Carbon Monoxide Emission Effects of Drive-Up Facilities

Curtis C. Lueck and Jill Merrick

The effects of drive-up facilities such as banks, restaurants, liquor stores, and laundries on air quality are investigated; particular attention is given to carbon monoxide emissions. The primary purpose of the study is to provide guidance on whether regulation of drive-up business is warranted and desirable. Carbon monoxide monitoring, on-site traffic counts, queueing and service times, and arterial traffic counts were simultaneously obtained at three typical drive-up facilities in Tucson, Arizona. The field data were analyzed to help determine the magnitude of air quality impact and the amount of traffic generated by the various facility types. A mail-out survey of drive-up facility regulations was also conducted. Significant insight about the current operation, use, and air quality effects of drive-up facilities is provided. First, field measurement is not an effective means of determining the level of carbon monoxide air pollution generated by a drive-up business. Second, computer modeling can be used effectively to estimate pollution levels at drive-up facilities. Third, many communities regulate the design and location of drive-up businesses, but not for reasons of air quality. Fourth, the use of drive-up facilities can produce less carbon monoxide pollution than the park-and-enter alternative if the service time is less than 2 min. Fifth, the traffic impacts of drive-up facilities are difficult to assess because only limited data are available. The amount of pass-by and diverted linked trips has not been adequately quantified for the broad range of drive-up services. The findings of this study reflect conditions in the Tucson metropolitan area. Recommendations and conclusions of the study may be also valid in other regions after local needs and conditions are carefully considered.

Drive-up facilities are commonplace in today's American cities. Their prevalence reflects American reliance on the automobile for personal transportation, enjoyment of a high degree of mobility, and insistence on speed, value, and convenience in many aspects of our daily lives. There has been continuing concern over the environmental implications—both energy use and air pollution—of drive-up restaurants, banks, stores, and related enterprises since their inception in the 1970s. Poorly planned and designed drive-up lanes can increase congestion, cause traffic circulation problems, and provide less-than-welcome intrusion into neighborhoods. Additionally, drive-up businesses often are at or near congested locations that may already be hot spots for air pollution.

This study addresses the interrelationship between air quality and the use of drive-up facilities in the Tucson, Arizona, metropolitan area. The study was authorized by the Tucson City Council and managed by the Tucson Department of Transportation, Planning Division, through a grant from the Arizona Department of Transportation.

C. C. Lueck, JHK & Associates, 110 South Church Avenue, Suite 470, Tucson, Ariz. 85701. J. Merrick, Transportation Planning Division, City of Tucson Department of Transportation, P.O. Box 27210, Tucson, Ariz. 85726.

STUDY PURPOSES

This study investigates the air quality impacts of drive-up facilities such as banks, restaurants, liquor stores, and laundries. Some public services are also provided on a drive-up basis. Therefore, the private sector should not be singled out as the sole user of drive-up establishments, although public use is small in comparison to the private sector. The thrust of the study is to determine what air quality impacts are associated with drive-up facilities and the magnitude of these impacts on an individual location or in the aggregate, and to determine whether or not such facilities should be regulated by local government. If such regulations are desirable, an ancillary purpose is to suggest what types of regulations should be imposed and how sites may be evaluated for their air quality impact. Another purpose of this study is to develop a local information data base on the service times at typical facilities, as well as the trip generation rate and the temporal distribution of demand for these kinds of enterprises. This information can then be correlated with other local and national data.

The study also provides an overview of existing air quality computer models developed by the Environmental Protection Agency (EPA) and state and local government, as well as other models available from the private sector. From these models, one or more may appear satisfactory for use in analyzing drive-up facilities.

Drive-up facilities are not all the same; therefore, this study attempts to categorize the different types of facilities and describes their relative effectiveness by design and use. A site-specific evaluation procedure is described that is based on current practice and may be used in the future whether or not the city of Tucson adopts specific air quality regulations. In other words, these procedures can be used to help refine the design of the facility itself relative to circulation, demand management, traffic flow, and parking. Mitigation strategies are recommended to help improve the design of drive-up facilities that will help minimize the amount of waiting time (vehicle idling time) encountered at typical drive-up businesses. Mitigation strategies may be mandated by city government as part of the development approval process. Alternatively, mitigation guidelines may be used by the design sector on an advisory basis to help improve the design of the project site.

This project has been conducted using several concurrent levels of investigation and analysis. First, a literature search of similar or related studies was undertaken using manual methods, as well as an on-line, interactive data base. We also used the Planning Advisory Service of the American Planning

Association to find ordinances and regulations of similar agencies that would otherwise not be identified through a literature search. This information proved invaluable in describing the historic development of drive-up facility regulation as well as the evolution of the industry itself.

Second, several levels of field analysis and data collection were undertaken. Air quality monitoring, on-site traffic counts, queueing and service times, and arterial traffic counts were simultaneously obtained at three typical drive-up facilities in the city of Tucson. The sites were monitored for a typical midweek business day during November 1990. Air quality data were collected by Pima County's Department of Environmental Quality, using a mobile monitoring van. Traffic counts were obtained into and out of the facilities, as well as on adjoining streets. An on-site observer monitored customer arrival, service, and departure times at the various facilities. The field data were analyzed to help determine the magnitude of air quality impact and the amount of traffic generated by the various facility types. The field studies also included gathering service time data at several other types of businesses. This information was used to help understand how various drive-up facility designs and services impact vehicle idling time.

Third, we obtained information from the drive-up industry about service goals, trends in technological innovation, and related background information. This effort included telephone discussions with local and corporate spokesmen for Burger King and McDonald's, as well as review of industry publications.

A mail-out survey of drive-up facility regulations was also conducted. More than 70 surveys were mailed out to a variety of municipalities throughout the United States. More than 40 surveys were returned and analyzed.

BACKGROUND: AUTOMOBILES AND AIR POLLUTION

The use of the automobile is directly responsible for a major portion of the air pollution problem in major metropolitan areas, including the Tucson region. The pollutants of concern include carbon monoxide (CO), nonmethane hydrocarbon (NMHC), sulfur oxides (SO_x), nitrogen oxides (NO_x), lead (Pb), and particulate matter 10 μm or less in aerodynamic diameter (PM_{10}). Ozone (O_3) is also a major concern, but it is a secondary pollutant formed by NMHC and NO_x in the presence of sunlight and is not directly emitted in auto exhaust. All of these pollutants are generated by transportation vehicles including cars, trucks, trains, and aircraft. Private vehicles (cars and light-duty trucks) are the greatest contributing factor to several of these pollutants (*1,2*). Most significant to this study are CO and PM_{10}. These two primary pollutants have caused the eastern Pima County air shed to fall out of compliance with national air quality standards. Pima County and the city of Tucson are generally in compliance with all other national standards.

The automobile produces differing levels of CO and PM_{10} under various operating modes and driving conditions. For example, CO concentrations can become excessive whenever a large number of vehicles are operating in a given location. This can happen in very slowly moving traffic during periods of congestion, and at signalized intersections. Vehicle idling also occurs at other locations, such as parking lots, service facilities, and drive-up lanes. PM_{10} includes microscopic dust particles from vehicle braking systems, tire wear, and engine exhaust. In the Tucson area, dust is created about equally by natural sources and transportation systems. The vortex of a moving vehicle causes surface dust to become airborne, or reentrained, resulting in impairment of visibility and potential hazards to health at high concentrations. The amount of dust produced by vehicles in motion is proportional to vehicle speed, particularly on unpaved surfaces. Since this study addresses drive-up facilities where vehicle speeds are less than 5 mph on paved surfaces, PM_{10} is not a major concern. Therefore, from an air quality perspective, CO is the principle pollutant of concern and will be emphasized throughout this study. The study looks only at the atmosphere outside the vehicle, so CO concentrations inside vehicles or drive-up establishments are excluded.

HISTORY OF DRIVE-UP FACILITIES

Drive-up restaurants and banks became increasingly popular in the 1970s, although their use has been traced back to the 1930s (*3*). Drive-up windows are popular because they offer perceived speed and convenience compared with parking a vehicle and entering a business for specific services. A wide range of businesses and public sector services are provided at drive-up windows. Banks, restaurants, liquor stores, laundries, and other private businesses rely on drive-up operations for a major portion of their revenue. Public sector drive-up services, such as vehicle registration, emission testing, and postal services have been used with great public acceptance. Drive-up facilities have become a recognized part of the American lifestyle.

TRENDS IN DRIVE-UP FACILITY USE

More and more businesses are using drive-up facilities to remain competitive. Several national fast-food restaurant chains have improved the design of their facilities by providing separate menu boards and pay windows in addition to the necessary service window. This trend has allowed faster service times and a greater proportion of business revenue to be generated through the drive-up window. Emerging technologies, such as radio communication and interactive video, are also being incorporated into drive-up design. The convenience and speed demanded by the customer has resulted in some businesses establishing service time goals. For example, Burger King and McDonald's have target service times of 90 sec or less. The trend towards more and faster drive-up services is apparent, both in the literature and the marketplace.

Emerging technologies may have an important influence on how, when, and where we travel in the future. A recent report announces a new petroleum refining process that reduces automobile air pollution by a third (*4*); oil companies encourage the public to drive less and carpool (*5*); and vehicle manufacturers are marketing the next generation of fuel-efficient vehicles. Telecommunications already allow us to conduct business without traveling, and mobile communications make it possible to be more productive while traveling. Vehicle guidance and navigation systems will help increase highway capacity and improve traffic safety (*6*). These technological trends will continue, resulting in an even more mobile society. The role of drive-up businesses is expected to increase, not diminish, as service becomes faster and mobility-enhancing technologies are implemented.

The recently adopted Clean Air Act Amendments of 1990 are already having a marked effect on urban planning, vehicle manufacturing, and fuel refining (*7*). Emission standards for light-duty vehicles have become more stringent, and the use of alternative or oxygenated fuels is mandated for some areas. As automobile usage increases, vehicles are becoming simultaneously "cleaner." The net result is that levels of carbon monoxide, overall, are improving in Tucson, and probably will continue to improve over the next 10 years until offset by rising regional vehicle miles of travel. This same phenomenon could also occur in larger, more severely polluted cities.

AIR QUALITY MODELS AND LAND USE CONTROLS

This section of the study addresses current computer models and the relevant land use controls exercised by other communities. Computer models are useful for estimating aggregate emissions or emission concentrations near stationary or mobile sources. This section emphasizes mobile source emission models applicable to slow moving traffic in urban areas, similar to traffic conditions at drive-up facilities.

Air Quality Models

Air quality models primarily include computer-based algorithms developed by governmental agencies or private software vendors. Air quality models, however, may also include simple manual calculations, as described in the literature. Computer models must rely on a set of assumptions about emission rates, dispersion methods, and physical processes affecting ambient air quality levels. Generally, the models are defined as numerical, Gaussian, statistical, or physical (*8*). Numerical models are extremely complex and use a finite element approach to estimating downwind pollution concentrations. These models are computationally rigorous, therefore, not utilized often. On the other hand, Gaussian models use a simplifying assumption that the pollutant plume is transported according to a normal distribution. This assumption greatly simplifies the computational process at the expense of theoretical precision. Virtually all models approved by the EPA for regulatory and screening purposes are Gaussian dispersion models. Statistical and physical models are used for special studies, not for routine analysis.

Project analysis for mobile source emissions of carbon monoxide should include preliminary screening techniques. If predicted concentrations using these techniques exceed the ambient air quality standards, then more refined techniques should be used to determine compliance with the standards. CALINE3 is the preferred model when refined analysis is required. A newer release of this model, called CALINE4, is also available, but it has not yet been approved by EPA. For free-flow sources, the latest version of mobile source emission factors available from the model MOBILE4 is required as input to CALINE3, and for interrupted flow sources, such as signalized intersections, procedures to calculate mobile emission factors are contained in other EPA guidance documents. Point and area sources are modeled using algorithms other than CALINE3.

Proprietary models are available from several private vendors. These models, however, vary little from the EPA models. Private vendors frequently obtain the public domain software and modify the software to make it more user friendly. Modifications typically include simplification of model input parameters, simplified file maintenance algorithms, and addition of screen graphic and printer output options. The costs of proprietary models are significantly higher than the public domain models, often by a factor of 10 to 20. Proprietary sources, however, can provide training on the use of these models which may not be available from public agencies. Proprietary models are as acceptable for regularly and screening purposes as the public domain version of the same models.

Research has recently been undertaken to evaluate the effectiveness of carbon monoxide models in the urban environment (*9–11*). There is some agreement among researchers that (a) the models tend to underestimate actual pollutant concentrations, (b) the models are difficult to calibrate with field data, and (c) the models tend to oversimplify the impact of meteorological conditions on the location of highest concentration downwind of an intersection.

Current Regulation of Drive-Up Facilities

For this study, we conducted a survey of other community's regulatory practices. The survey was distributed to more than 70 cities throughout the United States, but emphasized the Southwest. The surveys were mailed to cities ranging in size from 50,000 to 1,000,000 residents. Approximately 42 surveys were returned. The univariate results of the survey are tabulated in Figure 1. A multivariate analysis was also conducted, though not tabulated herein. The high response to the survey indicates that there is a significant interest in the regulation of drive-up facilities. This is also substantiated by the 92 percent of the respondents requesting a copy of this final study.

Almost one-third of the cities enforce some kind of specific drive-up business regulation, yet almost none requires an air quality impact study. Current regulations of drive-up businesses are generally not a response to local air quality problems. Most cities that currently have drive-up regulations feel that the regulations are ineffective. Those that feel their regulations are effective generally have special zoning ordinances for drive-up facilities, whereas regulations considered ineffective are general, governing all types of development. It can be concluded that effective regulation of drive-up facilities should (a) be specifically directed to drive-up uses, (b) include site design guidelines, and (c) include a development review committee process.

FIELD DATA COLLECTION

This section of the study describes the field data collection effort and presents the results of this effort.

I. BACKGROUND

C. Air Quality Status: Please indicate your community's compliance with National Ambient Air Quality Standards.

Pollutant	Compliance	Noncompliance	Don't Know
CO (carbon monoxide)	(18) 42%	(13) 30%	(12) 28%
PM_{10} (particulate matter)	(18) 42%	(10) 23%	(15) 35%
NO_x (nitrous oxides)	(25) 58%	(3) 7%	(15) 35%
SO_x (sulfur oxides)	(25) 58%	(2) 5%	(16) 37%
O_3 (ozone)	(16) 37%	(12) 28%	(15) 35%
Pb (lead)	(24) 56%	(1) 2%	(18) 42%

II. DRIVE-UP FACILITY REGULATIONS

A. Does your community enforce special planning, analysis, or design requirements on drive-up facilities?

Yes	NO	
(27) 63%	(16) 37%	(If No, Skip to F)

B. Which of the following do you require?

	Yes	No	Don't Know or (no response)
Air Quality Impact Study	(1) 2.0%	(21) 49.0%	(21) 49%
Design Review Committee	(20) 46.5%	(8) 18.5%	(15) 35%
Noise Impact Study	(2) 5.0%	(18) 42.0%	(22) 51%
Queueing Analysis	(17) 40.0%	(10) 23.0%	(16) 37%

C. Do you have a special section of your zoning or development code addressing drive-up facilities?

Yes	No	Don't Know or (no response)
(17) 39.5%	(15) 35%	(11) 25.5%

D. Approximately when were these regulations adopted?

1950 = Earliest
1960s = 4
1970s = 2
1980s = 11
1990s = 2
Most were adopted in the mid- to late 1980s.

E. Are your drive-up facilities regulations generally effective, and not in need of revision?

Yes	No	Don't Know or (no response)
(13) 30%	(14) 33%	(16) 37%

F. Are you currently considering adopting new regulations?

Yes	No	Don't Know or (no response)
(14) 33%	(27) 63%	(2) 5%

III. FURTHER INFORMATION

B. Indicate whether you would like a copy of the final study.

Yes	No	Don't Know or (no response)
(40) 93%	(3) 7%	(0) 0%

FIGURE 1 Survey results.

Multifaceted Collection Plan

A multifaceted field data collection effort was utilized to help quantify air quality impacts of three typical drive-up facilities in the Tucson area. The data collection effort was also used to evaluate whether monitoring a drive-up facility is a practical method of enforcing site-specific air pollution regulations using locally available equipment. Concurrent data were collected for carbon monoxide and meteorological conditions, on-site traffic, queueing/service data, adjoining arterial traffic volumes, and ambient carbon monoxide background concentrations. Data were collected in December 1990. These data were collected in a joint effort by the City of Tucson Department of Transportation, Pima County Air Quality Control District (PCAQCD) and the project consultant. The three sites selected include a fast food restaurant, a bank, and a vehicle emissions testing facility. The selected businesses and their locations are considered typical of the Tucson area. The emissions testing facility was included to help demonstrate that some public and quasi-public services are also provided on a drive-up basis. The sites were also selected because of their physical orientation allowing on-site parking of the PCAQCD van, adequate electrical outlets, ease of observation of the drive-up lane operation, and the cooperation of the facility manager.

The van was placed 100 to 400 ft from the drive-up lane, and CO data were collected at each site for 12 to 24 hr. The van was equipped with a single Monitor Labs 8830 infrared CO monitor, a Sumx 445 data logger, and a Linear 156 strip chart recorder. The CO sample inlet was located approximately 9 ft above ground level. Wind speed and direction were monitored at 13 ft above ground level. Air temperature inside the van was monitored to assure calibration of the equipment. Outside temperatures were obtained from the National Weather Service and the ACQD's permanent monitoring sites. For each site, a field visit and coordinating meeting with the facility manager or owner were conducted prior to data collection.

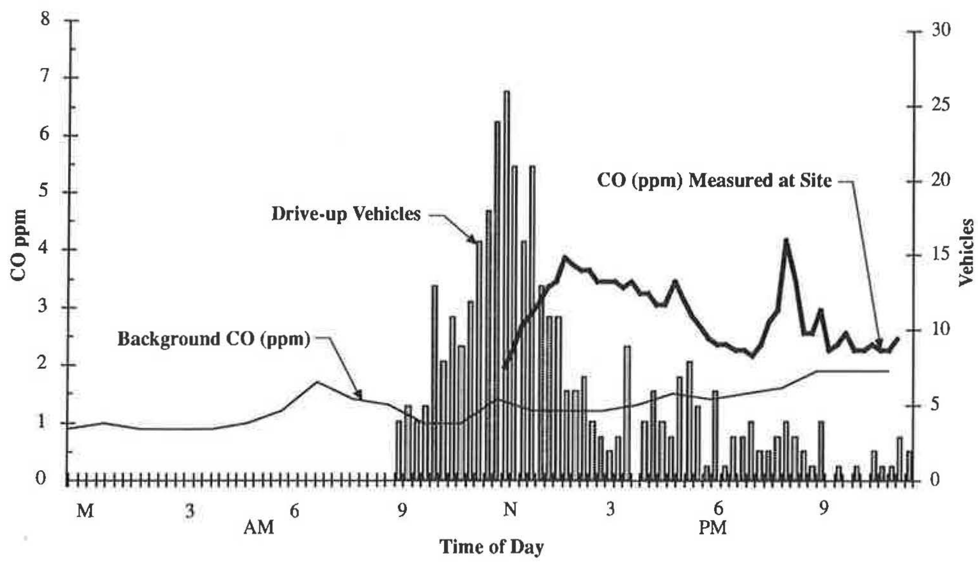

FIGURE 2 Field data summary: fast-food restaurant.

Typical results of the data collection efforts are shown in Figure 2. This exhibit contains time-based data regarding: (a) the number of vehicles queued at the fast-food facility, (b) the CO concentration measured at the site, and (c) the background CO concentration recorded at a permanent monitoring site several miles away.

The CO concentrations recorded at the sites are less than 9 parts per million (ppm), much less than the national standard of 35 ppm for 1-hr exposures. A graphical analysis approach using superposition of the data has been used. This technique is similar to an approach used by EPA (*12–14*). Although the data collection effort went smoothly, interpretation of the data shows little, if any, correlation between the amount of traffic through the drive-up facility and the CO level detected at the monitoring van. The major difficulties with this effort included: (a) variable winds that shifted the concentration point away from the single CO monitor at the sampling van, and (b) the low concentration of CO being emitted by vehicles in queue, as well as very low ambient levels of CO. The finding that measured CO concentrations do not correlate well with field observations of the emission source, although a disappointment in light of the amount of effort to collect the data, has also been concluded by others. For example, EPA (*8*) states that

> calibration of short-term models is not common practice and is subject to much greater error and misunderstanding. There have been attempts by some to compare short-term estimates and measurements on an event-by-event basis and then to calibrate a model with results of that comparison. This approach is severely limited by uncertainties in both source and meteorological data and therefore it is difficult to precisely estimate the concentration at an exact location for a specific increment of time. Such uncertainties make calibration of short-term models of questionable benefit. Therefore, short-term model calibration is unacceptable.

The findings of independent researchers are also consistent with this EPA viewpoint.

It can be concluded that the air quality monitoring approach used here is not a viable tool for enforcing locally adopted emission regulations at drive-up facilities. A much more sophisticated (and more expensive) approach using numerous monitors and extensive on-site traffic data collection would be needed. Drive-up facility regulation would be more effective in the form of site design and performance standards rather than the establishment of incremental emissions levels contributed by drive-up operations. Physical site constraints, variable meteorological conditions, the limitation of monitoring equipment, and the cost of data collection simply preclude site-specific monitoring as a realistic regulatory tool.

Industry Data

Personal communication with spokesmen of McDonald's and Burger King yields important insights into the fast-food business as well as the use of drive-up facilities. The industry is highly competitive and some of the major corporations have established service time goals that generally range from 90 to 120 sec from arrival time to departure time (*15,16*). To help improve service time, new technologies and architectural design strategies have been incorporated into drive-up facilities. The single-window design of the 1970s has evolved to a two-window (pay/pick-up) system with a separate menu board. This design allows speed of service during peak hours, and flexibility to operate with only one window open during lesser demand periods. State-of-the-art drive-up lanes provide service times, according to our field study, as quick as fifteen seconds. Industry spokesmen claim that video technology will be introduced into the next generation of drive-up facilities. This will allow "face-to-face" communication between patron and server that will minimize mistakes in order preparation.

The drive-up industry goal of quicker service time is consistent with any proposed regulatory program to minimize vehicle idling. However, the industry also attempts to site their businesses at high traffic locations. These locations also tend to be CO hot spots. Introduction of additional idling vehicles at already congested locations may be counter productive. This consideration must be weighed against the hours of peak air pollution at a given location. According to the spokesmen, the busiest time for drive-up restaurants is at lunch—that is, from 11:00 a.m. to 1:00 p.m.—and again after 5:30 p.m. for dinner. Drive-up financial services peak in the midafternoon. Therefore, industry data indicate that service time goals of 1½ to 2 min generally support environmental goals, whereas the desire to locate drive-up businesses near congested intersections does not.

Traffic Queueing Data

The analysis of the queueing portion of on-site traffic data collected for this study is identified in Table 1. It is evident that the national fast-food chains attempt to provide quick service in an effort to conform with their service goals. However, fewer than 20 percent of the customers were served within 90 sec and fewer than 30 percent were served within 120 sec. The peak periods identified by major fast-food industry spokesmen were verified by field observations. The maximum wait observed was 26 min in a line of 14 waiting vehicles at the emission testing station. The queueing/service discipline utilized at a specific site has a correlation with anticipated service time. Fastest service can be offered by the menu board/two-window system for already-prepared food. The range of service times at drive-up banking windows is highly variable depending upon the services provided. Businesses which use a single-window system for food items prepared on request can take the longest amount of time.

Results of Data Collection

Based on graphical interpretation and linear regression analysis, there is little observed correlation between the measured CO concentration and the amount of vehicle idling occurring at the various drive-up facilities. As mentioned previously, this is attributable to the low emission rates generated at the facilities, overall low CO concentrations, and the variability of wind direction limiting measured impact at the sampling van. Other elements of the data collection phase provide insight about trip generation rates at drive-up facilities, average service times and peak hours of service as these factors occur in the Tucson metropolitan area. The calculated trip generation rates are within the range of expectation of the ITE's Trip Generation handbook (*17*).

The evaluation of average service times can be related to both air pollution and energy consumption using a break-even analysis. This analytic approach relates the mass of CO emitted by a vehicle under hot start conditions with the time needed for an idling vehicle to emit the same mass of CO. Such an analysis is dependent on the vehicle fleet using drive-up facilities (generally passenger cars and light-duty trucks) and the air quality models used to estimate emission characteristics of that fleet. A range of break-even times can be established using a range of reasonable model input assumption.

For the 1990 vehicle fleet, the minimum break-even point for equal level of CO emission under the drive-up versus the park and enter scenarios has been calculated based on an incremental hot start emission rate of 15 g using EMFAC7D and idle emission rate of 147 and 423 grams per hour using EMFAC7D and MOBILE4, respectively. For CO, the primary concern of this study, the break-even range is approximately 2 to 6 min (K. D. Drachand, California Air Resources Board, unpublished data). Similarly, this compares with the average service time measured by this study at some of the project sites.

It can be concluded that an efficiently run drive-up lane (i.e., one that provides service in less than two minutes) produces less carbon monoxide than if a vehicle was stopped and restarted. This conclusion is generally consistent with those cited in the literature. Most of the observed service times, however, were within the 2- to 6-min break-even point range. For the observed facilities, the net impact on air quality is elusive.

An additional consideration in the break-even analysis is the effect of technological changes in the vehicle fleet. The estimates cited here are for the 1990 California fleet. A similar analysis for the 1995 California fleet results in longer break-even times because idle emission rates for this fleet are lower. The results of the break-even analysis are sensitive to factors such as inspection and maintenance programs, fuel oxygenation, and the composition of the vehicle fleet, among others. Care must be used in developing and applying break-even analysis for a specific location.

TABLE 1 On-Site Traffic Data

			Service Time (sec)				
Site	Business	Type of Queue*	Min	Max	Std Dev	Observations	Average
Valley Bank	Financial	One-to-Many	50	1,065	201	201	399
Emission Testing	Govt. Service	One-to-Many	180	1,575	236	212	366
Burger King	Fast Food	2-Window/MB	55	450	75	100	154
Liquor Store	Liquor	1-Window	65	295	150	10	176
KFC	Fast Food	1-Window/MB	145	430	153	3	320
Hardee's	Fast Food	1-Window/MB	74	180	33	12	111
Dairy Queen	Fast Food	1-Window	115	340	95	7	218

* The definitions of queuing disciplines are as follows:
MB - Menuboard
One-to-Many - One wait lane discharges to many service windows.
1-Window - A single window is used to take the customer's order, receive payment, and serve the order.
1-Window/Menuboard - Service is ordered at menuboard; payment and product are exchanged at the service window
2-Window/Menuboard - Service is ordered at a menuboard; payment is made at the first window; service is provided at the second window.

From an energy conservation perspective, a break-even analysis can also be conducted. The amount of fuel consumed during an average 2-min service time cycle is approximately 0.02 gal (*18,19*). This compares with a consumption of approximately 0.002 gal under the stop/restart scenario. It is apparent that approximately 10 times more fuel is needed to use the drive-up lane than to park and enter a business, primarily because restarting an engine relies on battery power, not gasoline. The amount of additional gasoline consumed in drive-up service lanes is not considered an important issue during times of abundant petroleum supply. More air pollution in the form of carbon monoxide could be created if use of drive-up lanes were restricted in an effort to conserve fuel. The characteristics of today's vehicles and drive-up operations have lead to an apparent conflict between public air pollution and fuel conservation policies. Energy conservation and contingency programs currently emphasize supply problems, not air pollution levels.

RECOMMENDATIONS AND CONCLUSIONS

The community survey and data collection efforts, as well as the many sample regulations obtained from other cities, provide significant insight and policy guidance. The city currently has no specific drive-up facility regulations, design guidelines, or mechanisms for review by city staff. Tucson currently complies with the NAAQS and is expected to remain in compliance in the foreseeable future. However, the region is officially designated as a CO nonattainment area by the EPA primarily because recertification as an attainment area has not been requested by local officials. The study effort leads to a series of recommendations regarding air quality maintenance and planning, site design guidelines, and agency review.

Overview of Study Results

This study provided needed information about the current operation, use, and air quality impacts of drive-up facilities. The results are summarized here as a preamble to the recommendations and concluding remarks.

1. Field measurement is not an effective means of determining the level of CO air pollution generated by a drive-up business. Ambient CO levels vary throughout the day, as do wind speed, wind direction, and traffic on nearby streets. The high variability of pollution sources and meteorological factors makes separation of source variables extremely difficult. The amount of pollution associated with operation of a drive-up facility can not effectively be measured in the field under real world conditions.
2. Computer modeling can be used to estimate pollution levels at drive-up facilities. The accuracy of current models is uncertain and model output represents an approximation of actual emission concentrations. Appropriate EPA-approved models currently include CALINE3 using MOBILE4.1 (adjusted for fuel oxygenation) as emission factor input.
3. Many communities successfully regulate the design and location of drive-up businesses, although not primarily for reasons of air quality. The most successful approach, according to the community survey, is adoption of a specific drive-up business ordinance and design review process. None of the communities responding to the survey prohibit drive-up businesses entirely, although some prohibit drive-up businesses in congested areas or in sensitive neighborhoods.
4. The use of drive-up facilities can produce less carbon monoxide pollution than the park-and-enter alternative, if the service time is less than the approximately two minute break-even point. Conversely, the park-and-enter alternative uses only about one-tenth the fuel required for the average drive-up operation. These relationships will undoubtedly change as technological advances in engine efficiency, zero emission vehicles, and cleaner fuels are introduced.
5. The traffic impacts of drive-up facilities are difficult to assess because only limited data are available. Applications of standard traffic engineering techniques are limited because on-site distribution of customers to park-and-enter and drive-up services has not been well documented in the literature. Further, the amount of pass-by and diverted linked trips has not been adequately quantified for the broad range of drive-up services.

Drive-Up Facility Design Guidelines

Effective drive-up facility planning includes consideration of many design elements. The city currently has no specific regulations for drive-up facilities, and should develop its own guidelines or ordinances based on local need and the success of other communities. The following recommendations will help attain this goal.

- Prepare site planning and design guidelines that regulate access, circulation, traffic impacts, location, noise, odors, lighting, and other elements important to the community. These guidelines should be advisory and made part of the design review process. The sample regulations obtained from other communities for this study, ITE guidelines, and the resources cited herein provide adequate guidance for this purpose.
- Because of the localized effects of carbon monoxide, air quality modeling should only be required for proposed facilities at critical locations, and not indiscriminately required of each proposed drive-up establishment.
- The regulations and review processes should be evaluated for their effectiveness on a periodic basis, and revised to reflect changes in technology, air pollution regulations, or community need.

Drive-up facilities are an expected part of the urban experience. They provide convenience, and efficient drive-up lanes (those with less than 2-min service times) create less CO, yet use more gasoline than the park-and-enter alternative. Site design guidelines can help provide more efficient drive-up operations. Adoption and implementation of appropriate design guidelines and air quality analysis procedures should be viewed as mutually beneficial to businesses and regulatory agencies. Additional research is needed regarding how the location of drive-up businesses along major arterials detracts from highway capacity. This interrelationship may actually be more significant than the design of the site itself because diminished arterial highway capacity increases congestion, which in turn, increases CO emissions and the need for highway improvements.

The findings of this study reflect conditions in the Tucson metropolitan area, and are subject to the uncertainty inherent to the use of air quality models. Recommendations and conclusions of the study may be valid in other regions after careful consideration of local needs and conditions.

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REFERENCES

1. T. Godish. *Air Quality*. Lewis Publishers, Inc., Chelsea, Mich., 1985.
2. B. James. *Highways and Air Pollution, A Citizens' Primer*. Sullivan Center for Science in the Public Interest, Washington, D.C., 1974.
3. A. McAllister. *Zoning For Fast-Food and Drive-In Restaurants*. Report 320. Planning Advisory Service, American Society of Planning Officials (now American Planning Association), 1976.
4. *Air Pollution—Air Quality Implications of Alternative Fuels*. General Accounting Office, July 1991.
5. *Shell Answer Series 5—Better Mileage Tips*. Shell Oil Company, 1991.
6. *Smart Highways—An Assessment of Their Potential to Improve Travel*. General Accounting Office, May 1991.
7. Pub. L. 101-549 (Nov. 15, 1990), *1990 Clean Air Act*.
8. *Guideline on Air Quality Models*, rev. ed. Environmental Protection Agency, Research Triangle Park, N.C., 1986.
9. *Air Pollution Reliability and Adequacy of Air Quality Dispersion Models*. GAO/RCED-88-192. U.S. General Accounting Office, Aug. 1988.
10. G. J. Schewe and T. Braverman. Evaluation of CO Intersection Modeling Techniques. Presented at the 70th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 1991.
11. J. Zamurs and R. Conway. A Comparison of Intersection Air Quality Models' Ability To Simulate Carbon Monoxide Concentrations in an Urban Area. Presented at the 70th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 1991.
12. *Carbon Monoxide Hot Spot Guidelines Volume I: Techniques*. Environmental Protection Agency, Research Triangle Park, N.C., Aug. 1978.
13. *Carbon Monoxide Hot Spot Guidelines Volume II: Rationale*. Environmental Protection Agency, Research Triangle Park, N.C., Aug. 1978.
14. *Carbon Monoxide Hot Spot Guidelines Volume III: Workbook*. Environmental Protection Agency, Research Triangle Park, N.C., Aug. 1978.
15. *Should Drive-Thru Restaurants Offer Service-Time Guarantees?* Restaurants and Institutions, 1989.
16. *Is Drive-Thru Service Ever Fast Enough?* Restaurants and Institutions, May 1987.
17. *Trip Generation*, 5th ed., ITE, 1991.
18. J. D. Fricker and H.-S. Tsay. Drive-Up Windows, Energy, and Air Quality. In *Transportation Research Record 1092*, TRB, National Research Council, Washington, D.C., 1986.
19. J. R. Baxter and D. B Stafford. User Costs and Fuel Consumption at Drive-Through Facilities. In *Transportation Research Record 1049*, TRB, National Research Council, Washington, D.C., 1985.
20. *Air Quality Impacts of Drive-Up Facilities*. JHK & Associates, Tucson, Ariz., 1991.

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