Corridor Management of Large Planned Special Events: Integrated Optimization of Park-and-Ride and Bus Contraflow Measures

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ABSTRACT

To improve the corridor efficiency during large planned special events, an integrated strategy with Park-and-ride (P&R) and bus contraflow is presented in this paper. This strategy eases the safety or performance limitations of the two congestion mitigation measures applied alone. A qualitative analysis first shows that P&R measure increases the transit demand on bus contraflow lane, while bus contraflow measure provides an express and non-congested service to P&R users. Then, a P&R facility location method is developed to search for the optimal P&R facility site. And a simulation corridor network is used to compare the performance of the proposed integrated strategy with the normal operation and the conventional P&R strategies, in four scenarios and with five groups of assumptions. The simulation results and measure of effectiveness (MOE) analysis indicate the benefits and applicability of the proposed integrated strategy.

INTRODUCTION

A planned special event (e.g., sports games, concerts, festivals) usually attracts and generates temporary trips and increases traffic demand on the corridors serving the event. Once the additional event-generated demand is very high and/or the background traffic is heavy, the imbalance between the supply and the demand could lead to an unacceptable level of service or even congestion on these corridors. Thus, to improve the performance of corridor operation, traffic management, particularly congestion management, is a critical component of pre-event planning. A number of studies have been made to explore potential strategies for lessening traffic congestion during large special events *(1,2,3)*. Among these efforts, park-and-ride (P&R) and contraflow have been considered to be two effective mitigation measures *(4)*.

P&R provides a staging area to transfer from low occupancy modes to a higher occupancy means of travel *(5)*. It is a demand-side measure which is used internationally as a means of dealing with car use, congestion and traffic-related pollution *(6)*. A considerable number of studies show the effectiveness of using well planned P&R schemes in relieving peak hour congestion. And these optimization schemes should be considered from various aspects, such as facility location *(7,8)*, parking policy *(9)* and parking fee pricing *(10,11)*. Meanwhile, although P&R has been widely applied in the planning of special events, relatively few quantitative studies were focused on this measure *(12)*.

Contraflow is the use of one or more lanes of low-demand travel for traffic movement in the high-demand direction, which increases the operational road capacity *(13)*. The research regarding corridor contraflow has concentrated on the effectiveness, feasibility and safety issues of implementing this measure. FEMA (2000) estimated that single-inbound-lane reversal and full reversal provide 30% and 70% increases in capacity, respectively, over the conventional two-outbound-lane configuration *(14)*. Using microscopic simulation, Theodoulou and Wolshon (2004), Lim and Wolshon (2005) and Williams et al. (2007) assessed the adequacy of the contraflow plan in terms of effectiveness or termination design *(15,16,17)*. In a recent study by Hua et al. (2012), a new variant of contraflow, named bus contraflow, was proposed for the evacuation of transit-dependent evacuees *(18)*. In actual applications, this measure has been widely used in the states along the Atlantic and Gulf Coasts of the U.S. for hurricane evacuation *(19)* and in the major metropolitan areas (such as Washington, D.C.) for efficiently daily commuting *(4)*.

Both mitigation measures have their own limitations when applied to corridor management alone during planned special events. The application of P&R cannot avoid congestion under explosive demand (e.g., discrete event ingress and egress); and the mixed traffic (transit traffic and automobile traffic) may be therefore blocked at ramp terminations. This situation would reduce the level of service as well as measure attraction of P&R users. On the other hand, traditional contraflow has never been considered in the corridor management of special events, which is a waste of roadway facility. The safety limits of implementing this measure prevent its application in real world operation *(16)*.

In order to address these limitations, an integrated strategy with P&R and bus contraflow is presented in this study. By the transformation of contraflow lanes into exclusive bus lanes, both operational efficiencies and safety are improved. The specific objectives of this study are: a) develop a feasibility analysis of the proposed integrated strategy; b) establish a facility location method for various P&R configurations; c) devise a simulation approach to test the efficiency of the integrated strategy and the location method.

METHODOLOGY

Integrated Strategy

Large numbers of vehicles often gather together in a very short time and small space during a large special event, which poses two challenges in corridor management: a) managing intense travel demand, and b) mitigating potential capacity constraints *(20)*. The former refers to the demand side of traffic management, which aims to reduce the total number of additional demand. This can be realized by influencing the efficiency associated with various travel modes, such as P&R measure. The latter focuses on the supply side, which aims to lessen the impact of corridor bottleneck. During event ingress and egress, the corridor bottleneck usually occurs at ramp terminations (either the ramp-corridor terminal or the ramp-street terminal), as shown in Figure 1(a), and contraflow is an efficient measure to increase the potential capacity.

P&R diverts private automobile users to transit through providing a more efficient way to get to the event venue. Two configurations of this measure exist in corridor management: mainline without or with exclusive bus lane *(1)*, as shown in Figure 1(b) and Figure 1(c), respectively. The configuration with exclusive bus lane is more attractive to drivers, as they can enjoy a higher level of service compared to the drive-alone option. However, this configuration also has its disadvantages. Firstly, it is impossible to introduce exclusive bus lanes on entrance/exit ramps, which are usually the potential bottlenecks in corridor operation. It would greatly reduce the operating efficiency of the mainline bus lane once congestion occurs at ramp terminations. Secondly, the exclusive lane may obstruct turning movements to and from mid-block driveways. Lastly, it may also cause congestion on the upstream of the lane start, and hence increasing the delay of background traffic.

The use of contraflow is based on the phenomenon that the traffic flow of one direction is very low, while the traffic demand in the opposite direction exceeds the available capacity of the existing roads *(16)*. Thus, the reverse of underused inbound lanes is a highly cost effective since significant capacity gains can be achieved without any major infrastructure changes. However, the safety limits of implementing this measure (such as invisible signs & pavement markings, operation confusion among drivers, and potential head-on accidents) prevent its application in corridor management, because the operation safety is adopted as an overarching criterion during special events *(21)*. These safety issues can be improved by the use of bus contraflow, which transforms contraflow lanes into exclusive bus lanes *(18)*. Pre-event training can be provided to transit drivers; and the possibility of inadvertently straying into the bus contraflow lane is also very low. But it is not a cost- effective measure until increasing the number of transit vehicles to a reasonable level.

The integration of P&R and bus contraflow in corridor management, as shown in Figure 1(d), can ease the limitations of the two measures applied alone. The application of P&R can significantly increase the transit demand on bus contraflow lane and thus enhance the availability of the latter measure. On the other hand, bus contraflow can provide an express and non-congested service to P&R users without lowering the operation efficiency of normal outbound lanes. This integrated strategy provides significant benefits on both the demand and supply sides of corridor operation.

On the operation aspects, the integrated strategy requires some technical preparations. The P&R facilities should be located on local roads to avoid the potential chaos, congestion and accidents during entering/exiting the facilities. The application of portable traffic signals can realize the termination control of bus contraflow lane, and the lane terminations can then be seen as signal intersections. Just as its effect in the maintenance of contraflow HOV facility in SE Expressway I-93, Quick-change Moveable Barrier (QMB) can be used to separate the bus contraflow lane and normal lane *(22)*.

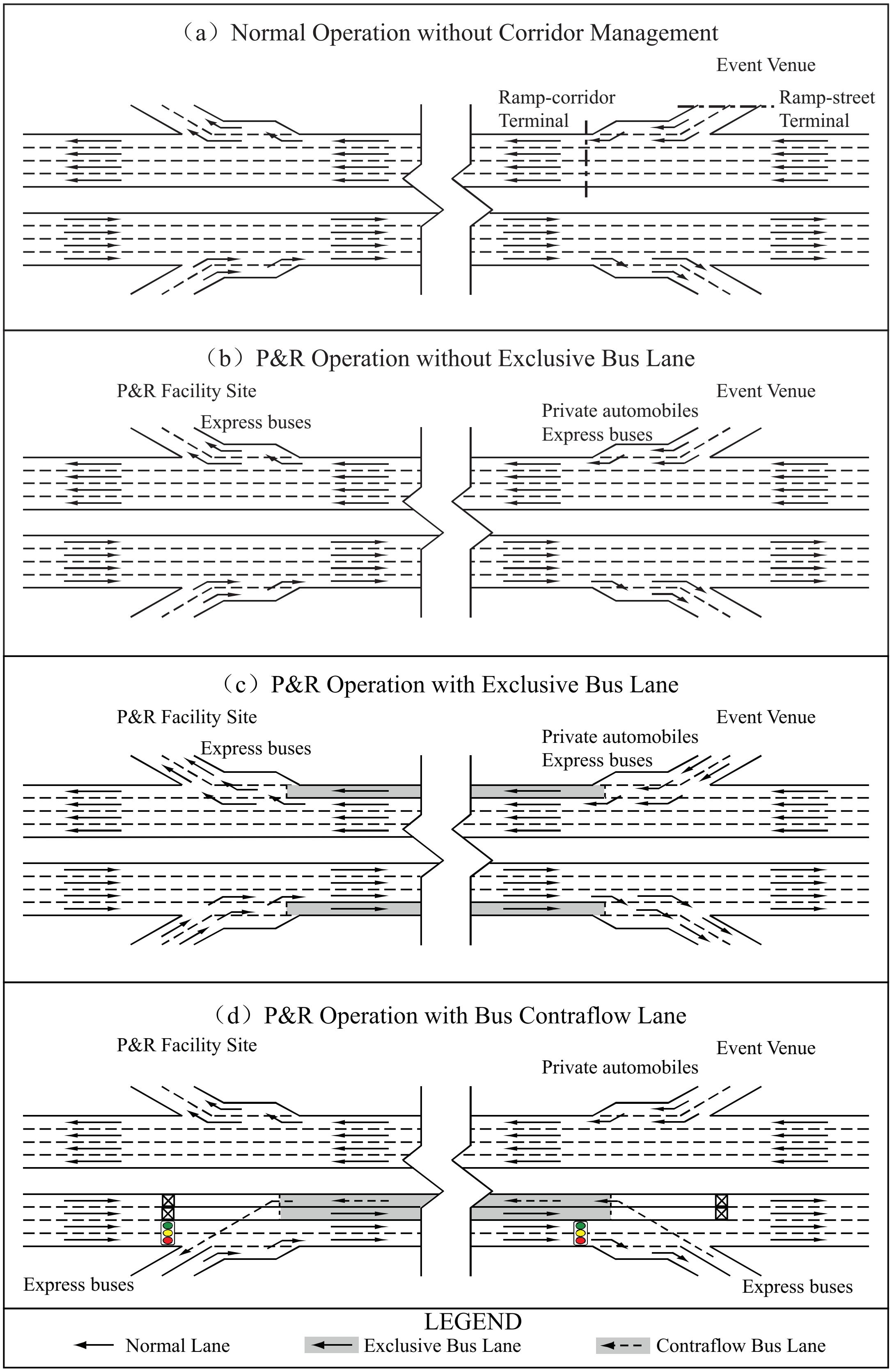

FIGURE 1 Comparison of corridor management strategies.

Facility Location Method

During large special events, the location of planned P&R facility is a critical element in corridor management. If the facility is placed very close to the event venue, new bottlenecks may occur on the ramp serving P&R users (for entering/exiting the P&R facility). Conversely, if the selected site is far away from the venue, the population of potential users may drop to an unaccepted level. Generally speaking, a driver is considered covered if they are within a maximum acceptable distance from a facility *(23)*. To address these problems, a facility location method for various P&R configurations (include the proposed integrated strategy) is presented in this subsection.

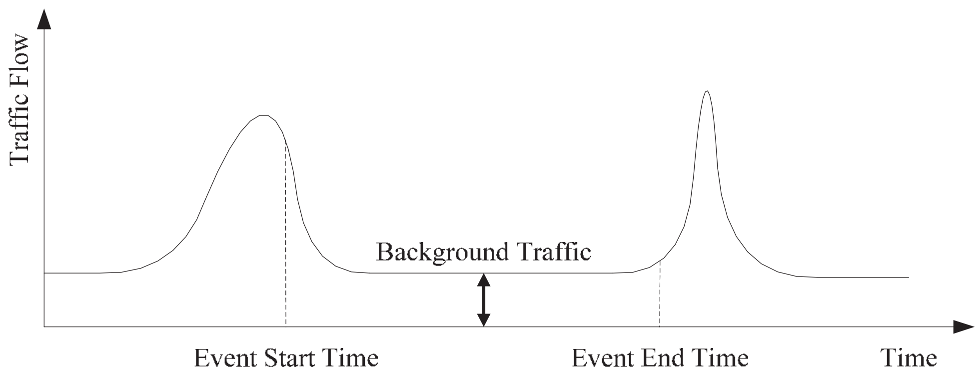

FIGURE 2 Time-varying traffic flows during planned special events.

The proposed method searches for the optimal facility site using the event egress data. This is based on the phenomenon that the duration of event egress is shorter than that of ingress, which causes a more concentrated event-generated demand, as shown in Figure 2. Meanwhile, event patrons accept a higher level of delay during egress than ingress *(4)*. These two features make it attractive to search for the optimal P&R facility site during event egress.

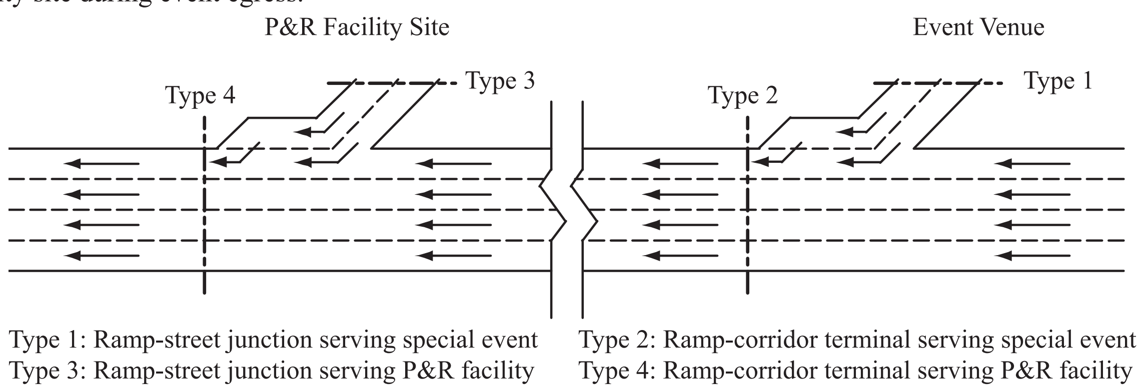

FIGURE 3 Potential corridor bottlenecks during event egress.

The facility location method works as follows: a) calculate the corridor efficiencies of a set of possible P&R facility sites; and b) compare these efficiencies and find the best one. The corridor efficiency is dependent on the load factor (i.e., volume/capacity ratio) of the "key" bottleneck. When P&R measure is applied during event egress, four potential bottleneck locations can be identified on the corridor, as shown in Figure 3. Congestion occurs at ramp-street junction once the access flow exceeds the ramp capacity. And if drivers have difficulty in merging into the mainline traffic, a ramp-corridor terminal becomes a bottleneck. Through the comparison of the load factors of the potential bottlenecks, the facility location method can then identify the "key" bottleneck using an efficiency evaluation model, which can be specified as follows:

$$F_{key} = \max(F_1, F_2, F_3, F_4) \quad (1)$$

Where:

$$F_1 = \left[(\sum_{n=1}^{n} (1-\eta^n) v_e^n + a \sum_{n=1}^{n} (\eta^n v_e^n / T) \right] / C_r^0 \quad (2)$$

$$F_2 = \left[\sum_{n=1}^{n} (1-\eta^n) v_e^n + b \sum_{n=1}^{n} (\eta^n v_e^n / T) + v_b^0 \right] / C_m^0 \quad (3)$$

$$F_3 = \sum_{n=x+1}^{n} \eta^n v_e^n / C_r^x \quad (4)$$

$$F_4 = (\sum_{n=x+1}^{n} v_e^n + \sum_{n=0}^{x-1} v_b^n) / C_m^x \quad (5)$$

F_{key}	Load factor of the key bottleneck on the corridor
F_1, F_2, F_3, F_4	Load factor of potential bottleneck types 1, 2, 3, 4
x	The location of P&R facility
C_m^0, C_m^x	Downstream mainline capacity (without bus lane capacity) at section 0 and section x
C_r^0, C_r^x	On-ramp capacity at section 0 and section x
v_b^n	Background flow variation (the arrival flow minus the departure flow) at section n
v_e^n	Event-generated flow departure from the corridor at section n
η^n	P&R rate (percentage of event-generated traffic transform to transit) at section n
T	Flow conversion coefficient (average bus occupancy/average automobile occupancy)
a, b	P&R configuration parameters, where a, b =0 or 1

The value of P&R rate η^n is based on the feature that the willingness of using P&R facility decreases as the distance from service increases *(24)*. Thus, this rate is kept at a high level when the related section is downstream from the facility site (i.e., $n \geq x$), and the value decreases with the increase of the distance between facility site and upstream section (i.e., $n < x$). On the other hand, the P&R configuration parameter $a = 0$ ($b = 0$) indicates the separation of express buses and automobiles at given ramp (mainline). Thus, the parameters have three sets of values: P&R operation without bus lane ($a = 1, b = 1$), P&R operation with bus lane ($a = 1, b = 0$), and P&R operation with bus contraflow lane ($a = 0, b = 0$).

EXPERIMENT DESIGN

Scenarios Development

The effectiveness of the proposed integrated strategy has been discussed in the last section. However, quantitative analysis is needed for the accurate estimation of this strategy. Moreover, the facility location method requires an approach to verify its validity in the real world. In order to meet these requirements, this study presents a simulation approach in CORSIM to imitate different corridor management strategies. The wide acceptance and adjustable parameters of CORSIM made it the ideal tool for the simulation experiments.

The opening ceremony of the 10th National Games of China was held in Nanjing Olympic Sports Center in 2005, and attracted more than 120,000 event patrons as well as about 11,000 vehicles in a very short time. Although the mass transit system (consist of temporary bus routes and underground railways) carried about 80% of the total audiences, the event-related area still took nearly 3 hours to restore normal conditions during event egress *(25)*. Especially, heavy congestion occurred on the Jiangdong Expressway, which is the main corridor connecting the Olympic Sports Center with the west and north of the city.

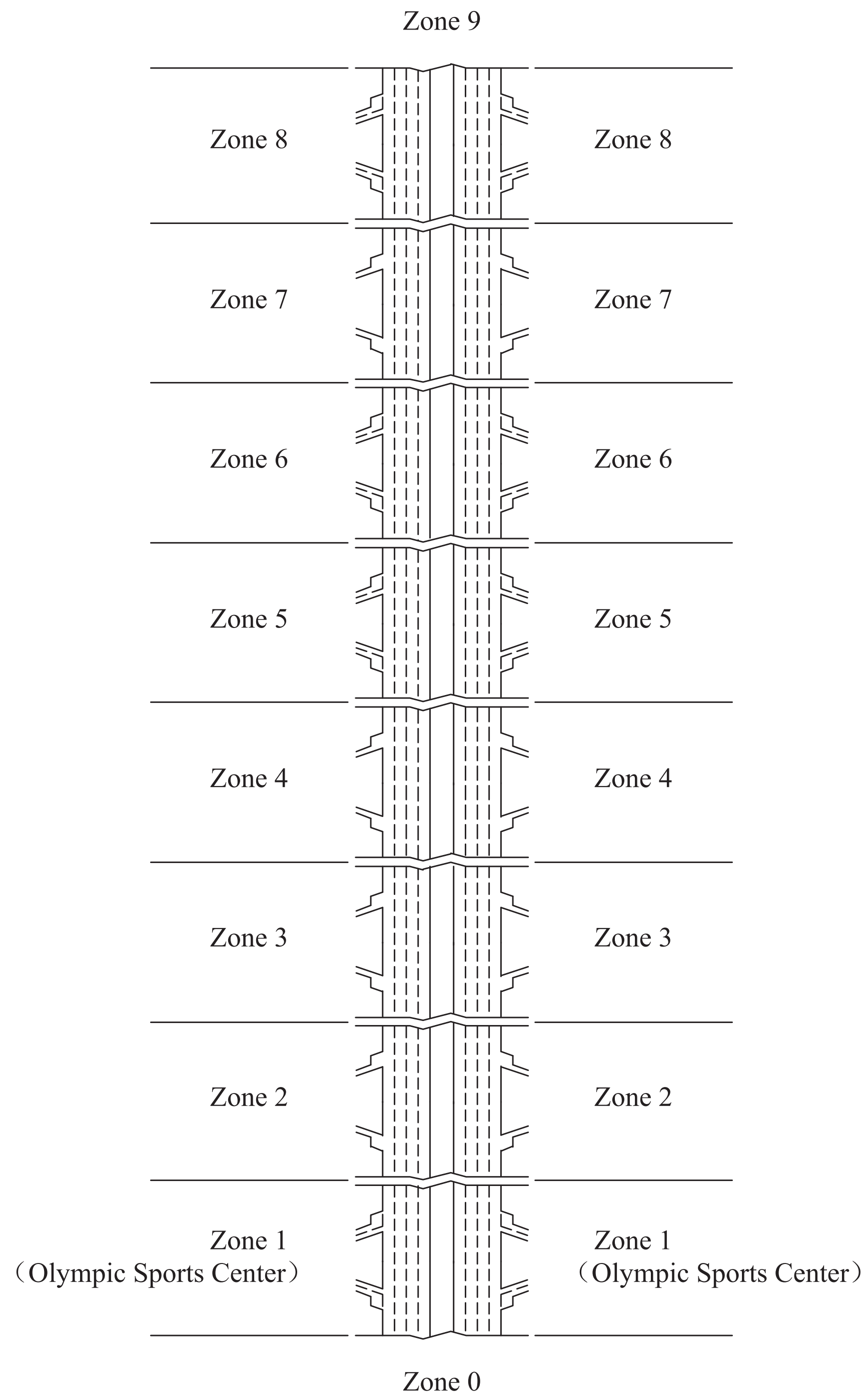

FIGURE 4 Simulation environment based on the layout of Jiangdong Expressway.

This study uses this event as case study. And the test environment in CORSIM, as shown in Figure 4, is developed according to the layout of Jiangdong Expressway. This test environment contains a conventional eight-lane expressway mainline with eight pairs of entrance and exit ramps. Each pair of ramps provides access to/from a certain area, which are numbered from 1 to 8 in Figure 4. The Olympic Sports Center is located at Zone 1, and the rest 7 zones (Zone 2 to Zone 8) are considered as potential locations of P&R facility. At last, the two terminations of this test environment are numbered by Zone 0 and Zone 9, respectively.

Four types of simulation scenarios are established based on this test environment. These scenarios aim to imitate the event egress process under different corridor management strategies: 1) Normal, normal operation without corridor management, 2) PR, P&R operation without exclusive bus lane, 3) PR-EBL, P&R operation with exclusive bus lane, and 4) PR-BCL, P&R operation with bus contraflow lane. And these four types are corresponding to the four configurations in Figure 2.

Key Assumptions

CORSIM does not explicitly support the construction of P&R facility or contraflow lanes in scenario edit. However, there are a series of CORSIM parameters that allow users to fine tune CORSIM to match these conditions. Thus, some key assumptions are needed to calibrate the parameters for strategy simulation and model simplification. These assumptions can be classified as one of the following five groups:

- Contraflow lane assumption
- Exclusive bus lane assumption
- P&R facility assumption
- Free flow speed assumption
- Vehicle type assumption

Contraflow lane assumption: It is not possible to simulate the flow conditions for contraflow lanes in CORSIM. Thus, the contraflow lane is constructed as a normal outbound lane in the simulation with several adjustments. The median strip is usually located between normal outbound lanes and the contraflow lane, and it prevents lane changing between these two lanes. To code this, a barrier is used to represent the median strip. Additionally, the research results of FEMA showed that the capacity of contraflow lane drops to 60% of its original value *(14)*. Thus, the car following sensitivity multiplier in the contraflow lane is adjusted to 250% to simulate the capacity decreasing characteristics in this lane.

Exclusive bus lane assumption: Because a bus lane is not supported on the expressway in the simulation software, a HOV lane is used instead of the exclusive bus lane with the parameter of “Allowed users” adjusted to “Buses only”. The scenario types of PR-EBL and PR-BCL applied this assumption, and the bus lane is interrupted ahead of each off-ramp in the former scenario to realize the turning movement of the mainline vehicles.

P&R facility assumption: As mentioned earlier, the value of P&R rate decreases with the increase of distance from facility. Although little research has been done on the P&R choice models, several qualitative analyses reflected the choice behaviors during planned special events *(26,27)*. Based on these studies, the P&R rate in this study is set to 40% to the downstream zones and declines by 10% every zone on the upstream direction. For example, P&R facility is located on Zone x, then, the P&R rate is set to 40% at Zone x to Zone 9; and this value is set to 30% at Zone x-1, 20% at Zone x-2, until 0% is reached at Zone x-4.

Free flow speed assumption: Free flow speed depends on lane condition, thus different types of lanes are assigned a fitness value in the simulation experiments. Free flow speed in normal outbound lanes is assumed to be 80 km/h, and this value drops to 70 km/h in contraflow lanes. There is also a distinction of this value on the ramps: free flow speed is reduced from 40 km/h to 30 km/h on the ramp connecting with the contraflow lane.

Vehicle type assumption: The flow conversion coefficient is based on the occupancy of event-generated private automobiles and P&R excusive buses. The average number of occupants of private automobiles is set to 2.7 according to the results of field survey *(28)*, and the value for buses is set to 35 (the general number of seats for 12-meter bus). Then, the flow conversion coefficient can be calculated to 13.0 based on its definition.

Apart from the key assumptions above, parameters of other aspects (e.g., expressway environment, vehicle performance, and travel behavior) are set to the default value in CORSIM because these aspects are not significantly different between event egress conditions and normal operation conditions.

Simulation Input

To compare the efficiencies of proposed integrated strategy and existing corridor management strategies, the simulation inputs of all experiments were generated using the same basic data. The data derived from the field survey immediately after the Opening Ceremony of the 10th National Games of China, and contained the Origin-Destination (OD) matrices for both event-generated and background demands *(28)*. During event egress, a total of 4,872 private automobiles and 192 regular buses were detected entering Jiangdong Expressway from the on-ramp located in Zone 1(the location of the Olympic Sports Center). The corridor management strategies in various simulation scenarios aimed to transfer part of the 4,872 private automobiles to express buses.

As the effectiveness of the P&R facility varies with different sites, a series of comparative experiments were performed to test the influence of the facility location in each scenario. The private automobiles could be divided into two parts: those who parked at Olympic Sports Center area and those who parked at P&R facility. The former entered the expressway from Zone 1 and the later entered from Zone *x*. The varying values of these two parts in simulation experiments, as shown in Table 1, could be calculated based on the P&R facility assumption described in the last subsection.

TABLE 1 Event-generated Simulation Input

Scenario type	Park & Ride facility information		Event-generated traffic from Sports Center (Zone 1)		Event-generated traffic from P&R facility (Zone *x*)	
	Location (Zone *x*)	Required buses (veh)	Demand (veh)	Heavy vehicle proportion	Demand (veh)	Start period number
Normal	NA	NA	5064	4%	NA	NA
PR PR-EBL PR-BCL	Zone 2	150	3265	10%	1907	5
	Zone 3	149	3275	10%	1782	5
	Zone 4	146	3313	10%	1552	6
	Zone 5	138	3405	10%	1298	6
	Zone 6	126	3555	9%	996	6
	Zone 7	108	3765	8%	671	7
	Zone 8	87	4022	7%	457	7

Based on these event-generated traffic data, the simulation input could then be developed as follows: Firstly, 19 periods (the CORSIM maximum) of 10 min were established in the simulation software. Secondly, the background flow was set in each period and the first 3 periods were used to achieve a stable state. Then, the event-generated traffic demand originated from Olympic Sports Center area was generated in period 4 to mimic the event egress process. Lastly, the event-generated traffic originated from the P&R facility entered into the expressway when the express buses reached the facility site. And once the Measure of Effectiveness (such as mainline speed, outflow rate) of a later period recovered to the values of period 3, the event egress was assumed to be completed.

Ten separate runs using different random seeds were conducted for each simulation input. The average values from each of simulation input groups were used for the statistical comparisons summarized in the following section.

RESULTS AND ANALYSIS

The simulation data were obtained from the experiments described above. Based on the analysis of these data, this section aims to discuss the following two issues: a) to verify the utility of the proposed facility location method, and b) to test the efficiency of the integrated strategy with P&R and bus contraflow.

Comparison of Simulation Results and Numerical Calculations

During event egress, the most meaningful Measure of Effectiveness (MOE) for corridor operation is its clear time (or recovery time). The objective of P&R facility location problem is to minimize this index value. Figure 5 summarizes the simulation results and shows the optimal facility sites for various P&R configurations. For all three configurations, a similar U-shaped relationship is found between corridor clear time and facility location. The clear time decreases first and then increases with an increase in distance between Sports Center and P&R facility site. The turning point, corresponding to the optimal facility site, occurs at Zone 4 or Zone 5 for PR, Zone 3 for PR-EBL and Zone 5 for PR-BCL, respectively.

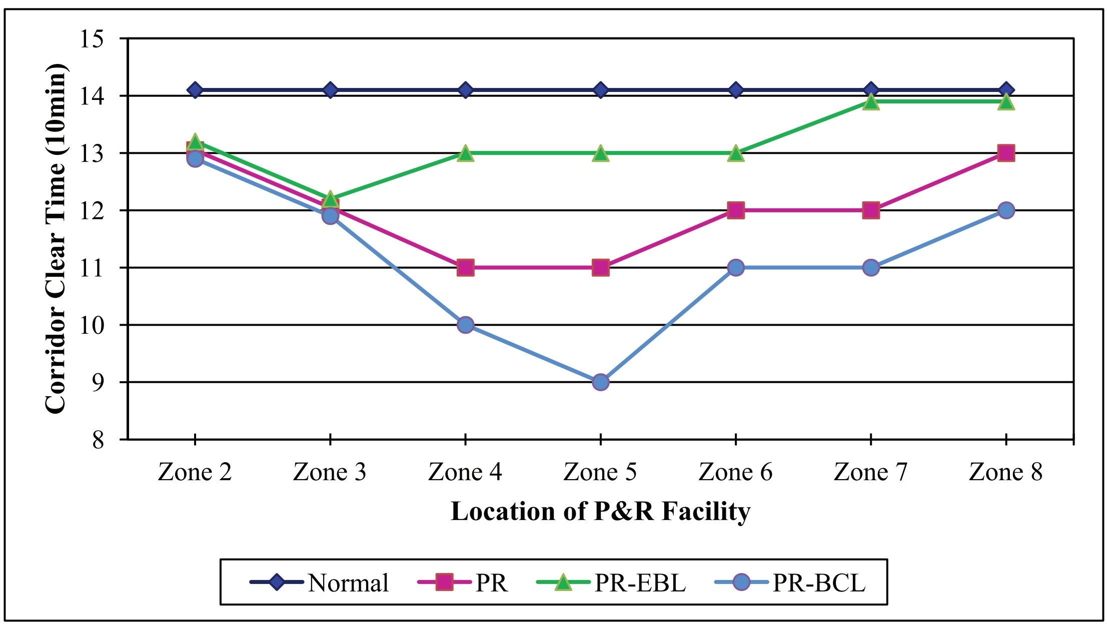

FIGURE 5 Simulation results of corridor clear time.

The numerical calculations of our facility location method show the corresponding results. The load factor of the "key" bottleneck also has a U-shaped relationship with distance from Sports Center. The facility site with bottom load factor is Zone 4 for PR, Zone 3 for PR-EBL and Zone 5 for PR-BCL, which is fully in accord with the simulation results. Moreover, the numerical calculations indicate the location of the "key" bottleneck for a given P&R site, which is useful for further optimization. If the "key" bottleneck occurs at the ramp servicing the Sports Center (i.e., type 1 or type 2), part of the event-generated traffic can be guided to alternative routes to mitigate congestion. And if the "key" bottleneck occurs at the facility-related ramp (i.e., type 3 or type 4), more attention should be given to the traffic requirements of P&R users.

TABLE 2 Numerical Calculations Using the Facility Location Method

P&R Location (Zone *x*)	Scenario type 2: PR		Scenario type 3: PR-EBL		Scenario type 4: PR-BCL	
	Key bottleneck [a]	Load factor (v/c ratio)	Key bottleneck [a]	Load factor (v/c ratio)	Key bottleneck [a]	Load factor (v/c ratio)
Zone 2	Type 3	1.19	Type 3	1.19	Type 3	1.19
Zone 3	Type 3	1.11	Type 3	**1.11**	Type 3	1.11
Zone 4	Type 1	**1.04**	Type 2	1.13	Type 3	1.00
Zone 5	Type 1	1.06	Type 2	1.15	Type 3	**0.91**
Zone 6	Type 1	1.11	Type 2	1.20	Type 1	0.99
Zone 7	Type 1	1.18	Type 2	1.28	Type 1	1.05
Zone 8	Type 1	1.26	Type 2	1.36	Type 1	1.16

Note [a]: Key bottleneck has four potential types. Type 1 indicates ramp-street junction at Zone 1 (Sports Center); Type 2 indicates ramp-corridor terminal at Zone 1; Type 3 indicates ramp-street junction at Zone *x* (P&R facility site); Type 4 indicates ramp-corridor terminal at Zone *x*

Both the simulation results and numerical calculations show the superiority of the proposed integrated strategy. The reference value of corridor clear time is set to 140 min in Figure 5, which is the simulation result under Normal scenario type. The trend lines of all three P&R configurations are found not exceeding the reference value, and moreover, the corridor clear time under the proposed integrated strategy (i.e., PR-BCL) is always the lowest among three configurations for a given P&R facility site. On the other hand, the comparison of index values associated with optimal facility site in each scenario also shows that the integrated strategy spends less time in corridor recovery than those of the two conventional configurations.

MOE Analysis

The index of corridor clear time focuses on the efficiency of the whole system but cannot explain the operation condition on the exclusive bus lane. Thus, for a more comprehensive evaluation of the proposed integrated strategy, several common MOEs (i.e., average travel speed and average stop delay) are selected for a quantitative analysis in this subsection. The values of the MOEs originate from the simulation output of optimal facility sites under various P&R configurations.

The simulation results of the selected MOEs are summarized in Table 3, which shows a great improvement in express bus efficiency by applying the proposed integrated strategy. In the results of PR and PR-EBL, the average stop delay of an express bus equals to the delay of an event-generated private automobile, and exceeds 30 min in both scenarios. Although exclusive bus lane is existed in Scenario 3, there is no bus priority provision on the ramp. On the other hand, the average stop delay of an express bus is 1.1 min for PR-BCL while the corresponding value of a private automobile reaches 35.9 min. The significant difference between the two modes should have a positive effect on diverting private automobile attendees to P&R users. The average travel speed in exclusive bus lane is also higher than that of corridor mainline, which indicates a better service in this lane.

TABLE 3 Summaries of MOEs under various simulation scenarios

Scenario type	Location of P&R facility (Zone *x*)	Corridor clear time (min)	Average stop delay (min) [a]		Average travel speed (km/h) [a]	
			Private automobile	Express bus	Corridor mainline	Exclusive bus lane
Normal	NA	140	51.6	NA	62.7	NA
PR	Zone 4	110	36.7	36.7	60.9	NA
PR-EBL	Zone 3	120	42.3	42.3	59.3	72.5
PR-BCL	Zone 5	90	35.9	1.1	63.4	65.3

Note [a]: The average stop delay and average travel speed are detected at the on-ramp and mainline in Zone 1

The efficiency comparison of the integrated strategy and alternative management strategies is shown in Table 4. The 35.7% decrease in corridor clear time and the 30.4% decrease in average stop delay for PR-BCL represent a considerable improvement over the Normal scenario. As compared to the two conventional P&R configurations (i.e., PR and PR-EBL), the integrated strategy shows its advantage in corridor clear time as well as operation efficiency of private automobiles (from both the average stop delay and average travel speed). Moreover, this strategy offers express buses protection from congestion, which can be seen through the 97% decrease in the average stop delay of an express bus. The only setback is the average travel speed in exclusive bus lane, the speed drops 11% compared to PR-EBL. However, considered together with the great improvement in stop delay, the P&R users still enjoy a higher level of service in PR-BCL scenario.

TABLE 4 Efficiency comparisons of the integrated strategy and alternative management strategies

Comparative scenarios	Clear time decrease	Average stop delay decrease [a]		Average travel speed increase [a]	
		Private automobile	Express bus	Corridor mainline	Exclusive bus lane
PR-BCL vs. Normal	35.7%	30.4%	NA	1.1%	NA
PR-BCL vs. PR	18.2%	2.2%	97.0%	4.1%	NA
PR-BCL vs. PR-EBL	25.0%	15.1%	97.4%	6.9%	-11.0%

Note [a]: The average stop delay and average travel speed are detected at the on-ramp and mainline in Zone 1

CONCLUSIONS AND FUTURE WORK

The successful implementation of a transportation management plan for planned special events results in lessened traffic congestion and improved safety for both event patrons and other transportation system users *(4)*. With this purpose in mind, a new corridor management strategy, integration of park-and-ride (P&R) and bus contraflow, is proposed in this study. P&R measure could divert private automobile users to transit, thus reduce the event-generated demand on the corridor. And bus contraflow measure transformed contraflow lanes into exclusive bus lanes to enhance the corridor capacity as well as bus priority.

The integrated strategy aimed to ease the limitations of the two measures applied alone and provided benefits on both the demand and supply sides of corridor operation. The application of P&R could increase the transit demand on bus contraflow lane, while bus contraflow measure could provide an express and non-congested service to P&R users without lowering the operation efficiency of normal high-demand lanes.

The location of planned P&R facility was a critical element in corridor management, and the optimal R&R facility site might vary according to P&R configuration. To serve the planning of the proposed integrated strategy, a facility location method was established in this study. An efficiency evaluation model was first developed to identify the "key" bottleneck on the corridor and calculated the corridor operation efficiency. Then, the optimal facility site could be found through the comparison of the efficiencies of possible P&R facility sites.

To evaluate the efficiency of the integrated strategy and to verify the validity of the facility location method, this study designed a series of simulation experiments for data collection. Four simulation scenarios in CORSIM were developed based on a real event egress. The scenarios simulated the normal operation without corridor management, the P&R operation without/with exclusive bus lane, and the P&R operation with bus contraflow lane on an expressway during event egress.

The comparison of simulation results and numerical calculations showed that the proposed facility location method performed well under all three P&R configurations. Also, the superiority of the proposed integrated strategy could be explained in terms of the MOE analysis. The new strategy reduced the corridor clear time compare to the normal operation and conventional P&R strategies. Meanwhile, this strategy offered express buses protection from congestion, which could be seen through the significant decrease in the average stop delay of an express bus. Thus, this new strategy was considered to have a positive effect on diverting private automobile attendees to P&R users.

There are a number of directions to pursue in the context of this study. The parameters in the facility location method, such as P&R rate and flow conversion coefficient, should be surveyed and analyzed in the future. The termination design of bus contraflow lane can also be discussed. Finally, other traffic management measures may be incorporated into the integrated control system. For example, alternative route guiding can reduce the load factor of the "key" bottleneck.

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