping people with alcohol problems by initiating programmes themselves, their own personnel could be trained in counselling, the co-operation of management and trade unions would of course be vital if this area of help was to be offered to people. The government themselves could initiate action by starting alcohol abuse programmes in the Civil Service, local government and public industry. In addition, government action, in terms of legislation, could be considered in preventing future alcohol abuse, by not increasing outlets for the sale of alcohol, raising the price of alcohol and not implementing certain aspects of the Erroll Report[7] which may lead to an increase in the prevalence of alcohol abuse.

The future role of Social Services Departments leads into consideration of primary strategies to prevent alcohol abuse, in terms of whether such departments will consider it part of their responsibility to positively promote features of attractive family and social life for people. Other questions which seem to be important on a primary level are whether people have sufficient space in which to live, what the quality of most people's lives are like, whether they have employment that is meaningful, whether their housing is something important and to be valued and how much leisure facilities are available.

In other words, like individuals, whether society is not O.K. and a difficult struggle or whether society is Born to Win and is liberated and transformed For people.

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The total of these three major factors is 99⅔. Carparks with low scores must be examined closely to reduce the possibility of a serious pollution hazard occurring under unusual conditions, e.g. for a city centre carpark the shopping period immediately before Christmas gives increased levels of use, and increased traffic flows in the city centre traffic systems. These are prime preconditions for congestion to occur within a carpark. Alternative existing procedures and routes offer the most readily available solution, together with an increased level of immediate management at peak times. A further precaution would be to instal a continuous monitoring system for carbon monoxide with an alarm system which activates warning signs asking people to switch off their engines. The diversity of carparks is such that each one must be surveyed and a specific solution found as necessary for each one.

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