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FEASIBILITY STUDY FOR A RESERVED H.O.V. LANE FOR THE APPROACH OF THE VICTORIA BRIDGE DURING THE MORNING PEAK PERIOD

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1.0 INTRODUCTION

The Victoria Bridge is one of the five links between the Island of Montreal and the South Shore. On the South Shore approaches, Sir Wilfrid Laurier Boulevard and the Highway 132 exit are the only roadways that carry traffic to the bridge. Presently during the morning peak period (7:00-9:30 a.m.), the approaches are working at capacity or overcapacity. Consequently, the local adjacent streets are under heavy traffic loads which cause air and noise pollution. The citizens in this region of St. Lambert have been complaining to their local political representatives. Moreover, the daily users that rely on this connection to Montreal have been demanding better service in recent years.

In many U.S. cities, high-occupancy vehicle lanes have been implemented with much success. Canada has only recently been following the trend of planning reserved lanes for priority vehicles. This report analyzes the feasibility of a reserved H.O.V. lane for the approach to the Victoria Bridge. In this project it will be determined whether the time savings due to travelling in the H.O.V. lane is beneficial compared to the problems that might occur as a result of its implementation. This includes examining the effect on the remaining lanes and the cost of the project itself.

2.0 HIGH-OCCUPANCY VEHICLE LANES

High-occupancy vehicle lanes are reserved facilities implemented on roadways for vehicles satisfying specified requirements. These vehicles may include buses, carpools, and vanpools. The carpool usage of this exclusive lane can be restricted to either two, three, four or more persons per vehicle. Moreover, the majority of H.O.V. lanes are implemented on freeways, with only a few on urban highways.

Several objectives should be attained when implementing H.O.V. lanes.

As stated in An Evaluation of the Cost Effectiveness of HOV lanes: "A recent study culled the following objectives from a national survey of HOV projects" (ref. 1, pg. 3):

1. To improve traffic flow by encouraging the use of shared ride vehicles (i.e. HOV's), and thereby creating more space on the highways during the peak commuting hours.

2. To reduce energy consumption through reduced vehicle miles of daily commuter travel.

3. To reduce air pollution (hydrocarbons, carbon monoxide, nitrogen oxides, sulphur and particles) through reduced vehicle miles of daily commuter travel.

4. To reduce the cost of transportation to the commuter through the encouragement of shared ride and hence shared cost, modes of travel.

5. To remove or reduce the need for new highway construction or highway repair by reducing the traffic volume that is responsible for road surface damage.

Transportation commissions across the United States regard the above goals as the most important reasons for a H.O.V. lane to be installed.

When implementing H.O.V. lanes, three major factors must be taken into consideration. First, for the start and end conditions, the lane should start as a new lane if possible and end without merging. This will prevent bottleneck situations. Second, adequate enforcement is considered to be essential to the successful operation of the H.O.V. facilities. Third, public acceptance can have a major impact on the implementation and success of the project.

3.0 EXISTING SITUATION

3.1 VICTORIA BRIDGE

The main characteristic of the Victoria bridge is the two lever drawbridges that are located in St. Lambert. The lever drawbridge function is to facilitate the vehicle and train traffic when there is a boat crossing the St. Lambert Lock as can be seen in Figure 1. When lever drawbridge #3 is lifted, traffic flow travelling from St. Lambert to Montreal will use Road #1 while the traffic flow travelling from Montreal to St. Lambert will use Road #3. On the other hand, if lever drawbridge #2 is elevated, traffic flow travelling towards Montreal will use Road #2b and vehicles coming from Montreal will use Road #2a. The annual average maximum traffic volume of vehicles travelling over the Victoria Bridge from St. Lambert to Montreal is currently 3319 cars per hour. This occurs during the morning peak period between 7-8 a.m..

In studying the existing situation, information pertaining to the operation and functioning of the Victoria Bridge was noted. First, the average time that traffic is stopped when switching from Road #1 and Road #3 to Road #2 or vice versa is approximately five minutes. This time is required for replacing the cones to redirect the traffic towards the other lever drawbridge. Second, during the morning peak period, the lanes used for the traffic travelling from Montreal towards the South Shore (i.e. Road #3 or #2a) is closed. This permits the usage of both sides of the bridge for the people travelling from St. Lambert to Montreal. Third, the Victoria Bridge has an 11-ton weight restriction. In order to satisfy this limitation, the buses that are presently using the bridge are limited to a maximum occupancy of 42 to 45 persons per vehicle. This number represents the number of seated places on a bus.

3.2 STUDY CORRIDOR

There are two connections to the Victoria Bridge: Sir Wilfrid Laurier Boulevard and the Highway 132 Exit (Figure 2). There is currently traffic lights at the intersection of the exit and Sir Wilfrid Laurier. These traffic lights were put up to stop traffic when there is a transfer between bridge #3 and bridge #2 and vice versa. However, during the morning peak period these traffic lights are disconnected. The percentage split of vehicles travelling over the Victoria Bridge is approximately 70%/30% for the Boulevard and the Highway Exit respectively.

Presently, the vehicles using Road #3 experience no delay because they travel single file. On the other hand, the vehicles using Road #1 are more likely to encounter waiting time. This is due to the fact that the vehicles using this route tend to travel side by side starting from the intersection of the freeway exit and Sir Wilfrid Laurier. Prior to travelling over the Victoria Bridge, the vehicles using Road #1 must merge into a single lane. This manoeuvre causes slower traffic movement compared to Road #3. Therefore, it is preferable that the H.O.V. lane use Road #3.

It was decided that the H.O.V. lane would be placed on Sir Wilfrid Laurier Boulevard and St. Louis in Lemoyne rather than on the Highway 132 Exit. St. Louis connects with two major highways on the South Shore: Highway 116 and Taschereau Boulevard. A H.O.V. lane on the Highway 132 exit would be very difficult to implement because of the crossing movement which transfers the traffic to the left lane. This is necessary if Road #3 is used as the H.O.V. lane route.

The study corridor which consists primarily of St. Louis and Sir Wilfrid Laurier Boulevard has a total of eight traffic lights. They are located at the intersections of St. Georges, Cartier, Laurier, Victoria, Arran, Queen, Prince Arthur, and the Highway 132 Exit. St. Louis is a four-lane undivided arterial. It becomes Sir Wilfrid Laurier just west of Victoria and expands to a six-lane divided arterial after Arran.

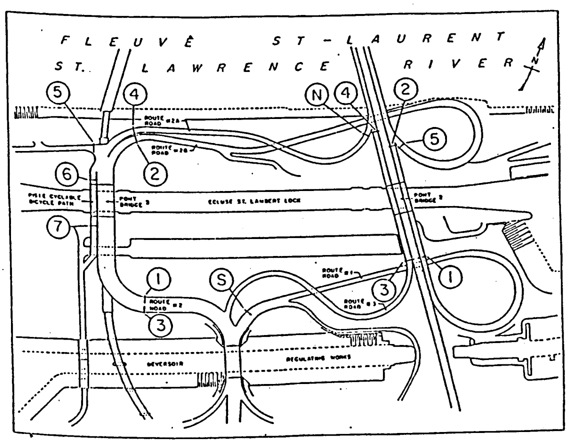
3.3 LEVEL OF SERVICE

Volume counts for Arran, Queen and Prince Arthur were obtained from M.T.Q. (Ministry of Transportation of Quebec). This project team performed short traffic counts at St. Georges, Cartier and Laurier where information could not be obtained from the City of Lemoyne. The existing phasing plan at all signalized intersections was obtained from M.T.Q. The Highway Capacity Software (H.C.S.) (ref. 3) was used to calculate the overall level of service for every intersection. It also determined the service of each approach at the intersections.

3.4 TRAFFIC CONTROL

During the morning peak period, the traffic light at Arran is disabled and operates as a flashing yellow light. Similarly, at the intersection of the Highway 132 exit and Sir Wilfrid Laurier there is a flashing yellow light to control the morning traffic flow. During the morning peak period, there are school crossing guards at Victoria, Queen and Prince Arthur to help children cross the street.

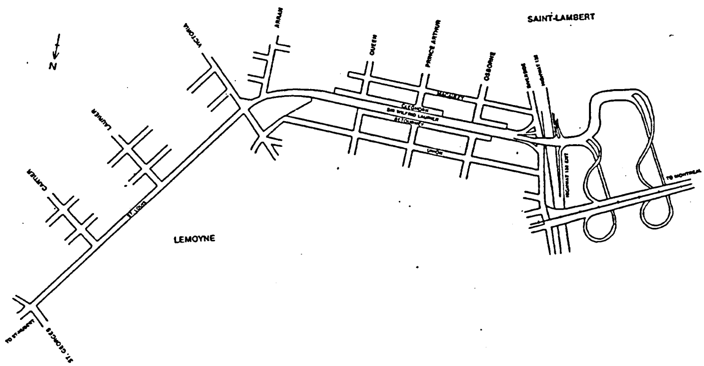
FIGURE 1: VICTORIA BRIDGE (ref. 2)



3.5 LAND USAGE

On both sides of St. Louis, there is mixed land usage. There is a combination of commercial and residential buildings. There are two schools just off Sir Wilfrid Laurier which are pedestrian generators during the morning peak period. There are two major commercial buildings around Arran. These include a shopping centre and a McDonald's which are large pedestrian and vehicle generators throughout the day. However, the shopping centre does not influence the morning peak period because it is not open during these hours. The land in the region adjacent to Sir Wilfrid Laurier is mainly in residential use.

FIGURE 2: STUDY CORRIDOR



3.6 PARKING RESTRICTIONS AND BUS STOPS

Along St. Louis, there are parking restrictions for trucks on both sides of the street between Laurier and Victoria. Trucks cannot park between 24h and 6h. A fruit and vegetable distribution centre located at #27 St. Louis is the cause of this restriction. There are many trucks entering and exiting this location. There is no parking anywhere on both sides of Sir Wilfrid Laurier.

There are no bus stops on St. Louis or Sir Wilfrid Laurier. However, bus stops are located on cross streets: St. Georges, Victoria and Osborne. The S.T.R.S.M. #55 bus travels southbound on Osborne before turning right on Sir Wilfrid Laurier and travels over the Victoria Bridge. This is the only bus that presently travels directly onto the bridge and only operates during the peak periods.

3.7 OBSERVED QUEUE LENGTHS

The information for this section was obtained from daily users of this route and from the traffic reporter for C.K.A.C. The daily queue length usually involves vehicles backed up to Victoria. The average travel time between Victoria and the Victoria Bridge is approximately 10 to 15 minutes. Occasionally, the line of vehicles waiting to cross the Victoria Bridge could be as far as the intersection of Cartier. The worst case of a queue length involved vehicles waiting as far as St. Georges.

4.0 GUIDELINES FOR THE DESIGN OF ARTERIAL H.O.V. LANES

A preliminary report prepared for the Quebec Ministry of Transportation by "Les consultants TRAFIX" and "Les consultants BCPTA inc." (ref. 4) outlines the major guidelines for an implementation of a H.O.V. lane. The guidelines were taken from different published reports in North America. The research was divided into three parts: minimum vehicles per hour, travel time savings and minimum length. In the first section, it was stated that the volume (person/hour) using the reserved lane must be greater than the existing volume of the present lane. Further, it was stated that a minimum volume of 650 vehicles per hour should use the H.O.V. lane during the peak period in order to justify its existence. However, a volume of 900 vehicles per hour is the more desirable quantity. The second section recommends that a time savings of approximately 10 percent be obtained. A cost savings for the users should also be 10 percent. In the last section, two reports recommend that the length of the reserved lane should be in a range of 2000 feet (0.38 mile) or 10 street blocks to 10560 feet (2 miles). A third report only specifies that the minimum length be a few street blocks. The above guidelines provided a basis for the feasibility of the different designs of a H.O.V. lane on the approach to the Victoria Bridge.

5.0 DESIGN ALTERNATIVES

5.1 DESIGN ALTERNATIVE #1

The high-occupancy vehicles use the right lane on St. Louis. For all design alternatives, the priority lane begins at St. Georges and continues until the traffic reaches the Victoria Bridge. On Sir Wilfrid Laurier just west of the intersection with Arran, there is an expansion to three lanes westbound. The H.O.V. lane remains in the same lane which is now situated in the centre until the Highway 132 exit. At that point, the H.O.V. traffic switches to the left lane and travels until it reaches Road #3 which leads the vehicles directly onto the south lane of bridge #2 (refer to Figure 3). The transfer of H.O.V. lane traffic to the left side will occur either by placing a police officer at this location to guide the movement or by changing the traffic light phasing to allow priority movement.

5.2 DESIGN ALTERNATIVE #2

In this design, the H.O.V. lane is located in the left lane on St. Louis and Sir Wilfrid Laurier. It remains in this lane until it reaches the entrance to the Victoria Bridge where it will use Road #3 (Figure 3). There will be no parking allowed during the morning peak period on St. Louis and Sir Wilfrid Laurier on both sides of the street. Left turns from the westbound direction will be eliminated at all intersections between St. Georges and the entrance to the Victoria Bridge. Signalized posts with a red "X" will be placed above any left turn bays to indicate no access to that lane. This will also help avoid confusing any H.O.V. lane users when a left lane temporarily appears.

On Queen, the left lane northbound is designated for entrance to the H.O.V. lane only. This was designed in an attempt to avoid a queue length of vehicles waiting to advance into the H.O.V. lane. The line-up of vehicles may develop because the southbound right turning vehicles are restricted to entrance to the mixed flow lanes only. At Victoria and Prince Arthur, there are similar restrictions in turning movements. The northbound left turning vehicles are only allowed to enter the H.O.V. lane. The southbound right turning vehicles are only allowed to enter the mixed flow lane(s). Presently at Arran there is a flashing yellow light controlling the intersection. The northbound left turning vehicles are only allowed to enter the H.O.V. lane only. This will help avoid the possibility of accidents that may occur if vehicles try to travel directly into the right lane of St. Louis while traffic is flowing freely.

The location of the H.O.V. lane in design alternative #2 does not allow bus stops to be placed anywhere along St. Louis or Sir Wilfrid Laurier at any time in the future. Because the H.O.V. lane is situated in the left lane, there is no space available for buses to stop without disrupting the traffic. Another problem is truck movement especially between Laurier and Victoria where the fruit and vegetable distribution centre is located. The trucks entering and leaving this particular business during the morning peak period will disrupt the H.O.V. lane.

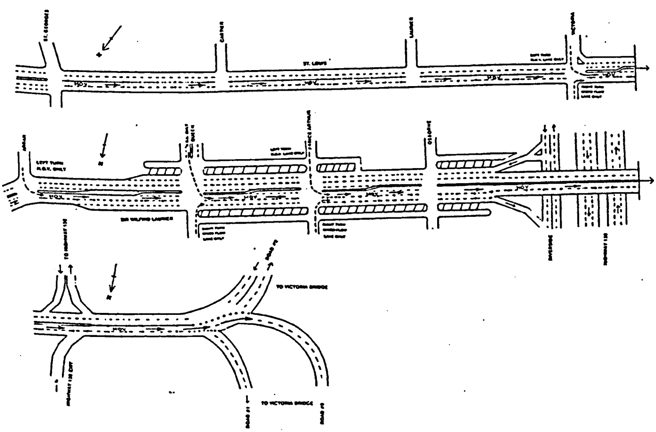
A decrease in overall capacity may occur because a lane is being taken from regular users. The H.O.V. lane will obviously not have as high a user vehicle volume as when it is being used as a mixed lane. If this was not true, the implementation of the priority lane would be unjustified.

There could be much difficulty in getting the public to accept the new H.O.V. lane. There are two main reasons why this may occur. As stated above, only one lane remains for regular users. On Sir Wilfrid Laurier there are three lanes but the right lane is not frequently used because it does not continue all the way to the entrance of the Victoria Bridge. Drivers who do not choose to or cannot use the H.O.V. lane will strongly object to the decreased level of service because of the reduction to one lane. The other cause of public rejection of this design may include the many restricted turning movements specified for vehicles travelling from the cross streets to St. Louis or Sir Wilfrid Laurier.

5.3 DESIGN ALTERNATIVE #3

Alternative #3 has the H.O.V.'s travelling in the left lane on St. Louis until the intersection of Victoria. At this point, the H.O.V. route moves across into the eastbound direction of traffic and begins to travel in contraflow. It continues in this direction until it reaches the entrance to the Victoria Bridge where it will use Road #3 for reasons already discussed (refer to Figure 3). Another option considered that was similar to this design involved the H.O.V. lane beginning to travel in contraflow at the intersection of Queen. This minor adjustment avoids the situation of leaving one lane only for eastbound traffic between Victoria and Queen.

FIGURE 3: ALTERNATIVE #2



6.0 PROCESS OF ELIMINATION OF THE DESIGN ALTERNATIVES

6.1 MATRIX DEVELOPMENT

A method to screen through the design alternatives was developed to determine the best choice for the situation. A matrix was created to consider all alternatives according to a set of criteria which are important for a H.O.V. lane design. The criteria were compared to each other to define the most prominent features. A point value was assigned to each item. Ten points was the high value while zero was the lowest. For each alternative, the list of criteria were rated under four possible status; excellent, good, acceptable and bad. Each status was worth a certain percentage of the points assigned to each criteria; 100%, 67%, 33% and 0% respectively. The values in parenthesis shown in Table 1 are the actual values of the points obtained according to the ranking of each criteria. The points were totalled for each alternative to determine the best choice, which was design Alternative #2.

It should be noted that this is just a general screening process. A design choice cannot be based only on the alternative with the greatest total. For example, if an alternative had good ratings for all criteria except for safety, it may still be eliminated even though it appeared to be the best option by the process described.

TABLE 1: CRITERIA OF ANALYSIS

POINTS	CRITERIA	ALT. #1	ALT. #2	ALT. #3
10	CAPACITY	BAD (0)	BAD (0)	GOOD (6.7)
10	TIME SAVINGS	BAD (0)	EXCELLENT (10)	EXCELLENT (10)
10	SAFETY	BAD (0)	EXCELLENT (10)	BAD (0)
5	OPERATION OF HOV	EXCELLENT (5)	EXCELLENT (5)	ACCEPTABLE (1.6)
2	MAINTENANCE	GOOD (1.3)	GOOD (1.3)	GOOD (1.3)
8	ENFORCEMENT	GOOD (5.4)	EXCELLENT (8)	EXCELLENT (8)
6	ACCESSIBILITY	GOOD (4)	GOOD (4)	GOOD (4)
3	ON-STREET PARKING	BAD (0)	BAD (0)	BAD (0)
5	BUS ROUTES & STOPS	EXCELLENT (5)	ACCEPTABLE (1.6)	BAD (0)
7	COSTS	GOOD (4.7)	GOOD (4.7)	ACCEPTABLE (2.3)
8	PUBLIC ACCEPTANCE	BAD (0)	ACCEPTABLE (2.6)	EXCELLENT (8)
9	CROSS STREET MOVEMENTS	BAD (0)	GOOD (6)	GOOD (6)
TOTAL		25.4	53.2	47.9

6.2 EXPLANATION OF CRITERIA

CAPACITY: Overall capacity of Sir Wilfrid Laurier/St. Louis upon implementation of the H.O.V. lane.
TIME SAVINGS: The decrease in the amount of travel time.
SAFETY: The safety of the overall traffic situation after the H.O.V. lane is implemented.
OPERATION OF H.O.V.: The daily preparation of operating the H.O.V. lane.

MAINTENANCE: The process of maintaining and replacing the necessary equipment (e.g. cones, signs).
ENFORCEMENT: The amount of police enforcement necessary to ensure that the H.O.V. lane is being used by people that it was intended for.
ACCESSIBILITY: The ease or difficulty in which mixed flow vehicles can exit to the local side streets.
ON-STREET PARKING: The amount of parking available on St. Louis/Sir Wilfrid Laurier after implementation of the H.O.V. lane.
BUS ROUTES & BUS STOPS: The compatibility of the location of the present bus routes and stops relative to the placement of the H.O.V. lane. This is important because the buses will be travelling in this lane but must be able to pull-over at bus stops.
COSTS: The overall cost of implementing the H.O.V. lane.
PUBLIC ACCEPTANCE: The reaction of the public to the change in the traffic system.
CROSS STREET MOVEMENTS: The ability for vehicles to turn from the cross streets and enter either the H.O.V. lane or mixed flow lanes on St. Louis/Sir Wilfrid Laurier without being confused or delayed greatly by the motion of the vehicles coming from the other direction.

6.3 RATING OF CRITERIA

The following discussion explains the reasoning behind some of the rankings of the criteria as displayed in Table 1.

6.3.1 ALTERNATIVE #1

This was given 'bad' ratings for some of the most important criteria such as capacity, time savings, safety and cross street movements. The fact that a lane is taken away from regular mixed flow users in the westbound direction causes problems with capacity and public acceptance. The cross street movements are another difficulty because the turning motions from both directions of the cross streets are very confusing.

6.3.2 ALTERNATIVE #2

The only major concern with design alternative #2 involves capacity. Once again there is only one lane for non-H.O.V. lane users. The public can be persuaded to accept this traffic flow change if they can be shown that time savings can be achieved with a H.O.V. lane. If the priority lane is efficiently used the effect on the remaining mixed flow lane can be minimal.

6.3.3 ALTERNATIVE #3

The most influential factor for this design choice is inadequate safety. The H.O.V. lane travels in contraflow for a portion of the approach to the

Victoria Bridge. It is dangerous to have regular drivers travelling in contraflow. They are not prepared to react to certain situations that may occur such as a cone that is knocked into the middle of the lane. Bus drivers would be trained to respond to events that could result in accidents or delays. With design alternative #3, the placement of bus stops on Sir Wilfrid Laurier/St. Louis is very unrealistic. The buses would be driving in the H.O.V. lane which is located in the left lane of westbound flow. It would be difficult to pull over to the right side of the road to pick up and drop off passengers without disrupting traffic flow. It is basically impossible for the bus to stop anywhere once it is travelling in contraflow. The currently running #55 bus would find it very difficult to reach the H.O.V. lane because it would have to cross a total of three lanes without the aid of a traffic light.

6.4 DISCUSSION ON ELIMINATION

Alternative #1 was eliminated very quickly due to poor ratings in the major criteria. Therefore, the choice was between alternative #2 and alternative #3. It was the differences in safety and cost for the two options that influenced the decision. The final decision was that alternative #2 is the best design for a H.O.V. lane for the approach of the Victoria Bridge during the morning peak period.

7.0 ANALYSIS OF THE DESIGN

7.1 PROBLEM DEFINITION

The main problem with the implementation of a H.O.V. lane is the estimation of the number of vehicles that will use the facility. Presently, there are no definite methods for estimating demand. As stated by the Guide for the Design of High-Occupancy Vehicle Facilities: "There exists today no one model/procedure or group of models/procedures that have come to the forefront and been established as proven H.O.V. demand estimation procedures ... and research in this area is needed" (ref. 5, pg. 6). The H.O.V. demand analysis can be estimated with the modal-split method. That is, the choice is related to the time and cost of the mode chosen (H.O.V.). However, statistics on employment, cost of fuel, the concentration of employment and residences, and other variables difficult to measure such as comfort and convenience will need to be obtained. Therefore, a complete demand analysis with the modal-split method will be beyond the scope of this project.

The second problem encountered with this project was that the majority of the H.O.V. lanes used in the United States and Canada are implemented on freeways. However, in the documentation found on reserved H.O.V. lanes in an urban area, the increase in carpooling and the reduction in travel time are usually the only items mentioned. Yet, there is no discussion on estimation or how to calculate the demand for this type of lane. Therefore, as a last alternative, it was decided that a case study would be found where statistics showed the percentage of car users switching to the reserved lane. Similar features of our study corridor with the case study would make it applicable to this project.

7.2 CASE STUDY

A case study was found in the report on Traveler Response to Transportation System Changes (ref. 6, pg. 66). The Kalanianaole Highway is an arterial H.O.V. reserved lane located in Honolulu, Hawaii. On this highway the H.O.V. lane is 2.5 miles in length, on which 1.9 miles runs contraflow on a four-lane undivided highway and 0.6 miles runs with-flow on a six-lane divided highway. The high-occupancy vehicle lane is shared by carpooling and buses. Following the 2.5 miles, there is another 1.5 miles of reserved lane for buses but not for carpools. A minimum of three persons per vehicle is required to use the reserved lane and the lane is only used during the morning peak period. The average time savings is 2.0 to 2.9 minutes. Further, it was determined that 8.6% of the one- and two-person vehicles found a third person so that they could qualify to use the carpooling lane.

When comparing the case study with the project, similar characteristics can be noted. First, both lanes are relatively short; 1.4 miles compared with 2.5 miles. Second, both reserved lanes begin with a four-lane undivided arterial and are followed by a six-lane divided highway. The only difference is in the restriction on the number of persons needed to use the facility. In this project, a minimum of two persons per vehicle will be required. Currently in Quebec, the majority of the population has never been offered a carpooling option so a two-person incentive to save travel time must seem realistic and attainable. Finally, it was decided to apply this case study to the project to estimate the number of vehicles which will use the H.O.V lane.

7.3 ASSUMPTIONS

In order to reduce the complexity of the analysis, four major assumptions were made. First, the area under study was considered to be isolated. In this case, all the traffic counts given by the M.T.Q. or recorded by the project team were kept for further analysis. This in turn helped determine the number of vehicles which will use the H.O.V. lane by applying the required percentage of the single drivers who will switch to the reserved lane. Second, the vehicles that already have an occupancy rate of two or more were assumed to use the H.O.V. lane. Third, a maximum of 20 buses per hour was assumed to use the H.O.V. lane. In this case, the percentage of heavy vehicles can have a major effect in decreasing the level of service at particular intersections. For example, at Laurier and Cartier, the percentage of heavy vehicles was found to be 6% for both intersections with only 20 buses per hour. Last, the traffic growth factor during the morning peak period was considered negligible. As it was said earlier, the immediate approach of the Victoria Bridge is presently running at capacity. Therefore, there should not be an expected large growth in traffic volume.

7.4 H.C.S. ANALYSIS

7.4.1 CASE STUDY APPLICATION

A survey was made on February 14th, 1992, to determine the vehicle occupancy of the morning peak period. A sample of 1498 vehicles indicated that a percentage of 30.37% of the total had an occupance of two or more.

The Highway Capacity Software (H.C.S.), based on the Highway Capacity Manual (H.C.M.) (ref. 7), was used to calculate the approach delays for all of the intersections in the study corridor. The delay was computed in seconds per vehicle. The study period for this analysis was taken for the highest vehicle volume for one hour. Further, the calculation of delays was computed for the westbound direction only; the direction in which the H.O.V. lane will be implemented. The other intersection approaches were not modified. The analysis was first made with respect to the Do-Nothing Alternative, followed by applying the 8.6% shift taken from the case study. In this project, 8.6% of the single drivers were assumed to find someone to carpool with them and therefore switch to the H.O.V. lane. Note that the criteria for usage of the reserved lane as a carpooler is an occupancy of two or more persons per vehicle.

The first delay analysis was calculated with the Do-Nothing Alternative (Table 2). The calculation of waiting time and capacity began at Cartier Street. Since the H.O.V. lane begins right after St. Georges, the westbound approach at this intersection has the same waiting time with or without the reserved lane. Therefore, waiting time was computed between Cartier and Prince Arthur. Presently, both levels of service (LOS) at Cartier and Laurier are B, with an average waiting time per vehicle of 5.9 seconds and 5.3 seconds respectively. On the other hand, at Victoria, Queen, and Prince Arthur, all westbound approaches have a LOS F. This indicates that all three intersections are currently working at capacity. The total waiting time for the five intersections is 288.6 seconds.

By applying an 8.6% shift of one person per vehicle to two person per vehicle using the H.O.V. lane, new waiting times for the H.O.V. lane and the other lane were computed. As seen in Table 2, the people travelling in the H.O.V. lane will theoretically save 176.5 seconds (2.94 minutes) if compared with the present situation. However, it was estimated that a real time savings of 5 to 6 minutes would occur. On the other hand, the single drivers will be enormously penalized because at Victoria, Queen, and Prince Arthur the other lane will be working at overcapacity. The H.C.M. states that waiting time cannot be computed because traffic flow is considered to be unstable at overcapacity (ref. 7, pg. 9-5).

By comparing the case study (Kalanianaole Highway) with the Victoria Bridge approach study, the average time savings were found to be similar. An average of 2.9 minutes in time savings was determined in the Honolulu highway case and an average time savings of 2.94 minutes was found in this analysis. Therefore, an application of the 8.6% shift to our study seems reasonable. However, other percentage shifts will also be analyzed in the next section.

7.4.2 OTHER PERCENTAGE APPLICATION

Shifts of 15% and 20% from one-person to two or more persons per vehicle were also tested. These new shifts were used to analyze the effect of adding more vehicles to the H.O.V. lane. The capacity and waiting time were analyzed using the same process as in the previous section and the delay time was compared with the current situation.

By applying a shift of 15%, the LOS at the intersections of Cartier and Laurier did not change (Table 2). For Victoria, Queen, and Prince Arthur the LOS remained constant at D, E and D respectively. The total time savings decreased by 10% from 2.94 to 2.67 minutes.

By applying a shift of 20%, the LOS B was maintained at Cartier and Laurier. As for the other intersections, at Queen and Prince Arthur, for example, the LOS was found to be inadequate at F and E respectively. Therefore, a shift of 20% from the other lane to the H.O.V. lane will not be considered for the benefit/cost evaluation.

TABLE 2: DELAY TIMES (IN SECONDS) AND LEVEL OF SERVICE

	DO-NOTHING	8.6% SHIFT		15% SHIFT		20% SHIFT	
		H.O.V. LANE	OTHER LANE	H.O.V. LANE	OTHER LANE	H.O.V. LANE	OTHER LANE
CARTIER	5.9 (B)	5.4 (B)	7.6 (B)	5.7 (B)	7.0 (B)	5.9 (B)	6.6 (B)
LAURIER	5.3 (B)	5.0 (B)	6.0 (B)	5.1 (B)	5.8 (B)	5.3 (B)	5.6 (B)
VICTORIA	112.3 (F)	27.5 (D)	XXXXX	31.8 (D)	XXXXX	36.8 (D)	XXXXX
QUEEN	82.2 (F)	40.7 (E)	XXXXX	46.5 (E)	XXXXX	60.1 (F)	165.3 (F)
PRINCE ARTHUR	82.9 (F)	33.5 (D)	XXXXX	39.4 (D)	XXXXX	51.6 (E)	158.7 (F)
Delay	288.6	112.1	XXXXX	128.5	XXXXX	159.7	XXXXX
Time saving vs.Do-Nothing		176.5s (2.94 min)		160.1s (2.67 min)		128.9s (2.14 min)	

Note: xxxxx = overcapacity, delay time is unstable.

7.4.3 NEW SIGNAL PHASING PLAN

The signal phasing was changed for Victoria, Queen, and Prince Arthur Boulevard because the level of service for the H.O.V. lane was found to be unsatisfactory with LOS D, E, and D respectively. The new cycle lengths were reduced from 120 seconds to 95 seconds (Table 3). By maintaining the same cycle length, the coordination of the traffic lights would be easier. On the other hand, the eastbound left turn phase was removed on Queen and Prince Arthur. Presently, 14 vehicles per hour are turning left at these two intersections. However, the new movement restriction would not have a major effect since these vehicles will be able to turn left at Victoria.

By applying an 8.6% shift, the level of service on all three intersections was brought back to C. The new overall waiting time was calculated to be 71.4 seconds which is a saving of 3.62 minutes compared with the Do-Nothing Alternative. For the 15% shift, Victoria is the only intersection which has a LOS D for the H.O.V. lane. However, the waiting time is 25.4 seconds which is at the limit of the LOS D range. The total time savings was found to be 3.44 minutes.

TABLE 3: DELAY TIMES (IN SECONDS) AND LEVEL OF SERVICE (With Changed Cycle Lengths)

	DO-NOTHING	8.6% SHIFT H.O.V. LANE	8.6% SHIFT OTHER LANE	15% SHIFT H.O.V. LANE	15% SHIFT OTHER LANE
CARTIER	5.9 (B)	5.4 (B)	7.6 (B)	5.7 (B)	7.0 (B)
LAURIER	5.3 (B)	5.0 (B)	6.0 (B)	5.1 (B)	5.8 (B)
VICTORIA	112.3 (F)	21.8 (C)	XXXXX	25.4 (D)	XXXXX
QUEEN	82.2 (F)	18.0 (C)	63.5 (F)	20.1 (C)	41.2 (E)
PRINCE ARTHUR	82.9 (F)	21.2 (C)	XXXXX	23.8 (C)	119.3 (F)
Delay	288.6	71.4	XXXXX	81.7	XXXXX
Time saving vs. Do-Nothing		217.2s (3.62 min)		206.9s (3.44 min)	

Note: xxxxx = overcapacity, delay time is unstable.
The cycle length at Victoria, Queen, and Prince Arthur are reduced to 95 seconds except for the Do-Nothing Alternative.
Eastbound left turn movements at Queen and Prince-Arthur are removed.

8.0 BENEFIT/COST EVALUATION

8.1 USER COST

8.1.1 COST OF DELAY

Because of the isolation of the study area, only people travelling by car were considered for this analysis. The calculation for cost of delay was done on the westbound approach only, i.e. on St. Louis and Sir Wilfrid Laurier. Furthermore, all vehicles using the H.O.V. lane were assumed to have two-person vehicle occupancy in order to be conservative for the calculation of user cost. For each intersection, the number of cars using the H.O.V. lane was determined and the annual cost of delay was then computed. As previously mentioned, the computation was done for a shift of 8.6% and 15%. Then, for the basis of comparison, the cost of delay was calculated for the Do-Nothing Alternative by applying the same number of cars using the reserved lane.

The annual average income of the people who are most likely to use the Victoria Bridge was determined. The average income was taken from the 1986 Canadian Government Census (ref. 8) and was brought forward to 1992 dollars by applying an average inflation rate of 5%. The present annual average income became $30,306. Then, the annual income was brought back to an hourly rate of $14.60. To calculate the cost of delay, the hourly rate was multiplied by 40%. As a result, the cost of delay was found to be $5.84 per hour. Therefore, every hour spent waiting in traffic, costs the automobile user $5.84.

TABLE 4: COST OF DELAY

INTERSECTION		NO. OF CARS	H.O.V. COST ($/YEAR)	DO-NOTHING COST ($/YEAR)
CARTIER	(8.6%)	310	682	744
	(15%)	348	835	835
LAURIER	(8.6%)	239	484	525
	(15%)	268	590	590
VICTORIA	(8.6%)	376	3336	17258
	(15%)	426	4383	19553
QUEEN	(8.6%)	530	3895	17861
	(15%)	596	4380	20085
PRINCE	(8.6%)	597	5850	20447
ARTHUR	(15%)	671	6575	23015

The calculation of the westbound approach delay was calculated using the Highway Capacity Software (Table 3). For all intersections, the number of cars using the H.O.V. lane was determined for the 8.6% and 15% shifts as shown in Table 4.

Then, the annual cost of delay was calculated by multiplying the daily cost of delay by the following factors: waiting time, the number of working weeks (49) and the number of automobiles using the H.O.V. lane. The same procedure was followed for the Do-Nothing Alternative. By adding all intersections, the total annual cost of delay was found to be:

Do-Nothing Alternative	$ 113,730	Do-Nothing Alternative	$ 128,156
Alternative #2 (8.6%)	$ 28,482	Alternative #2 (15%)	$ 29,146

8.1.2 FUEL SAVINGS

The annual fuel saving was calculated at each intersection separately. Annual change was computed with Equation 1:

$$\Delta F = 0.045 \times \Delta VMT + 0.60 \times \Delta VHT \quad \text{(ref. 9, pg. 15)} \quad [1]$$

where, ΔF = change in fuel consumption (gallons)
ΔVMT = change in Vehicle Miles of Travel
ΔVHT = change in Vehicle Hours of Travel

In this study, the change in the Vehicle Miles of Travel was equal to zero (0) because the distance travelled between each intersection was the same for Alternative #2 and the Do-Nothing Alternative. In addition, the travel time between intersections was also constant. Therefore, the annual change in Vehicle Hours of Travel will only be calculated by taking the difference in waiting time between both alternatives. By applying the formula, the annual fuel savings was found to be 4294.7 gallons/year and 4646.7 gallons/year for the 8.6% and 15% shift respectively. Next, these annual fuel savings were multiplied by 3.785 to convert gallons to liters, and the figure obtained was multiplied by an estimated cost of $0.60 per liter. The annual energy cost saving, between the Do-Nothing and Alternative #2, was found to be:

Alternative #2 (8.6%)	$ 9,753
Alternative #2 (15%)	$ 10,552

8.2 COST OF ALTERNATIVES

8.2.1 ALTERNATIVE #2

In this section, an assumption was made that the H.O.V. lane will be used for a period of 10 years. Each alternative included the cost of capital, operation, maintenance, and enforcement. Moreover, all costs were calculated on an annual basis (Table 5).

The capital cost included the purchase of traffic lights and new controllers which will be placed over the westbound left turn bays. In addition, cones and signs will have to be purchased. It was decided to include the cones in the design for better safety and to use a worst-case cost scenario, even though, the Guide for the Design of High-Occupancy Vehicle Facilities (ref. 10, pg. 71) does not require any cones for a with-flow H.O.V. lane. Two signs between intersections to indicate the path of the H.O.V. lane will have to be placed. The total capital cost was approximated to be $157, 600. This value was converted to an equivalent annual annuity by applying an average discount rate of 10% over 10 years.

The operating cost included all daily work which is needed to operate the reserved lane. The maintenance cost was comprised of the overhaul of the signs, the replacement of the cones, and the street painting which will be needed twice per year. For the enforcement of the H.O.V. lane, a police officer will be positioned at the Victoria Bridge entrance to prosecute illegal users of the H.O.V. lane. Therefore, the total annual cost of the design Alternative #2 is expected to be $167,400.

8.2.2 DO-NOTHING ALTERNATIVE

The cost of the Do-Nothing Alternative is the cost of running the facility at the moment. The total cost included capital, operation, maintenance, and enforcement. It was also computed on an annual basis (Table 5).

The capital cost only included cones which were bought in 1991. This was calculated to be approximately $6,000. This value was converted to an equivalent annual cost using the same assumptions as for the Alternative #2 calculations. Operating costs referred to the labour needed for the daily installation and removal of the cones and for the two police officers needed for the traffic control; one at Prince Arthur and another at the Victoria Bridge entrance. Similarly to design Alternative #2, maintenance involved the replacement of the damaged cones and the regular street painting. The enforcement cost included the employment of police officers to prevent violation of the various restricted movements in the area. Therefore, a total annual cost of $112,300 is expected for this alternative.

TABLE 5: COST OF ALTERNATIVES

	DESIGN CHOICE COST	DO-NOTHING COST
CAPITAL COST	$ 25,700 /yr	$ 1,000 /yr
OPERATION COST	$ 114,000 /yr	$ 88,400 /yr
MAINTENANCE COST	$ 12,100 /yr	$ 7,300 /yr
ENFORCEMENT	$ 15,600 /yr	$ 15,600 /yr
TOTAL ANNUAL COST	**$ 167,400 /yr**	**$ 112,300 /yr**

8.3 BENEFIT/COST RATIO

To be consistent with the previous analysis, the benefits were only applied for one hour whereas the cost of alternatives were calculated for the whole peak period. A greater value of benefits would be obtained if calculations were taken over the entire peak period.

The benefit/cost ratio was calculated by dividing the difference in benefits by the difference in costs between both alternatives. The total benefits were computed by taking the difference in benefits between the Do-Nothing situation and Alternative #2 and then adding the fuel savings to the result. The ratio was analyzed for the 8.6% and 15% shift. By having a B/C ratio greater than unity for both cases, Alternative #2 was found to be economically feasible. Because it was decided to consider only car users for the cost analysis during a one hour period, a further study in which the transit user would be included would obviously show a higher benefit/cost ratio. The computation of the benefit/cost ratio follows:

H.O.V. (8.6%): B/C = 95,001 / 55,100 = 1.72
H.O.V. (15%): B/C = 109,562 / 55,100 = 1.99

9.0 COMPARISON OF ARTERIAL H.O.V. LANE GUIDELINES AND DESIGN ALTERNATIVE #2

Table 6 shows a comparison between the arterial H.O.V. lane guidelines that were discussed earlier and alternative design #2. The length requirement was satisfied. Also, the travel time savings and the decrease in cost of travel were greater than the minimum specified. It was only the minimum vehicle per hour criteria that was not achieved by design #2. But, it should be noted that if design #2 with the new phase plan discussed earlier is implemented, the vehicles per hour will be greater than the required minimum of 650.

TABLE 6: ARTERIAL H.O.V. LANE GUIDELINES VS. DESIGN #2

CRITERIA	GENERAL ARTERIAL H.O.V. LANE	DESIGN #2 (8.6% SHIFT)
MINIMUM LENGTH MAXIMUM LENGTH	2000 FEET 10560 FEET	7392 FEET
MINIMUM VEHICLE/HOUR	650	522
MINIMUM TRAVEL TIME SAVED (%)	10%	46%
MINIMUM DECREASE IN COST OF TRAVEL (%)	10%	46%

10.0 RECOMMENDATIONS

In order to implement design Alternative #2 successfully, the external factors that negatively affect the H.O.V. lane should be eliminated or altered. There are areas in our study corridor where delays will be experienced by the priority users. The following are recommendations of actions that should be taken if design #2 is to be brought to reality:

1) Attempt to restrict the passage of ships going through the St. Lambert Lock during the morning peak period.

2) Attempt to restrict truck movement on St. Louis near the fruit and vegetable distribution centre at 27 St. Louis.

3) In order to improve the service of bus #55, a traffic light should be placed at the intersection of Sir Wilfrid Laurier and Osborne.

4) Develop a marketing scheme to encourage the public to carpool or use the transit system.

11.0 CONCLUSIONS

Three different routes and design for a H.O.V. lane were chosen along the study corridor. A screening process based on criteria for a H.O.V. lane such as safety and capacity was established. After comparing the design alternatives, the best option was determined to be Alternative #2 with the new signal phasing plan. It was the safest design and provided excellent time savings. A possible problem can be overall capacity. A complete analysis of the chosen design was undertaken.

Overall, the implementation of a H.O.V. lane on the approach of the Victoria Bridge is physically feasible. It is realistic to state that the physical construction is possible. The many restrictive movements along the study corridor must be readily accepted as a major part of the physical implementation. The reserved facility is economically feasible as proven by the benefit/cost evaluation. The benefit/cost ratio was analyzed with the worst cost scenario to ensure that in the case of any minor changes such as cones not being used, the ratio can only increase or improve. Therefore, the reserved lane will always have its "raison d'être".

Public acceptance can be a major obstacle for the implementation of the H.O.V. lane. The many restricted movements along the study corridor and the decrease of service in the other lane will produce a negative reaction by the users. A possible solution is the establishment of a marketing plan provided by the provincial government. People would be educated in the benefits of using the reserved lane. The issues related to the fruit and distribution centre and the passage of boats in the St. Lambert lock must be dealt with before the reserved facility can be realized. Further studies should be completed to obtain a more accurate estimation of the volume of future H.O.V. lane users. This may include the use of sensitivity or modal split analysis. The studies could include the benefits for the people travelling on the buses.

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