WHEN SHOULD WE PROVIDE SEPARATE AUTO AND TRUCK ROADWAYS?

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1. INTRODUCTION

The concept of the general purpose (GP) lane has dominated modern highway thinking and practice in OECD countries, especially for limited-access highways such as inter-city motorways and urban expressways, whether tolled or non-tolled. This paper raises the question of whether, in some circumstances, specialized lanes for light vehicles (cars, vans and pickup trucks) and heavy vehicles (generally more than two axles) might be cost-effective.

The case for GP lanes appears to rest on two principal advantages: capacity and cost-savings. First, for road capacity in a single direction, the provision of two GP lanes permits somewhat higher throughput (vehicles/lane/hour) than two separate lanes. That is because with more than one lane, faster vehicles can pass slower-moving vehicles. This effect is less pronounced as the total number of lanes per direction increases, but even with four or five lanes in one direction (as on some Californian freeways), reserving one lane for specialized use subjects that lane to the problem of faster vehicles in that lane being unable to pass slow-moving vehicles—and hence that restricted lane is scored by traffic engineers as having lower capacity than the adjacent GP lanes that do permit lane-changing.[1] Special lanes for high-occupancy vehicles (HOVs) are sometimes opposed by traffic engineers for this reason, at least where only one such lane is provided per direction.[2]

The second argument for GP lanes concerns cost. Separate lanes are generally proposed for a subset of vehicles. In the United States today, the vehicle categories most often proposed for "managed lanes" are carpools (HOV lanes), buses (exclusive busways), toll-paying vehicles (HOT or Express Toll Lanes) or trucks (truck-only lanes). However, if the fraction of vehicles eligible to use the special lane is a significantly higher or lower percentage of the projected daily traffic than one lane's worth, the special lane may provide either too little or too much capacity for the designated subset of vehicles. The "lumpiness" of a lane's capacity means that, in general, the risk of building the wrong amount of capacity is less if all the lanes can be used by all types of vehicles—i.e. be operated as GP lanes.

Against this background of conventional wisdom, this paper will explore whether there are cases where, despite these factors, specialized lanes could make sense in coming decades. The next section provides a brief overview of exceptions to the standard GP lane practice, drawn from US experience. Next, the paper examines arguments for cars-only (actually light-vehicles only) roadways or lanes that have emerged in the transportation literature in recent years. This is followed by a comparable review of arguments that have been put forth in favour of truck-only lanes (or roadways). Following the cars-only and trucks-only discussions, the paper further explores the pros and cons of separate versus GP lanes, adding a more detailed consideration of vehicle operators' values of time. This is followed by a discussion of safety and environmental considerations that may be relevant in considering the creation of specialized lanes in coming decades.

2. EXAMPLES OF SEPARATE LANES AND ROADWAYS

2.1. Cars-only parkways

The United States, in the first half of the twentieth century, developed a number of cars-only roadways. They were generally called "parkways" and were the country's first grade-separated and limited-access highways. The parkway phenomenon was especially prominent in the northeastern states and many of these parkways were developed as toll roads. Table 1 lists some examples, most of which are still in operation today, though nearly all without tolls. Parkways were generally built in suburban areas, sometimes in the flood plains of small rivers. They typically followed winding routes through forested areas and were often designed in part by landscape architects who sought to fit them into the existing landscape, minimizing cuts and fills and preserving as much of the treescape and waterways as possible (today this would be called "context-sensitive design"). They generally had low overhead clearances (e.g. 11-feet) aimed at reinforcing the policy of non-use by trucks, had short onramps (often with stop signs) and narrow lanes, typically 10-feet rather than today's US standard of 12-feet. Originally they were not equipped with breakdown shoulders or median barriers and were designed for speeds lower than today's limited-access highways.[3]

Table 1. **Representative US parkways**

State	Name of parkway
California	Arroyo Seco Parkway (later became Pasadena Freeway)
Connecticut	Merritt Parkway
	Wilbur Cross Parkway
Maryland	Baltimore-Washington Parkway
	Clara Barton Parkway
	Suitland Parkway
New Jersey	Garden State Parkway
New York	Bronx River Parkway
	Henry Hudson Parkway
	Hutchinson River Parkway
	Interboro Parkway
	Sawmill River Parkway
	Sprain Brook Parkway
	Taconic Parkway
Virginia	George Washington Parkway
	Mt. Vernon Parkway

Source: Peter Samuel, Note 3.

2.2. Separate truck lanes

A second example is the provision of separate truck lanes on major US highways. In most cases, these are provided as climbing lanes at locations where the highway's rather steep grade forces heavy trucks to slow considerably. To prevent these trucks holding up faster traffic, state transportation agencies often designate the right-most lane as a truck-only climbing lane. In a few cases, such as on I-5 north of Los Angeles, such truck climbing lanes are physically separate from the main roadway, taking a longer route to permit a somewhat less-steep grade.

One of the best-known examples of separated lanes is on a 45-mile section of the New Jersey Turnpike. For this "dual/dual" section, the Turnpike consists of four parallel roadways, each consisting of three 12-foot lanes. The inner roadways are designated cars-only, while the outer lanes are usable by cars and trucks. The Turnpike is heavily used by trucks, which account for about 12% of average daily traffic and about 34% of revenue. In 2008, the state proposed a USD2 billion project to extend the "dual-dual" configuration an additional 25 miles, including reconfiguration of seven interchanges.[4]

2.3. HOV and HOT lanes

The most common type of specialized lane in current US highway practice is the high-occupancy vehicle (HOV) lane, aimed at promoting carpooling. These lanes began to be added to urban freeways in the 1960s, originally as exclusive busways. The first one was added to the Shirley Highway (I-395) in northern Virginia, a commuter route to the Pentagon and Washington DC. However, although bus service on the new (reversible) lanes was popular, there was considerable unused capacity. Hence, in December 1973, vanpools and four-person carpool vehicles (HOV-4) were allowed to begin using the busway. After more than a decade of use under this policy, there was still unused capacity, while adjacent GP lanes had become highly congested during peak periods. So, in 1989, the minimum occupancy requirement was reduced to HOV-3.[5]

A similar evolution took place in Houston, where "transitways" were added to several key freeways starting in 1979. Initially, they were single-lane, reversible busways, but by the mid-1980s the existence of unused capacity led to opening these lanes first to vanpools, then HOV-4 and soon after, HOV-3 in 1985, and HOV-2 in 1986. In most other urban areas, carpool lanes became the freeway capacity addition of choice during the 1980s and 1990s, and nearly all such lane additions were designated for HOV-2 operations, where nearly all remain today.[6]

Because all but a handful of HOV lane projects (as they are now called) offer only a single lane in each direction, their performance in relieving traffic congestion has been criticized. On one hand, some studies suggest that most HOV lanes reduce overall freeway capacity compared with that additional lane being a GP lane, since most move fewer vehicles per lane per hour than the adjacent GP lanes and their single-lane configuration limits their speed to that of the slowest vehicles using them.[7] On the other hand, a few HOV lanes attract so much peak-period traffic that they become congested during peak periods and hence lose their intended time-saving advantage for carpoolers and buses.

Both phenomena—unused capacity and excessive use—have been cited as reasons to convert HOV lanes to HOT (high-occupancy toll) lanes. In the case of unused capacity, the rationale is to open up the HOV lane to those willing to pay a market-price toll in order to save time. In the case of HOV lanes that have been overcrowded, the rationale is that an increase in the occupancy requirement (generally to HOV-3) will create significant unused capacity, which can then be sold. Since 1993,

when the original paper urging HOV to HOT conversions was published[8], such conversions have taken place for individual HOV lane facilities in Denver, Houston, Miami, Minneapolis, Salt Lake City, San Diego and Seattle.

A somewhat different case has more recently been made for adding a version of HOT lanes to congested freeways that do not already have HOV lanes. The prototype for this is the 91 Express Lanes project in Orange County, California. Space had been reserved in the median of this congested freeway for HOV lanes, but in the 1990s neither the state nor the county had funds available to build them. A private-sector proposal to finance, build and operate the lanes was put foward as express toll lanes was accepted by the state transport agency (Caltrans) with the proviso that discounts be offered to carpools of three or more people (HOV-3), and the project was financed and built on that basis.[9] Subsequently, private-sector proposals to add express toll or HOT lanes have been accepted in northern Virginia (I-495), Florida (I-595) and Texas (with the I-635 in Dallas and I- 820/SR 183 in Fort Worth). All of the private-sector projects thus far, like the original 91 Express Lanes, are two or more lanes in the peak direction, rather than single-lane facilities.

As of 2009, the US transportation community has generally accepted the term "managed lanes" to refer to all types of specialized (non-GP) lanes, though nearly all the literature using this term refers to lanes using some kind of pricing.

2.4. Truck only toll lanes and roads

This relatively new idea first arose in the 1990s. In 1995, under a Minnesota transportation public-private partnership law, a firm called Transportation Industries International proposed a privately financed (USD1.3 billion in 1996 dollars) trucks-only highway, mostly along the right of way of SR 2, from Winnipeg (in Saskatchewan, Canada) to Duluth, Minnesota.[10] To be built with heavy-duty pavement aimed at handling heavier trucks than those permitted on ordinary Interstate highways, it was intended to compete with freight railroads in carrying grain and lumber from Canada to the Great Lakes shipping port at Duluth and to Mississippi barge lines near St. Paul, Minnesota. Potential later extensions would have extended this "truckway" southeast to Chicago and points further east. The project was one of five submitted by private firms, all of which were ultimately rejected as either lacking sufficient local support or failing various benchmarks set by Minnesota DOT for financial and technical feasibility.

In the late 1990s, the Pennsylvania Turnpike—a very truck-intensive roadway—considered adopting the "dual/dual" configuration noted above on the New Jersey Turnpike. According to an interview with the Pennsylvania Turnpike's research manager at the time, the idea was being considered for both safety and cost reasons. The former was to reduce the likelihood of car/truck accidents and the latter was based on the much higher pavement wear caused by heavy trucks. Since the Turnpike's lanes were to be reconstructed, those designated as truck-only lanes could be built to handle even heavier loads than before, while those no longer serving heavy trucks could be rebuilt to lower-cost standards and would have much lower life-cycle cost.[11]

Those thoughts helped to generate the concept of Toll Truckways, introduced by the Reason Foundation in 2002. In 2000, the US Department of Transportation released a major truck size and weight study.[12] That report highlighted the potential productivity gains that could be realized if longer and heavier truck configurations (referred to generically as Longer Combination Vehicles—LCVs) could operate nationwide on limited-access roadways. However, the cost of upgrading that entire system to thicker pavements and stronger bridges was seen as a significant obstacle to bringing that about, as were unresolved concerns about the safety of automobiles on portions of the national

network where traffic is far denser than in the mountainous western states where LCVs may legally operate in GP lanes on selected highways.

The 2002 Reason study proposed, instead, the addition of truck-only toll lanes to those Interstate highway routes that function as major truck corridors. The new lanes would be designed specifically for LCV-category trucks, would have separate on-ramps and off-ramps and would be separated from GP lanes by concrete barriers. They would charge tolls (electronically) to recover the cost of building and maintaining the lanes. LCVs would be allowed to operate in states from which they are currently banned, but only on the toll truckway lanes. Other trucks would have the option of using the truckways, if paying the toll offered enough value in terms of higher average speed, increased safety or other factors.[13]

The study modelled truck operations on a hypothetical Interstate highway corridor, testing a large number of scenarios assuming various fractions of truck traffic (including those newly induced to shift to LCV rigs) opting to use the truckway, and estimating the productivity gains from using the truckway. Those gains were quantified, using trucking industry data, and used to estimate possible toll rates for using the truckway. The analysis concluded that under a variety of scenarios, such truckways could break even or be revenue positive, though not necessarily at commercial rates of return on investment. Also quantified were savings in operation and maintenance costs to state DOTs from reduced wear and tear on the GP lanes, depending on the fraction of truck traffic shifted to the truckway lanes.

In 2007, the US Department of Transportation made grant funding available, on a competitive basis, under a new program called "Corridors of the Future". One of the winning proposals was from a set of four state DOTs along 800 miles of the I-70 corridor, a major truck route from Kansas City on the west to Columbus, Ohio on the east. Their proposal was for a detailed feasibility study of adding LCV-capable truck-only lanes to I-70, as a possible alternative to doing the needed widening of that Interstate by adding GP lanes. The final environmental impact statement, completed in June 2009, selected the "Truck-Only Lanes Strategy" as the preferred alternative, compared with the "Widen Existing I-70 Strategy."[14] And in 2008, the Montana DOT undertook a feasibility study on widening I-80 across that state, with toll truck lanes as one of the alternatives.

3. ARGUMENTS FOR CARS-ONLY LANES

3.1. Rethinking traditional design standards

What leads to the extremely high costs of urban expressways? Ng and Small, in a provocative 2008 paper, suggest that the US design standards that evolved in the 1950s for urban freeways lead to needlessly high cost per lane-mile.[15] The basic reference for these standards is the AASHTO Design Standards—Interstate System, produced by the American Association of State Highway and Transportation Officials (and most recently revised in 2005). Expressway design standards are based on two underlying assumptions. The first is that urban expressways must be designed for safe travel at high speeds. Second, they must be able to carry mixed traffic, including large trucks. However, if urban expressways are congested for much of the day, so that only a small fraction of their daily traffic

can operate at high speed, Ng and Small ask if we should still design them to standards based on those high speeds. Furthermore, should all such expressways be designed to accommodate large trucks?

Ng and Small then explore the trade-offs involved in narrower lane and shoulder widths (which require lower design speeds). Specifically, they compare a 40-right of way, which would normally provide two 12-foot lanes and shoulders of six and ten feet, with an alternative configuration consisting of three 10-foot lanes plus shoulders of two and eight feet. Both configurations would have essentially the same construction cost, but the "narrow" configuration would have significantly more capacity, despite its lower design speed, under real-world conditions of serious congestion during long peak periods. Ng and Small present graphs showing travel times on regular versus narrow expressways for various levels of average daily traffic, illustrating a fairly wide range of traffic conditions under which the narrow expressway performs better, due to having greater capacity (but at the same construction cost as the regular expressway). They make a similar comparison between a regular urban arterial (with two 12-foot lanes) and a "narrow" arterial (with three 10-foot lanes)—both within the same 38-foot right of way. Their performance findings are similar to those for expressways. Ng and Small do not recommend that large trucks be allowed to operate on their proposed "narrow" expressways and arterials. These new types of roadways would be for light vehicles only.

3.2. Making use of unconventional rights of way

Another approach to adding needed highway capacity in urban areas is to seek out rights of way that were created for another purpose and use them for specialized roadways. If the mental model is a conventional expressway, these rights of way will generally be rejected as too narrow. Peter Samuel has suggested three such right of way categories:

- Underused railroads;
- Drainage channels;
- Power line corridors[16].

These days, underused or disused railroad rights of way in US urban areas are reflexively thought of only as corridors for commuter-rail or light-rail service. Yet those corridors may or may not be well-located for that purpose. An alternative is to use the corridor for a combination busway and HOT lane, providing both transit improvements and a higher-speed alternative for motorists. Railroad rights of way are typically 50 to 100-feet wide, enough to provide from four to eight "narrow" 10-foot lanes for light vehicles and buses. Samuel gives an example of a disused rail line in Los Angeles that would provide a shorter (ten mile) route from Los Angeles International Airport to downtown than the current nearly 15-mile freeway route. He also cites examples of two Texas urban toll roads, Houston's Westpark Tollway and the Dallas North Tollway, both built on former railroad line right of way. Another possible use for disused rail lines is urban truckways. Samuel cites possibilities in both Chicago and Brooklyn, New York, in which congestion caused by numerous trucks on regular city streets could be significantly relieved by converting little-used rail right of way to urban truckways[17].

Drainage channels in metro areas with arid climates could be the location of parkway-type roads sized for light vehicles (and possibly buses). One such project is in the planning stages along the flood plain of the Trinity River in Dallas, Texas. Others have been proposed for concrete-lined flood control channels of the Los Angeles River in Los Angeles and the Santa Ana River in Orange County, California. (One such roadway, a portion of Burbank Blvd., exists in the Sepulveda Dam Recreation Area of Los Angeles). Such roadways require access control so that they could be closed to traffic on those rare occasions when rainstorms would make them unusable as roadways due to the possibility of flash floods.

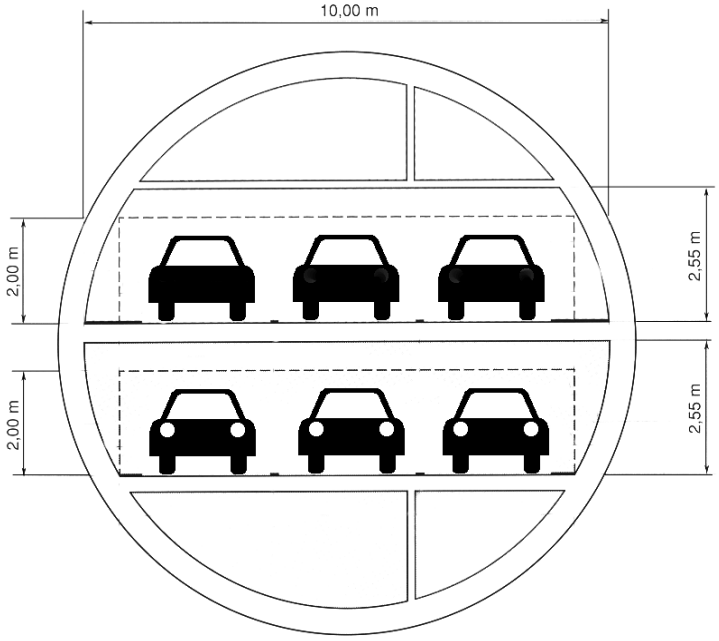
Power line corridors are sometimes wide enough for conventional expressways, but when limited to 50 to 100-feet, they would be better suited to specialized roadways, either for light vehicles only or for truckways. Samuel points to an example from the Maryland suburbs near the District of Columbia, in which a wide power line reservation was proposed as right of way to extend the I-95 expressway inside the Capitol Beltway, providing a new radial route to the nation's capital; that route would have extended about five miles, followed by a one-mile tunnel to permit it to connect with the existing I-395 near the Capitol Building. That project was defeated by local anti-highway opposition.

3.3. Retrofitting urban expressways

Besides having narrower lanes, expressways designed for light vehicles rather than heavy trucks need lower overhead clearance requirements. That opens up significant possibilities for adding capacity at less cost than conventional approaches.

An excellent European example is the missing link on the A86 Paris ring road. After several decades of opposition to a surface motorway through the Versailles area, toll road company Cofiroute made an unsolicited proposal to complete that 6.2 mile link as a deep-bore tunnel, financed entirely by congestion-priced toll revenues. Given this revenue constraint, Cofiroute needed to come up with an affordable design. By limiting the tunnel to light vehicles only, it was able to fit six 10-foot lanes into a double-deck configuration with an inside diameter of 34-feet. (Initial operations will use two lanes in each direction, with the third lane reserved as a breakdown lane). This basic concept appeared in Gerondeau's 1997 book[18], and is illustrated in Figure 1. Actually, the origins of the idea date back to at least 1988, when a private-sector proposal called for a network of toll-financed underground cars-only roadways in Paris named LASER.[19]

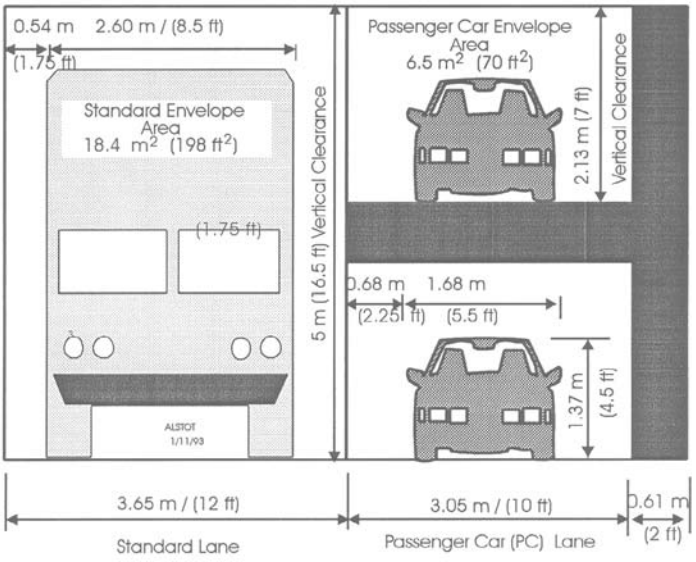
Figure 1. **Metroroute cross-section**



Source: Gerondeau, Note 18.

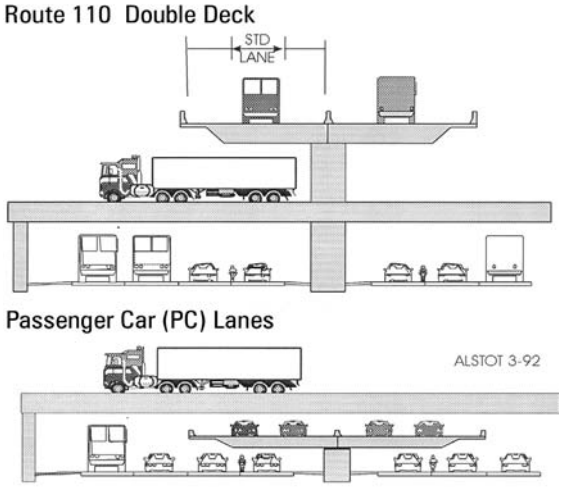
Reduced vertical clearance would also permit the addition of significant amounts of capacity to existing urban expressways without the need to acquire additional right of way. Figure 2 shows standard US roadway dimensions, illustrating that two lanes for light vehicles can be stacked, with ample vertical clearance, within the standard clearance height required for GP lanes able to accommodate large trucks. This provides an alternative to conventional double-decking approaches, such as that used to add an elevated busway/HOV lane on I-110 in Los Angeles.

Figure 2. **Standard US truck and car clearance dimensions**



Source: Gary Alstot, presentation to the American Society of Civil Engineers (March 1992).

Figure 3. **Double deck lanes *vs.* passenger car lanes**

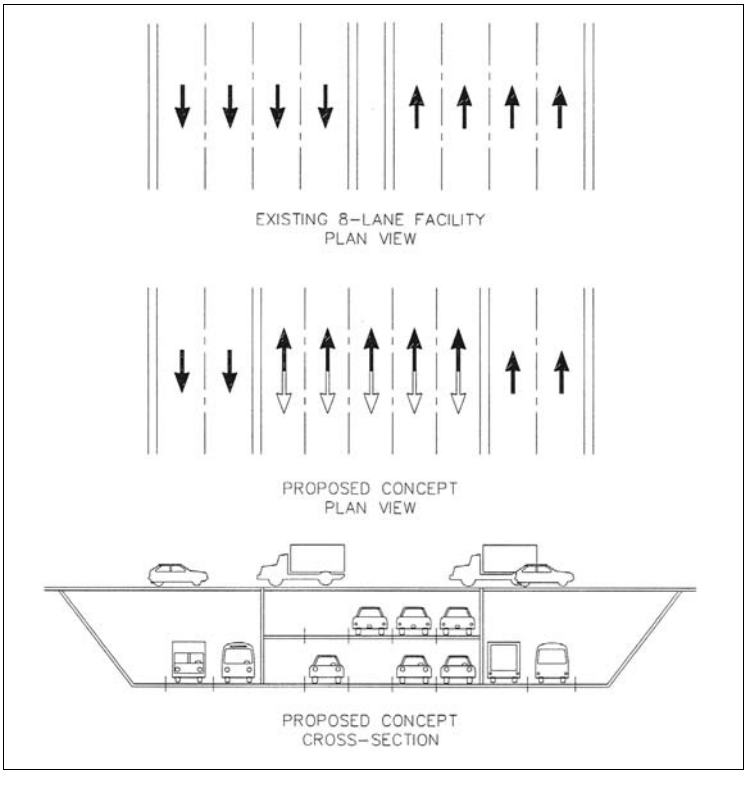


Source: Gary Alstot, presentation to ASCE (March 1992).

Figure 3 shows that if an auto-only second deck were acceptable, it could be built within the existing clearance height of the freeway.

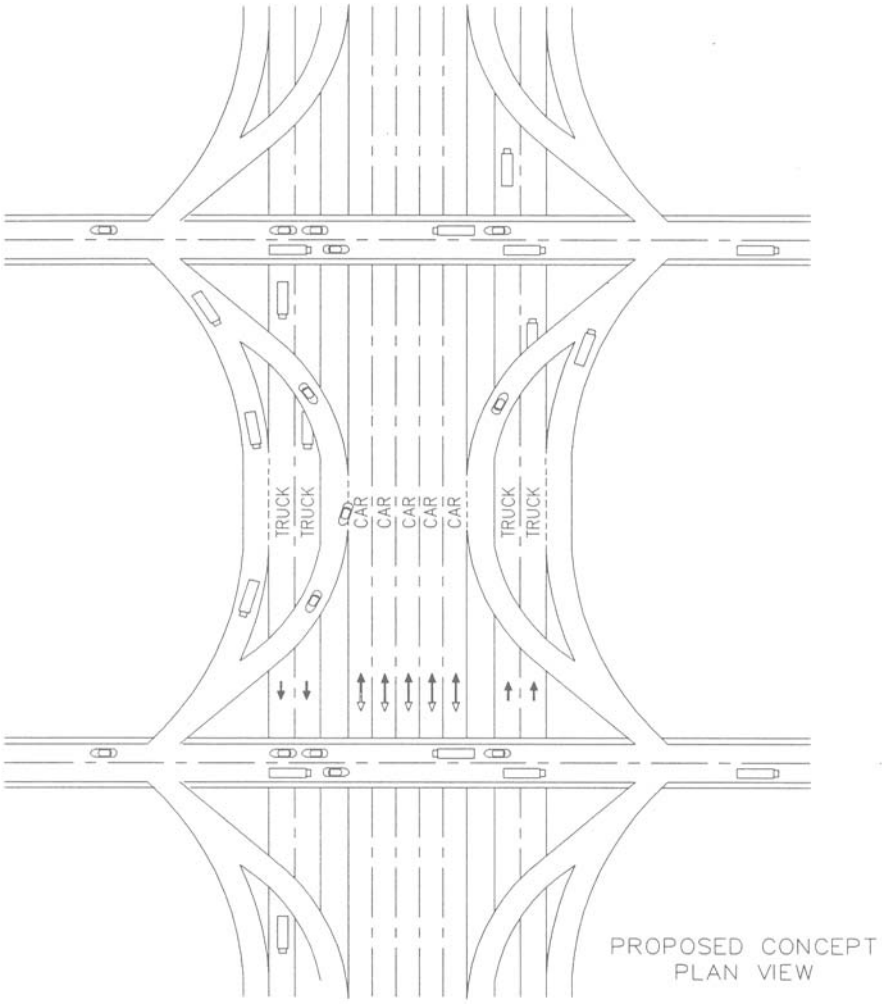
Civil engineer Joel Marcuson has taken these ideas further, envisioning how an eight-lane urban expressway could be reconfigured with cars-only lanes in its centre section, as shown in Figures 4 and 5. While these reconfigurations would be costly, they provide an alternative to the generally "politically impossible" prospect of condemning expensive urban land to add capacity by widening the expressway right of way.

Figure 4. **Reconfigured freeway using cars-only lanes**



Source: Joel Marcuson, Sverdrup, July 1995.

Figure 5. **Ramps to serve reconfigured freeway**



Source: Joel Marcuson, Sverdrup (July 1995).

3.4. Buses plus light vehicles

The A86 tunnel and the reduced clearance height designs shown previously all presume that only auto-size vehicles (cars, passenger minivans and pickup trucks) are allowed to use these non-GP lanes. There is a trade-off involved if these roadways are designed to also accommodate city buses. Clearance heights would have to be greater in this case, but not as high as needed for large trucks (for which the US standard is 16.5-feet). Moreover, ten-foot lanes might require the use of station-keeping technology for buses using these lanes.

US transit buses are typically ten feet and eight inches high, meaning a clearance height of 12 feet, rather than the seven feet shown in Figure 2. That would preclude the kind of double-decking

shown in Figures 3 through 5. For tunnels, that clearance height would require a somewhat larger diameter. In both cases, the addition of buses to the vehicle mix would increase the costs, and this suggests that some applications might be limited strictly to light vehicles rather than including buses.

The feasibility of buses operating on narrow lanes has been demonstrated repeatedly on a small scale since the 1980s, via "curb-guided bus" technology. Under this approach, conventional city buses are equipped with small guide wheels that roll along an adjacent curb-side. A 2006 article cited 11 such systems in operation as of that time, with three more in the planning stages — in Australia, Germany, Japan and the United Kingdom.[20]

4. ARGUMENTS FOR TOLL TRUCK HIGHWAYS

4.1. Productivity gains

The primary rationale for toll truck lanes is productivity gains, due to being able to haul more freight payload per unit of fuel and driver cost. In the 2002 Reason study, the productivity analysis compared a hypothetical toll truckway permitting higher axle loads (weight per axle) than in either of two base cases, corresponding to current weight limits in various subsets of US states.[21] These cases were analyzed for two truck configurations: the common tractor/single-trailer rig with 18 wheels and the long double rig, with a tractor plus two long trailers and 34 total wheels. The toll truckway would produce the largest gains in states with lower axle-load limits and a maximum gross vehicle weight of 80 000 lbs., but there would also be significant gains in states that have more liberal limits. The higher-capacity trucks were found to be more economical for trips longer than about 50 miles.

The preceding analysis focused solely on productivity gains due to greater payload, and involved relatively long-haul (inter-city) corridors. A more recent toll truckway analysis looked into a high-capacity toll truckway to serve trucks in shorter-haul drayage service between the ports of Los Angeles and Long Beach and a large region of warehouses and distribution centres about 55 to 70 miles distant.[22] In this case, the source of productivity increases is two-fold. Current drayage rigs consist of a single 40-foot (or sometimes 53-foot) container on a chassis, hauled by a tractor. The proposed toll truckway would permit the operation of dual-container rigs, thereby doubling the payload of each drayage trip. However, in addition, since the existing freeways are heavily congested much of the day, a separate toll truckway would permit significantly higher speed, allowing for a larger number of "turns" per shift per driver.

Table 2 is reproduced from the 2005 report, and is based on freight rates and operation costs as of 2004. As can be seen, the estimated revenue gains from the combination of increased payload per trip and increased speed far outweighs the increase in costs of operating the larger and heavier rigs (in which "double-short" refers to two 20-foot containers, "triple-short" means three 20-foot containers, and "double-long" refers to two 40-foot containers). The bottom line of this analysis is that shippers would benefit from lower freight rates, truckers would gain additional revenue for overhead and profit and the toll truckway operator would be able to charge quite high tolls, ranging from USD0.61 to USD 1.83 per mile.

Table 2. **Urban toll truckway productivity**

	Col 2	**Col 3**	**Col 4**	**Col 5**	**Col 6**	**Col 7**
	Mixed freeway semi-trailer	**Mixed freeway double-short**	**Truckway semi-trailer**	**Truckway double-short**	**Truckway triple-short**	**Truckway double-long**
Payload	45 000 lbs	45 000 lbs	45 000 lbs	45 000 lbs	67 500 lbs	90 000 lbs
Metric tons	20t	20t	20t	20t	30t	40t
100 mile delivery – 2004 freight rates	$500	$500	$500	$500	$750	$1 000
Average speed on the road (mph)	38	38	60	60	60	60
Miles driven in 8-hr shift (6 hrs driving)	228	228	360	360	360	360
Revenue from 6 hrs payload at 2004 rates	$1 140	$1 140	$1 800	$1 800	$2 700	$3 600
Variable costs per shift	$684	$684	$684	$684	$1 007	$1 165
Available for overhead, profits, tolls	$456	$456	$1 116	$1 116	$1 693	$2 435
Extra earnings from using truckway/shift/ day			$660	$660	$1 237	$1 979
Assume the extra productivity split 3 ways			1/3 = $220	1/3 = $220	1/3 = $412	1/3 = $660
Shipper's savings on 100 mile delivery, $ & %			$61 12.2%	$61 12.2%	$76 15.2%	$91 18.3%
Additional for trucker for overhead & profit/day			$220 43%	$220 43%	$412 90%	$660 145%
Truck tollway – possible toll per mile			$0.61	$0.61	$1.15	$1.83

Source: Samuel, Note 22.

4.2. Operating and maintenance cost savings

Highway cost allocation studies have quantified the damage that heavy trucks do to pavements not specifically designed for such loads. Such damage is proportional to the third power of weight, so

as the researchers Small, Winston and Evans note, "for all practical purposes, structural damage to roads is caused by trucks and buses, not by cars."[23] Thus, to the extent that heavy truck traffic can be shifted from GP lanes to specialized truck-only lanes, highway owner-operators have the potential for considerable savings in operating and maintenance costs.

In the 2002 Reason toll truckways study, the authors made a rough estimate of these savings. They used the World Bank's Highway Design and Maintenance model, which relates road usage to maintenance needs. In the case that was analyzed, only trucks of longer length and heavier weight than are currently allowed in a state would be required to use the new truck toll lanes; all other trucks could opt to use them if they judged the benefits (e.g. time savings, increased safety and better pavement condition) to be greater than the toll charged. The model calculated the GP lanes' pavement conditions each year over a 50-year period, estimated maintenance and repaving needs and produced annual operations and maintenance costs for a range of truck-shift assumptions (ranging from 25% of total corridor truck traffic using the truck lanes to 100%). For the 100% case (which would apply if the law required all trucks to use the truck lanes), the annualized operation and maintenance cost savings on the GP lanes equaled 80% of the fuel tax revenue that would have been paid by the trucks had they remained on the highway's GP lanes. (In this example, it was assumed that trucks using the new truck lanes would pay tolls *instead of* current fuel taxes). While at first glance this might appear to be a losing proposition to the highway owner, one must also take into account the avoided cost of adding a lane to the highway—i.e. the new lane in each direction would be paid for by the toll revenues, rather than by means of fuel taxes. Once that is taken into account, the highway owner comes out substantially ahead.[24]

5. HETEROGENEOUS VALUES OF TIME

5.1. Motorists' values of time and reliability

Most transportation studies use a single value of time for motorists (or occasionally two different values, one for business travel, including commuting, and one for leisure/personal travel). Increasingly, however, researchers are finding that values of time vary greatly, depending on factors such as individual preferences, trip purpose, time of day and week, etc.

The complexity of commuters' value of time has been studied in some detail in recent years in the United States, in connection with the introduction and use of HOT lanes and express toll lanes, where the price charged varies in proportion to demand. The variably priced facility that has been in operation the longest is the 91 Express Lanes, on SR 91, a congested freeway linking the bedroom communities of inland Riverside County (Calif.) with the employment centres in coastal Orange County. Small, Winston and Yan studied traveller behaviour in that corridor in some detail, and summarized their findings as follows: "We find that the users of SR 91 have high average values of travel time and travel-time reliability, and that the distributions of these values exhibit considerable dispersion[25]."

To illustrate the extent of heterogeneity in their sample of SR 91 corridor commuters, they found the median value of time (VOT) of Express Lane users to be USD 25.51, compared with USD 18.63 for the GP lane users. But the range of those values was very large: from a 5th percentile of USD 11.50

to a 95th percentile of USD 39.99/hour for Express Lanes users, and from USD 7.76 to USD 29.08/hour for GP lane users. And those were just the value of time figures. Also measured was the value of reliability (VOR), with median values of USD 23.78 for Express Lane users and USD 19.50 for GP lane users—and with even greater variability than shown for value of time. Moreover, their database is drawn from the A.M. peak period, whose toll levels (and hence presumably VOT and VOR) are considerably lower than those in the P.M. peak. As Small *et al*. sum up, motorists in this corridor "exhibit a wide range of preferences for speedy and reliable travel, as total heterogeneity in VOT and VOR is nearly equal to, or greater than, the corresponding median value. On average, express-lane users have higher values of travel time and reliability than do users of the [GP] lanes, as expected, but wide and overlapping ranges exist within these two groups, resulting from strong heterogeneity in preferences."

Small *et al.* use these findings to critique standard arguments for freeway congestion pricing, which would generally impose a uniform charge for all users of all lanes during peak periods, with lower or zero charges at other times of day. Using a demand model, they estimate the social welfare implications of policies such as HOV or HOT lanes alongside GP lanes, tolling all lanes, or charging different rates on premium and GP lanes. They conclude that some version of the latter (which they call a "two-route HOT" policy) is a reasonable compromise, providing some degree of peak-spreading and time-savings for all lanes on the expressway, but without greatly over-charging the majority whose VOT and VOR are lower than what needs to be charged to keep premium lanes uncongested during peak periods.

Douglass Lee has generally been critical of separate lanes such as HOV and HOT on the familiar grounds discussed in this paper – that overall capacity is less with multiclass lanes than with all GP lanes – while conceding that HOT lanes are generally an improvement over HOV lanes, since the former are more likely to operate at high throughput while avoiding hypercongestion.[26] In response to Small *et al.*, he argues that "the only way HOT lane[s] could be superior [to an all-GP lanes roadway] would be to charge prices on both lane classes, at least enough to keep both lane [types] at full capacity, but not identical flows." Lee also concludes that "the justification for more than one class of service requires that the preferences (value of travel time, or VOT) among users be very heterogeneous." While we thus far do not have detailed data on peak-period commuters' VOT and VOR from many urban areas, the detailed data from the SR 91 corridor at least suggests that such commuters have VOT and VOR far more heterogeneous than has traditionally been assumed.

5.2. VOT and VOR in urban trucking

Many studies of goods-movement use a single value of time, generally based on an assumed average value of time saved (*e.g*. by using a toll road), not explicitly taking into account the value of reliability. This unsophisticated approach is beginning to change, however, as further research is done. A study carried out by the American Transportation Research Institute and the Federal Highway Administration in 2005 measured travel times and delays in five Interstate highway corridors and used the data to derive both a travel time index (TTI) and a Buffer Index (BI). The former compares actual travel time with free-flow travel time, while the latter is a measure of travel-time variability.[27] That report also noted that "shippers and carriers value transit time at USD 25 to USD 200 per hour, depending on the product being carried. Unexpected delays can increase that value by 50 to 250 per cent."

A truck toll lane facility must be analyzed based on the types of goods movement most likely to be carried out on that facility. In the case of the proposed toll truck lanes in the Los Angeles region, as noted previously, their principal purpose would be the drayage of containers between the ports and the

distribution centres and warehouses mostly located about 60 miles inland. In 2007, the Southern California Association of Governments (SCAG) prepared an analysis of that market, estimating both VOT and VOR for container drayage in that corridor.[28] The analysis estimated year-2030 values for both travel time index and buffer time index for the principal freeway routes that would be used if the toll truck lanes are not built. The combined VOT and VOR during peak periods was estimated at USD 73/hour for heavy drayage trucking.

Based on SCAG's travel demand models, truck speeds on the truck lanes were estimated to be up to three times as fast as would otherwise be the case in mixed-flow traffic on the freeway GP lanes. For three different destinations to/from the ports, the study produced the data shown in Table 3.

Table 3. **Los Angeles truck toll lane data, 2030 a.m. peak**

District		Min. Saved	Hours	Value @ $73/hr	Toll Cost @ $.86/mi	Net Savings	Savings/ Toll
Downtown	To	85	1.42	$103	$17	$86	5.1
	From	97	1.62	$118	$17	$101	5.9
Ontario	To	192	3.2	$233	$32	$201	6.3
	From	298	4.97	$361	$32	$329	10.3
Victorville	To	285	4.75	$345	$64	$281	4.4
	From	405	6.75	$490	$64	$426	6.7

Source: Killough, Note 28.

The numbers in Table 3 do not take into account either (a) additional productivity from an increased number of trips per driver per shift due to these time savings, or (b) higher value thanks to increased productivity from being able to haul multi-container rigs. As a point of comparison, SCAG estimates the construction cost of the truck toll lanes at USD 20 billion and the total project cost (including environmental mitigation) at over USD 30 billion. While the study did not estimate whether this mega-project could be financed solely based on toll revenues, the assumed USD 0.86/mile toll can be seen as far below what might be able to be charged, given the increased productivity gains of which the value is not included in the analysis summarized here.

6. SAFETY CONSIDERATIONS IN SEPARATION OF CARS FROM TRUCKS

One of the key issues that must be addressed in any consideration of separate lanes for cars and trucks (or, more accurately, light vehicles *vs.* heavy vehicles) is safety. We look first at empirical data regarding "narrow" roadway designs and then specifically at car-truck accidents. In addition, we consider trends that are likely to mean smaller automobiles in coming decades.

6.1. Safety data re "narrow" designs

In their paper making the case for "narrow" designs of expressways and arterials, Ng and Small provide an overview of recent research on the safety record of roadways with narrower lanes than current US AASHTO standards. The studies they examine focus on accidents involving injuries and fatalities on urban arterials and on expressways of four or more lanes.

They reviewed a number of studies, both before/after (e.g. narrowing the lane widths on certain freeways) and cross-sectional (comparing accident rates on narrow and conventional roadways in a given state). Their conclusion is as follows:

> *"[B]oth theoretical and empirical evidence linking road design to safety are ambiguous, although on balance they contain some indications that greater lane width and shoulder width may increase safety. Thus, we think it is an open question whether the 'narrow' road designs considered here would in fact reduce safety, but it is certainly a potential concern. Probably it would depend on factors that vary from case to case, especially the speeds chosen by drivers[29]."*

They go on to discuss design features that should accompany "narrow" designs, such as lower speed limits. They note the successful use in Germany and the Netherlands of variable speed limits, variable message signs, temporary shoulder use, and other techniques. Studies that use driving simulators and traffic simulation models, they report, find that speed limitation reduces average speed, speed variation, and lane-changing movements, all of which reduce accident rates. The US freeway operations community is currently exploring a number of these concepts under the rubric of "active traffic management."[30] Thus, active traffic management techniques offer an important complement to "narrow" roadway designs, to enhance their safety.

6.2. Car-truck accidents

Another factor in making "narrow" designs safer, as Ng and Small point out, is to limit such designs to light vehicles only – thereby avoiding car-truck accidents. They cite a study of the "dual/dual" sections on the New Jersey Turnpike which found that accidents are higher in the mixed-traffic lanes than in the autos-only lanes (which are otherwise identical in configuration) and that trucks are disproportionately involved in the accidents in the mixed-traffic lanes[31]. They cite another paper that uses an econometric model to conclude that overall accident rates are nearly four times as responsive to the amount of truck travel as the amount of car travel[32].

In the United States, about 4 800 large trucks are involved in fatal accidents per year (resulting in about 5 000 fatalities), and about 140 000 are involved in non-fatal crashes (resulting in about 90 000 injuries), according to the Federal Motor Carrier Safety Administration. FMCSA's Large Truck Crash Causation Study involved a sample of 963 large-truck crashes (involving 1 123 trucks and 959 other vehicles) during 2002-2003.[33] Of the total, 73% of the crashes involved a large truck colliding with at least one other vehicle; 50% of the total sample involved car-truck crashes. For this subset of crashes, the causation study assigned the "critical reason" for the crash to the truck in 44% of the cases, meaning that in 56% of them, the car was the critical reason for the crash. For truck-initiated crashes, the two most likely factors were brake problems and drivers either travelling too fast or being unfamiliar with the roadway. For passenger vehicle-initiated crashes, the most important factors were interruption of the traffic flow and unfamiliarity with the roadway. Interestingly, comparing these "associated factors" between truck-initiated and car-initiated crashes, several factors stood out in the car driver but not truck driver data: alcohol and drug use, fatigue and illness.

Since nearly half the car-truck crashes appear to be the "fault" of the truck, separation of car traffic from truck traffic would appear to have significant potential for reducing the deaths and injuries due to car-truck crashes.

6.3. Downsizing of automobiles

One other factor relating to car-truck accidents is the likely downsizing of automobiles in response to concerns over energy use and greenhouse gas emissions. In the United States, the Obama administration in Spring 2009 announced new federal Corporate Average Fuel Economy (CAFE) regulations for both cars and light trucks. The new requirement calls for new autos produced in 2016 to average 39 miles per gallon (compared with 27.5 today) and light trucks 30 mpg (*vs*. 22.5 today). Meeting those requirements is widely expected to require downsizing of new vehicles by 2016.

There is a definite correlation between vehicle size/weight and the seriousness of crashes, as measured by deaths and injuries. A 2002 National Research Council study on the impact of CAFE standards found that the vehicle downsizing that occurred in the 1970s and early 1980s due to the original CAFE standards appeared to have led to between 1 300 and 2 600 additional crash deaths in 1993. In recommending further increases in fuel economy of new vehicles, the NRC authors noted that there were alternative ways that fuel economy could be increased by vehicle manufacturers, and that even a scenario that involved further downsizing would likely involve considerably lower additional crash deaths than in the 1980s, due to the significant increase in safety features built into new vehicles in the intervening years. It concludes by saying "if an increase in fuel economy is effected by a system that encourages either down-weighting or the production and sale of more small cars, some additional traffic fatalities would be expected[34]."

Given the likely further downsizing of both cars and light trucks, the impact of crashes involving those vehicles and heavy trucks will almost certainly be more severe than has been the case historically. This provides a further reason for considering future roadway models that include facilities for light vehicles only.

7. ENVIRONMENTAL ISSUES

Some have argued against the provision of truck-only lanes as the wrong course to follow, on environmental grounds. One aspect of this argument is that since heavy trucks are largely powered by diesel engines, which are considered serious polluters in the United States, government policy should not be facilitating the expansion of goods movement by truck. On a larger scale, this argument calls for policy that aims to shift goods movement as much as possible from road to rail. While somewhat beyond the scope of this paper, these points cannot be ignored.

7.1. Greener trucks

Large-scale transportation infrastructure projects take a decade or more from initial studies to entry into service. Consequently, what is relevant in considering future truck-only toll projects is the truck fleet that will likely exist several decades from now (over the expected service life of the truckway), not the truck fleet of the past several decades. In the United States, new low-sulfur diesel fuel standards came into effect in 2006, to facilitate the requirement that all trucks sold after January 1, 2007 use of new low-emission diesel truck engines. A study by the American Transportation Research Institute, presented at the 2006 Transportation Research Board meeting, projected that by 2015, the US diesel truck fleet would produce 63% less particulate emissions and 53% less nitrogen oxides than the 2005 fleet.[35]

A second factor to consider is the positive impact of increased trucking productivity on truck emissions. A truck tractor hauling two long trailers hauls 100% more payload while using only about 60% more fuel. Thus, the emissions-intensity of goods movement is reduced considerably to the extent that the trucking industry adopts the more-productive longer combination vehicles. This point was confirmed by Cheryl Bynum of the US Environmental Protection Agency's SmartWay Transport Team in 2004. In response to a query by this author, she wrote:

> *"If a [trucking] fleet uses longer trailers and/or multiple trailers, total ton-miles are improved for that trip, and there are fewer trips. This also provides—in addition to the fuel and GHG savings—criteria pollutant savings. The actual environmental benefits depend upon the input the fleet enters into the FLEET Performance model, since it is specific to mileage, equipment type, mpg, and payload".*[36]

The EPA's FLEET model quantifies the fuel savings and emission reductions from various trucking company strategies.

7.2. Roads *vs.* rail

Recent years have seen a number of studies comparing the socio-economic costs of goods movement by rail and by truck. For example, a series of U.K. studies by the Commission for Integrated Transport found that the rail's environmental impacts were only about one-fourth those of road transport. Those impacts were then monetized and included in overall socio-economic

benefit/cost analyses. While the rail projects tended to have Benefit/Cost ratios of less than 3:1, most of the goods-movement highway investment projects had BC ratios of 10:1 or higher.[37]

The reasons for this disparity stem from supply chain performance differences, which are the main driver of mode choice for shippers and receivers. Transit time, reliability and availability on-demand are what the market demands for most goods other than bulk commodities (for which rail has an overwhelming advantage). These points were quantified in an assessment of road vs. rail trade-offs for a study in South Africa. A possible truck-only toll road was compared with an expanded rail line over a 600 km route between Johannesburg and Durban. While both the fuel costs and CO_2 costs for the rail alternative were less than one-quarter those of the tollway, the additional (quantified) supply chain costs made rail nearly 50% more costly (and a large disparity would still exist even at double the current oil price). The bottom line was that a R30 billion investment could produce 72 million tons of economic capacity via the road alternative, but only 24 million tons of capacity (that would operate at a loss) in the rail alternative.[38]

France's Institut National de Recherche sur les Transports et Leur Securite (INRETS) is researching the most promising techniques for future goods movement in France and Europe in the 2030 time frame. According to a presentation given as part of a 2008 study tour in the United States, among the ideas they are exploring are automated trucking and "dedicated truck or goods train toll lanes."[39]

Automation and truck-only toll lanes have been studied by researchers at the PATH project at the University of California, Berkeley and at San Jose State University. Tsao and Botha of San Jose State have made a detailed proposal for dedicated, heavy-duty truck lanes equipped with a variety of high-tech aids to reduce driver workload and increase safety. An evolutionary path is aimed at bringing about what they call Segregated Electronic Road Trains (SERTs)—essentially a platoon system for trucks.[40] This could permit dramatically increased vehicle throughput, reducing the number of lanes required.

A somewhat similar proposal for an urban truck lane project was proposed for Chicago by researchers from PATH at UC Berkeley. Shladover *et al*. proposed a similar evolutionary path, initially building a two-lane (one lane per direction) urban truckway, of which the BC ratio was estimated at 3.6, based on truck travel time reductions and roadway congestion-relief benefits. When demand increases to the point where more capacity is needed, they propose adding platooning technology, which would double the truckway's capacity at significantly less cost than right of way and construction costs for adding two more lanes. The BC ratio for the second-phase truckway is estimated at 5.15.[41]

8. CONCLUSIONS

Despite the traditionally cited advantages of general purpose lanes, there is growing evidence that specialized lanes have a role to play in twenty-first century highways. Reduced lane widths and clearance heights would permit the addition of cars-only urban highway capacity in locations and configurations that have not been seriously considered, and at lower cost than conventional approaches to expanding expressways and arterials. In the inter-city market, specialized truck-only lanes could produce large productivity gains in goods movement, along with reduced environmental impact and significant safety benefits, due to the separation of large trucks from what will likely be smaller future automobiles. Separate lanes fit well into future urban road-pricing plans that take full account of the very large heterogeneity of values of time and reliability, for both individual motorists and trucking companies. Consequently, transportation planners should include consideration of at least the following types of non-GP lanes in their planning studies:

- Light-vehicle-only lanes and roadways, for both expressways and arterials in urban areas.
- Premium-priced and regular-priced lanes on urban expressways.
- Truck-only toll lanes in selected urban and inter-city corridors.
- Truck-only toll roads as alternatives to expanded rail lines in certain corridors.

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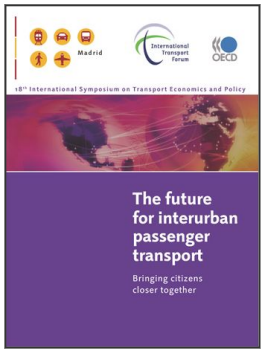

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