Toll Plaza Design To Minimize Carbon Monoxide Levels at Roadway Rights-of-Way

ALICE LOVEGROVE AND STEVEN WOLF

Compliance with national and state ambient air quality standards is an important consideration in designing a toll plaza. With the increased focus on air quality created by the enactment of the Clean Air Act Amendments of 1990, air quality concerns must now be regarded along with other design criteria. Meeting ambient air quality standards can often require the acquisition of additional right-of-way (ROW) around the toll plaza. This approach, which increases the distance between source and receptor, is often impractical in terms of land use and cost. Some toll plaza design concepts have been developed at existing and proposed toll plazas to achieve lower pollutant concentrations while minimizing ROW requirements. By designing the plaza to eliminate the overlap of high-emission zones and by introducing automatic vehicle identification toll gates, the ROW needed to avoid an air quality violation can be greatly reduced.

With the enactment of the new Clean Air Act Amendments of 1990, air quality concerns must be regarded along with other highway design criteria. In designing a toll plaza, compliance with national and state ambient air quality standards is an important consideration. Meeting these standards may require additional right-of-way (ROW) to maintain an adequate distance between the toll plaza and either existing or planned sensitive land uses. This study discusses toll plaza design concepts that have been developed to achieve lower air pollutant concentrations while minimizing required ROW acquisition.

These concepts are applicable to existing roadways with limited ROW (i.e., near sensitive land uses) and to new roadways for which the land acquisition costs for ROW are very high.

BACKGROUND OF CLEAN AIR ACT

The Clean Air Act Amendments of 1990 direct the Environmental Protection Agency (EPA) to implement strong environmental policies and regulations that will ensure cleaner air quality. These amendments will affect all proposed transportation projects. According to Title I, Section 101, Paragraph F, "No federal agency may approve, accept or fund any transportation plan, program or project unless such plan, program or project has been found to conform to any applicable (state) implementation plan in effect under this act." Title I of the amendments defines conformity as follows:

- Conforming to an implementation plan's purpose of eliminating or reducing the severity and number of violations of the National Ambient Air Quality Standards (NAAQSs) and achieving expeditious attainment of such standards; and
- Ensuring that such activities will not
  - Cause or contribute to any new violation of any NAAQS in any area,
  - Increase the frequency or severity of any existing violation of any NAAQS in any area, or
  - Delay timely attainment of any NAAQS or any required interim emissions reductions or other milestones in any area.

CARBON MONOXIDE: HEALTH IMPLICATIONS AND STANDARDS

Toll plazas have traditionally been known as areas with high carbon monoxide (CO) levels. CO is the pollutant of concern for projects involving congested roadways. High CO levels around toll plazas are caused by queueing at and accelerating from the plaza.

CO is a colorless and odorless gas. It is a localized problem; high concentrations are normally limited to locations within a relatively short distance (300 to 600 ft) of a heavily traveled roadway. Because of the increased source strength at a toll plaza, this distance can increase to 1,000 ft.

Exposure to CO can lead to serious health risks. CO is a relatively insoluble compound that easily enters the tiny air sacs, or alveoli, in the lungs along with oxygen. Once in the lungs, CO diffuses through the alveolar walls, entering the bloodstream. In the bloodstream, CO joins with hemoglobin to form carboxyhemoglobin. Hemoglobin normally bonds with oxygen, but it has an affinity for CO that is about 210 times greater. This bonding causes a decrease in the oxygen supply in the blood. As shown in Figure 1, this can have serious health implications. On the basis of this information, EPA established NAAQSs for CO and several other pollutants. The standards for CO are 9 ppm for 8 hr and 35 ppm for 1 hr. These standards are levels to which pollutant concentrations should be reduced to avoid undesirable effects. The primary goal of these standards is to protect public health. The secondary goal is to protect the nation's welfare and account for the effects of air pollution on soil, water, vegetation, and other aspects of general welfare.

This study will use the 8-hr standard to determine the minimum ROW necessary for each configuration to avoid surpassing the regulated levels.

Parsons Brinckerhoff Quade & Douglas, Inc., One Penn Plaza, New York, N.Y. 10119.

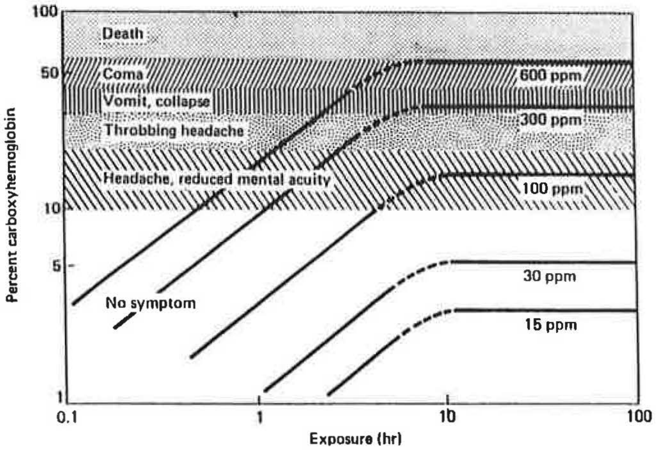

FIGURE 1 Effects of exposure to CO on man.

CO LEVELS AT TOLL PLAZAS

Emission of CO from a vehicle in grams per mile is very high at lower speeds and idling. CO emission also greatly increases during acceleration. All these vehicular operating conditions are present at toll plazas. Because of this, CO levels near toll plazas are often extremely high. To avoid air quality violations, ROW must often be increased. This places sensitive receptor sites beyond the area in which CO levels would exceed the standard. For all practical purposes, this approach is a condemnation of the land; it is also inefficient in both cost and land use. A better way to achieve compliance with the air quality standards is to have the air quality and civil engineers work together to design a toll facility that meets standard toll requirements and minimizes CO levels.

METHODOLOGY

Four toll configurations were analyzed. Each configuration was divided into transition and queueing zones, as shown in Figure 2. The high-emission zones shown in this figure are the queue zone and the acceleration zone. Each toll design is based on the location of these areas.

For each toll configuration, a minimum ROW distance needed to avoid an air quality violation was determined. The minimum ROW required is defined as the distance between a receptor and roadway needed to achieve a predicted CO concentration below the 8-hr standard of 9 ppm. The ROW distances required for each toll plaza design were compared to the ROW requirements without the toll plaza. Each toll plaza design alternative was then ranked in terms of the ROW required to meet air quality standards.

The analysis of the air quality impact of each toll configuration used emission and dispersion modeling programs. Pollutant dispersion analysis uses a line source air quality model that simulates the physical conditions in the study area. It is based on the assumption that the dispersion of pollutants follows a Gaussian, or normal, distribution. The model used for this analysis was CALINE4. A complete explanation of the mathematical formulation, basic assumptions, and limitations of the model are given elsewhere (*1*).

Parameters for the air quality analysis are presented in Table 1. The analysis considered wind directions ranging from 0 to 360 degrees to determine the worst-case level, which was calculated for each receptor. These values, used for all scenarios, were based on design conditions used to evaluate major highway projects in California. Emission factors used were determined through the California emissions program EMFAC7C. This program, using vehicle mix, temperature, California registration and fleet information, and other parameters, determines an average emission factor for a vehicle traveling at a specified speed. Although this information is specific for California, the resulting trends can be applied nationwide.

TABLE 1 Parameters for Toll Analysis

Parameter	Value
Volume -	
Peak Direction	3850
Off Peak Direction	2300
Free Flow Speed	55 mph
AVI Speed through gate	30 mph
Number of Manual Lanes	
No AVI usage	10
With AVI usage	5
Percent of AVI usage	50%
Number of AVI Lanes	5
Average Queue (# of vehicles/gate)	10
Wind Speed	.5 m/s
Stability Class	7
Surface Roughness	100 cm
Ambient Air Temperature	50 F
Persistence Factor	0.7
Vehicle Mix	
Autos	75.00%
Light Duty Trucks	19.00%
Medium Duty Trucks	4.20%
Heavy Duty Trucks	1.80%
Vehicle Operating Mode	
Hot Start	2.00%
Cold Start	10.00%

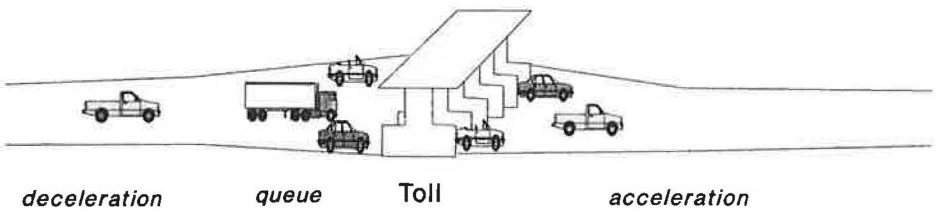

FIGURE 2 Transition and queueing zones.

Emission strength and the distances at which they were applied were determined on the basis of the CALINE4 dispersion model for predicting air quality pollutant concentrations near roadways. The actual emission strength values will vary depending on the defined roadway configuration and use. For this analysis, using the parameters in Table 1, the emission zones ranked from highest to lowest strength were the queue zone, 30- to 55-mph acceleration zone, 0- to 30-mph acceleration zone, and the deceleration zone.

The emissions for the acceleration zones were calculated using the following equations from the CALINE4 model (*1*):

$$\mathrm{EFA} = \mathrm{BAG2} * 0.76 * e^{0.045 * \mathrm{AS}} \quad \text{(at rest)} \quad (1)$$

$$\mathrm{EFA} = \mathrm{BAG2} * 0.027 * e^{0.098 * \mathrm{AS}} \quad \text{(moving)} \quad (2)$$

Average acceleration rates were taken from the CALINE4 mode surveillance driving sequence data. The modal acceleration speed product (AS) was determined to be 30.3 $\mathrm{m}^2/\mathrm{hr}^2$-sec for the 0- to 30-mph acceleration zone (Equation 1) and 61.2 $\mathrm{m}^2/\mathrm{hr}^2$-sec for the 30- to 55-mph acceleration zone (Equation 2). Both of these values were within the acceptable ranges of the equations.

The total strength of these zones is determined by the combination of source strength and area in which they apply. The distance over which acceleration takes place is greater than the distances needed for queueing. The combination of distance and source strength makes the acceleration zones the areas of most concern for this analysis.

The toll configurations were also analyzed with the introduction of automatic vehicle identification (AVI). AVI is a system used for identifying vehicles passing a specific point. Other expressions for this system include electronic toll and traffic management and electronic toll collection. This system allows vehicles to pass a point—in this case, a toll collection facility—and be identified and charged for passage, all without stopping. The system may be optical or electronic. The driver would receive a monthly bill or would have the toll amount deducted from an account each time the registered vehicle passed the collection point. This system can reduce pollutant emissions resulting from vehicles using this system since it will eliminate the queue and reduce the amount of acceleration emissions.

ALTERNATIVE TOLL PLAZA DESIGNS

The first configuration is the traditional straight line design (Concept 1) shown in Figure 3. The second (Concept 2), shown in Figure 4, is a staggered design in which acceleration zones overlap. The third (Concept 3), shown in Figure 5, is a staggered design with no overlapping zones. Concept 4, shown in Figure 6, is based on Concept 3; it has separated manual and automatic toll gates.

Analysis

The first part of the analysis determines the ROW requirements for each toll configuration, and the second part considers the effects caused by the use of AVI to each of the four designs. The pay-in-one direction toll concept was not analyzed in this study. This concept will generally reduce ROW requirements, but care must be taken when it is analyzed because of the potential change in traffic patterns that may occur if a toll-free route is available nearby. Because of this, the concept was not studied.

Although the distances shown in the analysis are specific for these examples, the trends illustrated can be applied to similar scenarios.

Concept 1: Traditional Design

Traditionally, toll plazas have been designed as straight strings of gates crossing both directions of traffic (Figure 3). As shown in this figure, the queue zone and the opposing acceleration zone are parallel. These two zones generally emit the highest

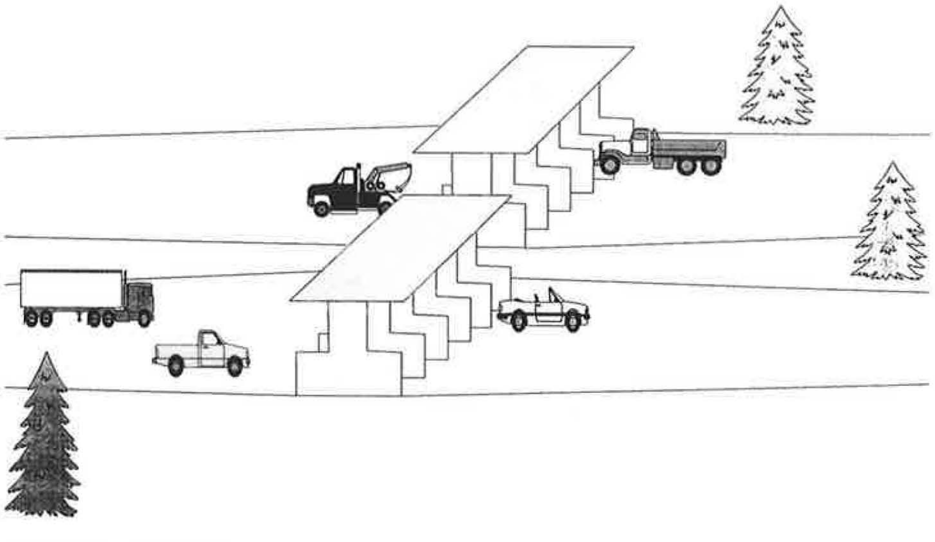

FIGURE 3 Concept 1.

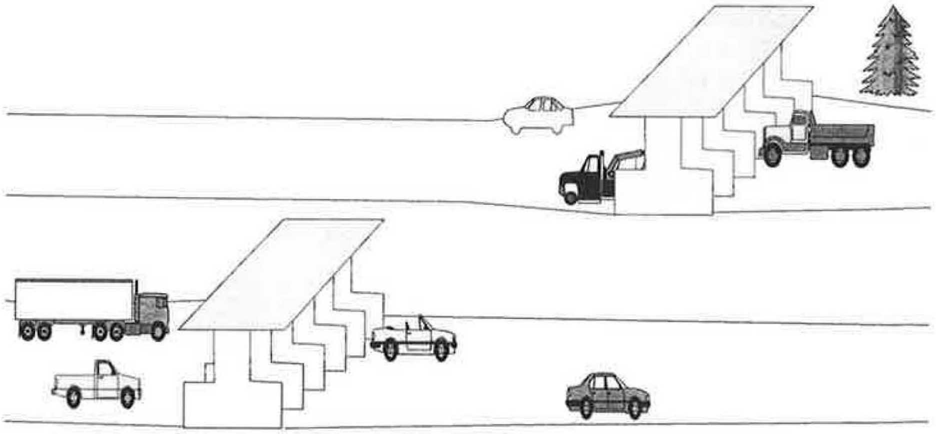

FIGURE 4 Concept 2.

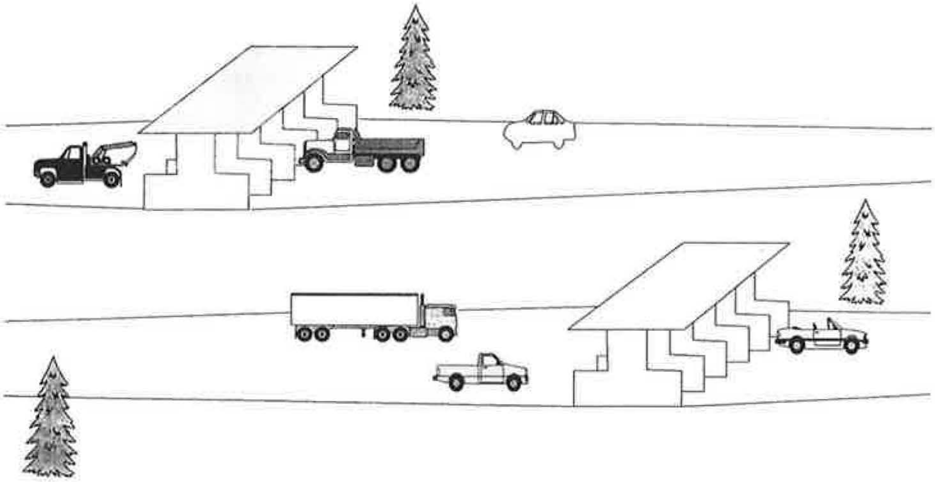

FIGURE 5 Concept 3.

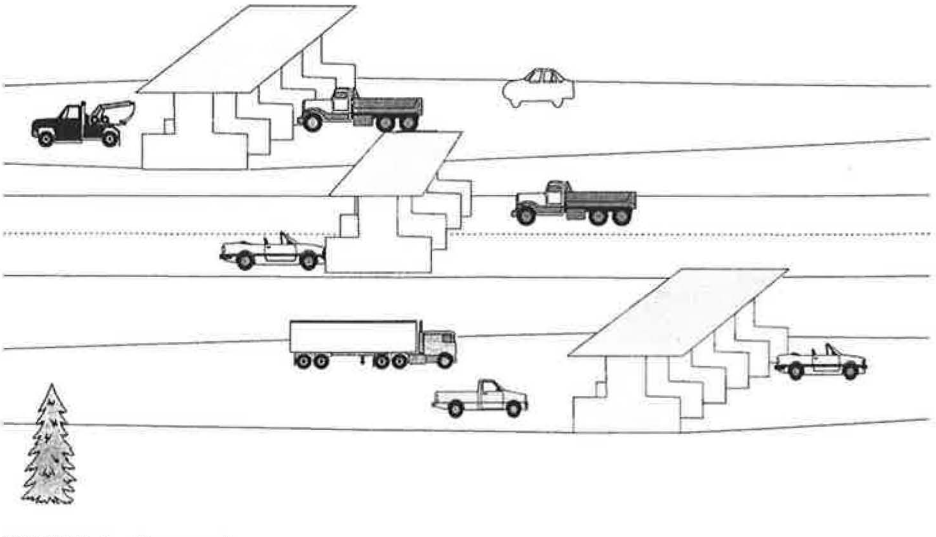

FIGURE 6 Concept 4.

amounts of CO. These zones also combine to create a band of high CO concentrations. This increased source strength will require more space to dissipate, thus increasing the ROW beyond the area right next to the source.

As shown in Figure 7, a ROW to avoid a violation of the 8-hr CO standard under this concept would require roughly 750,000 ft^2, with a maximum distance of 510 ft from the edge of the roadway. The ROW maximum distance without the toll would be only 20 to 30 ft. For an existing roadway this type of land requirement may be impossible to attain. In such a situation, one way to reduce the ROW would be to introduce AVI. Figure 8 shows the ROW with the introduction of AVI technology. It was assumed that 50 percent of the vehicles entering the plaza area used AVI. The required ROW to avoid a violation of the 8-hr CO standard is about 680,000 ft^2 of land, with a maximum distance of 490 ft from the edge of the roadway. This is more than a 9 percent reduction in land requirement when compared with no AVI usage.

Concept 2: Staggered, Acceleration Overlap

The two directions can also be staggered, as shown in Figure 4. This design creates an overlap of each direction's acceleration zone. The acceleration zone is an area of high emissions and thus creates an area of very high pollutant concen-

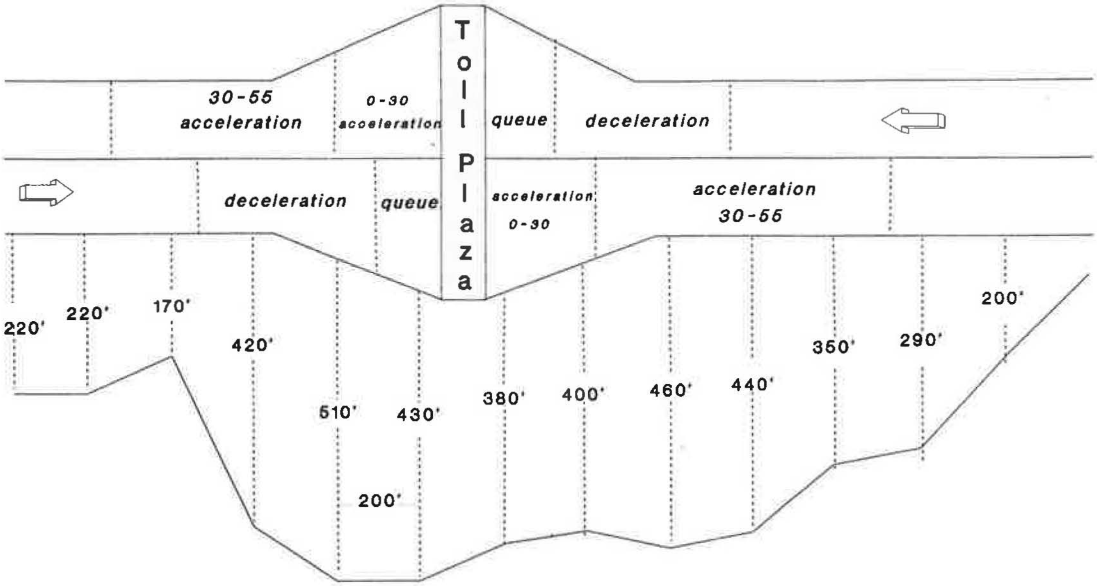

FIGURE 7 ROW for Concept 1.

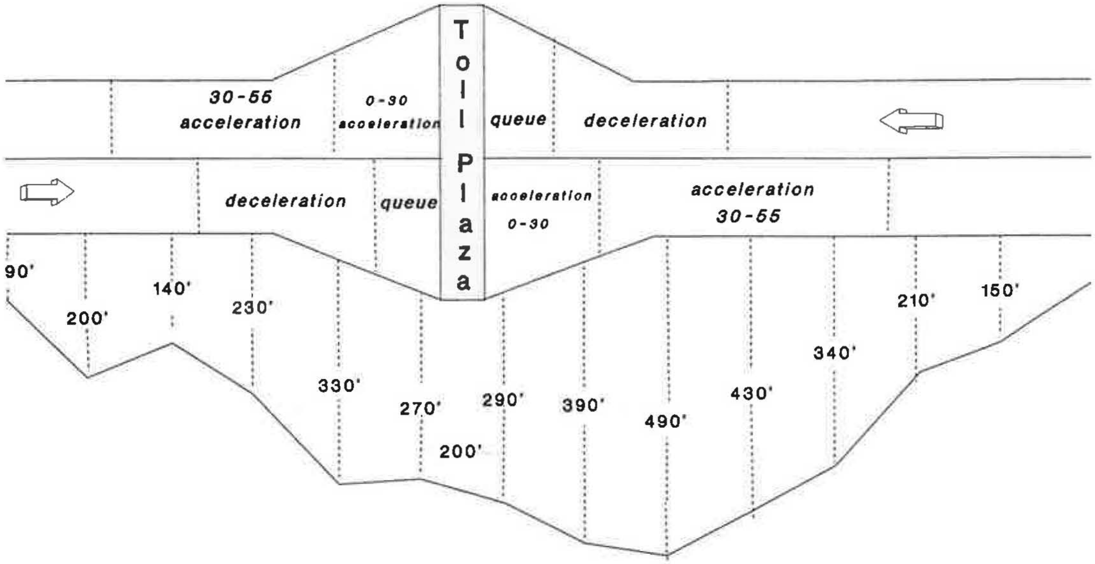

FIGURE 8 ROW for Concept 1 with AVI.

tration. This increased concentration takes more space to dissipate, increasing the ROW around the overlap area (Figure 9). Although this area is greater than the area needed for Concept 1 in this zone, the ROW for Concept 2 returns to its free-flow width in a shorter distance. Thus Concept 2 could be used in areas where a large ROW is attainable within a short span of roadway.

Figure 10 illustrates the ROW using Concept 2 with AVI technology. The required ROW distances were not reduced using this method. This is due to the continuing contribution of the acceleration zone from the AVI vehicles. The AVI vehicles were assumed to decelerate from 55 to 30 mph and then accelerate from 30 to 55 mph. The acceleration of the AVI vehicles combines with the opposing traffic flow's queue

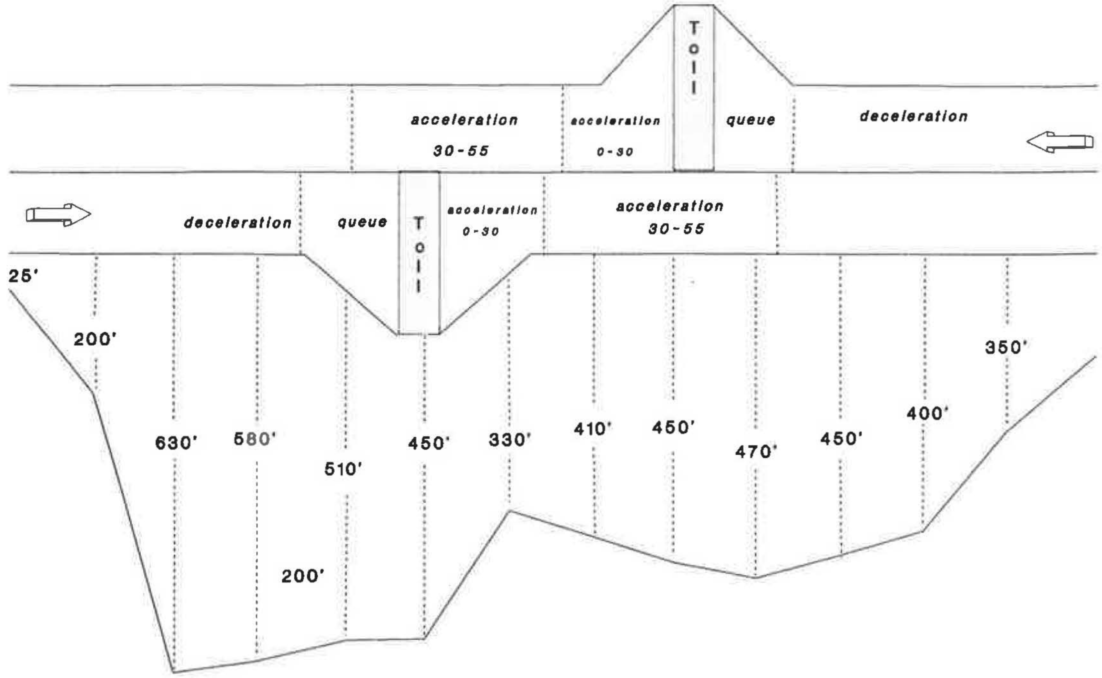

FIGURE 9 ROW for Concept 2.

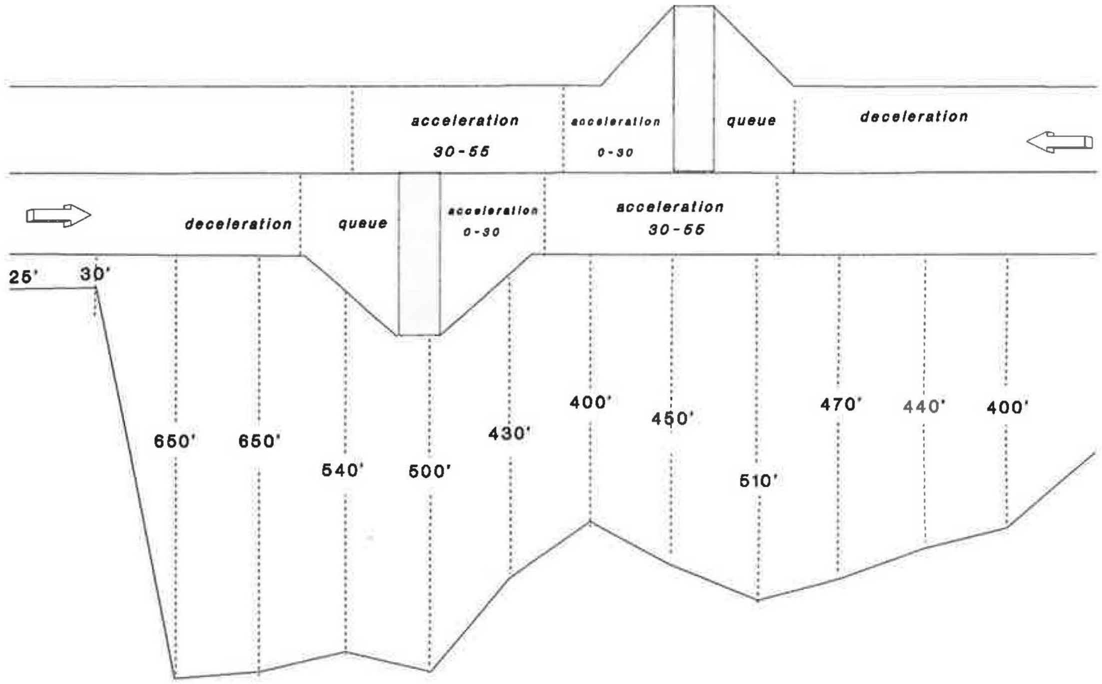

FIGURE 10 ROW for Concept 2 with AVI.

to create a very high emission source—higher than the zone created with no AVI usage. This leads to slightly higher ROW requirements.

This design concept exaggerates the required ROW zone by overlapping each direction's acceleration zones, so no significant improvement is gained by using this concept and AVI.

Concept 3: Staggered, No Overlap

Figure 5 illustrates the staggered design introduced in Concept 2, but here the acceleration zones are separated so that they do not overlap. This design greatly reduces the necessary ROW needed to avoid an air quality violation. By using this design, the high-emission acceleration zones are separated. This design leads to a peak ROW distance of 390 ft and a total area requirement of approximately 635,000 ft^2 (Figure 11). This is a 15 percent savings of land acquisition when compared with Concept 1 without AVI. The introduction of AVI technology to this concept reduces the ROW even more, resulting in an area requirement of approximately 500,000 ft^2. This is a 26 percent decrease in land requirement using no AVI (Figure 12). Concept 3 with AVI also results in a 33 percent decrease in land requirements compared with Concept 1 and a 26 percent decrease compared with Concept 1 with AVI. This design results in the smallest ROW requirement when compared with Concepts 1 and 2.

Concept 4: Concept 3 Design with Lane Separation

Concept 4 uses the principles developed in Concept 3 and adds lane separation. As shown in Figure 6, Concept 4 staggers the traditional toll gates so that there is no overlap of the acceleration zones. It also separates the AVI tolls from the manual tolls. As shown in Figure 13, this design reduces

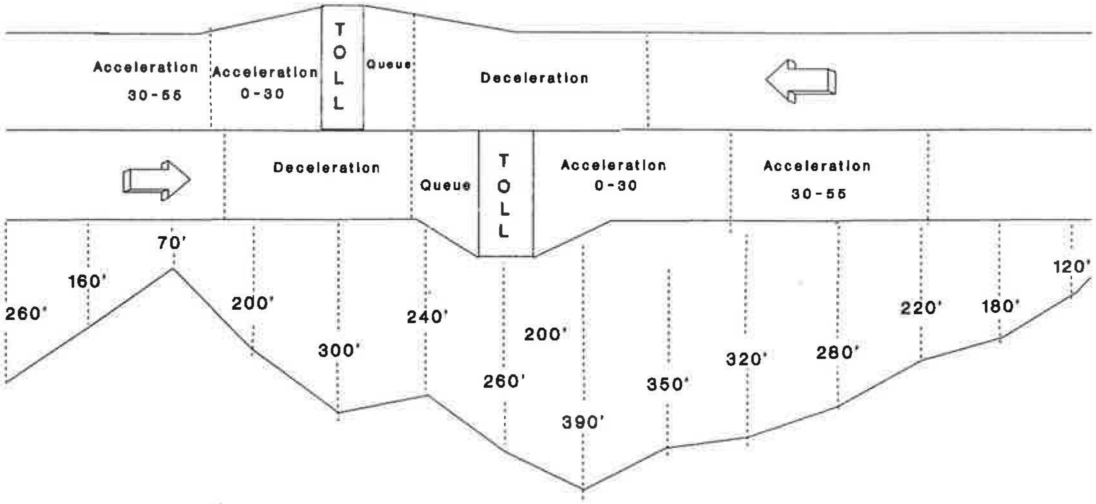

FIGURE 11 ROW for Concept 3.

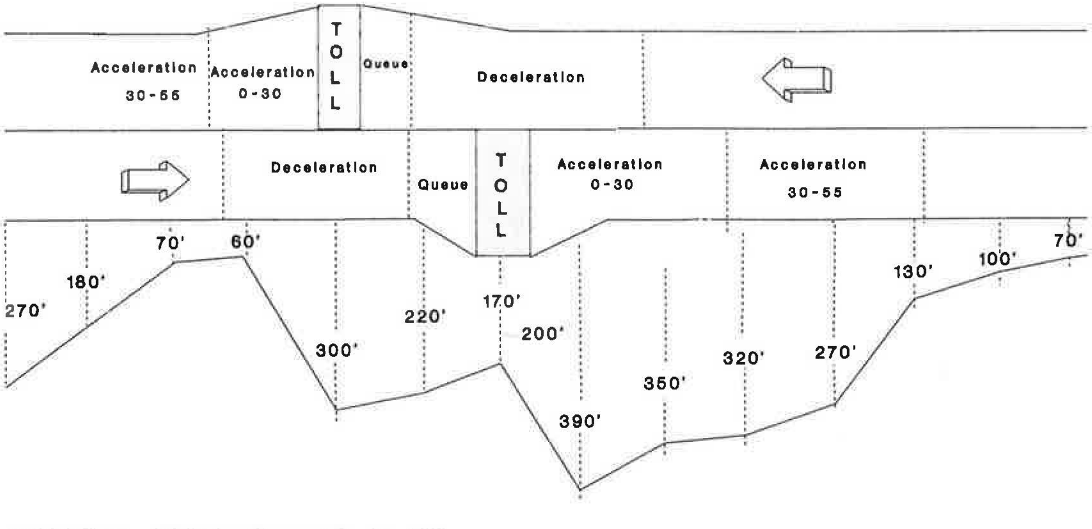

FIGURE 12 ROW for Concept 3 with AVI.

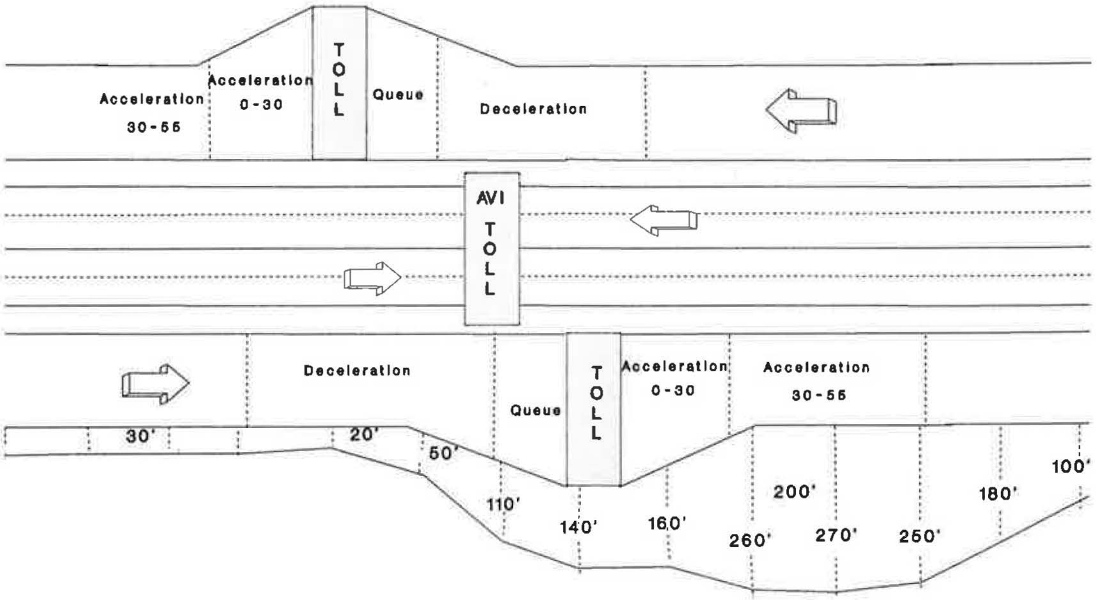

FIGURE 13 ROW for Concept 4.

the ROW requirements to about 331,000 ft^2—which reduces land requirements by more than 33 percent when compared with Concept 3 using AVI. This design, however, requires more land for the roadway design. It would best be applied to a wide roadway on which the lanes could be easily separated.

CONCLUSION

The trends illustrated by the toll designs in this analysis all have specific applications. The choice of the design will be of paramount importance in the reduction of ROW. Existing roadways that are introducing tolls could minimize the ROW requirement due to air quality considerations by used AVI as illustrated with Concept 1. Concept 2 could be used along a roadway that has available ROW in a limited location. Thus this design may be useful in very specific situations. Concept 3 requires a smaller ROW than the previous concepts and appears to be the most applicable to a large number of roadway designs. The introduction of AVI to this concept further reduces the needed ROW, increasing the concept's feasibility. Concept 4 requires an even smaller ROW than Concept 3. It, however, requires more land for the actual construction of the roadway. This design could be applied to roadways on which there are more than three lanes or on which the size of the median would provide additional space.

The addition of a toll facility, regardless of design, will most likely increase CO levels on both a micro (local) and meso (regional) scale level. Steps should be taken to minimize this impact. Air quality considerations are usually taken into account after the toll plazas have been designed. This often leads to costly mitigation and redesigns. By having the air quality and civil engineers work together at the initial design stage, the best design that satisfies both groups can be developed.

This analysis highlights some of the design elements that can be used to allow for a functional toll plaza design that meets air quality standards using the least amount of ROW.

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