Building Balanced Roadway Networks

A multi-modal methodology

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Abstract

The traditional approach to roadway network planning has been to undertake a travel demand model analysis, identify the links that are predicted to experience congestion, and widen them to increase their capacity. While this may improve the operation of the section of road that is being widened, the release of that bottleneck frequently attracts more traffic to the area. As a consequence, other parts of the corridor or connecting roads, which may otherwise be expected to operate well, may become congested themselves.

Where roadway improvements lead to an increase in network efficiency, drivers may simply choose to commute further instead of banking the travel time savings. This effect actually increases the overall demand on the network in terms of vehicle kilometres travelled, which may negate some or all of the benefits achieved from the roadway improvements.

Efficient use of the limited funds available for roadway improvements means encouraging more efficient use of the network itself. The majority of vehicles on the road have only one occupant, and each driver requires much more road space than they would if they were sitting on a bus or riding a bike. Transit and active transportation also have wider benefits in creating more livable, healthier and more sustainable communities. When deciding which sections of roadway to improve, potential enhancements for these non-auto modes should be considered.

It is also important to remember that roads are conduits for the transfer of freight. Congested or otherwise inadequate goods movement corridors increase the overheads incurred in bringing products to stores and supermarkets, and this is often reflected in higher prices for the consumer. The direct cost of roadway improvements, in both financial and environmental terms, should be considered too.

Objectives

This paper and the accompanying presentation will provide background on traditional modelling approaches along with theories and examples related to travel behavior patterns. An alternative methodology will be described for the incorporation of the aforementioned factors into the analysis of the network to identify the transportation improvements that can give the most “bang for the taxpayer’s buck” by building a more efficient network. Also described are some of the tools that have been developed to effectively undertake the calculations and to present the inputs and outputs in a clear, graphical manner for inclusion in Transportation Master Plan studies.

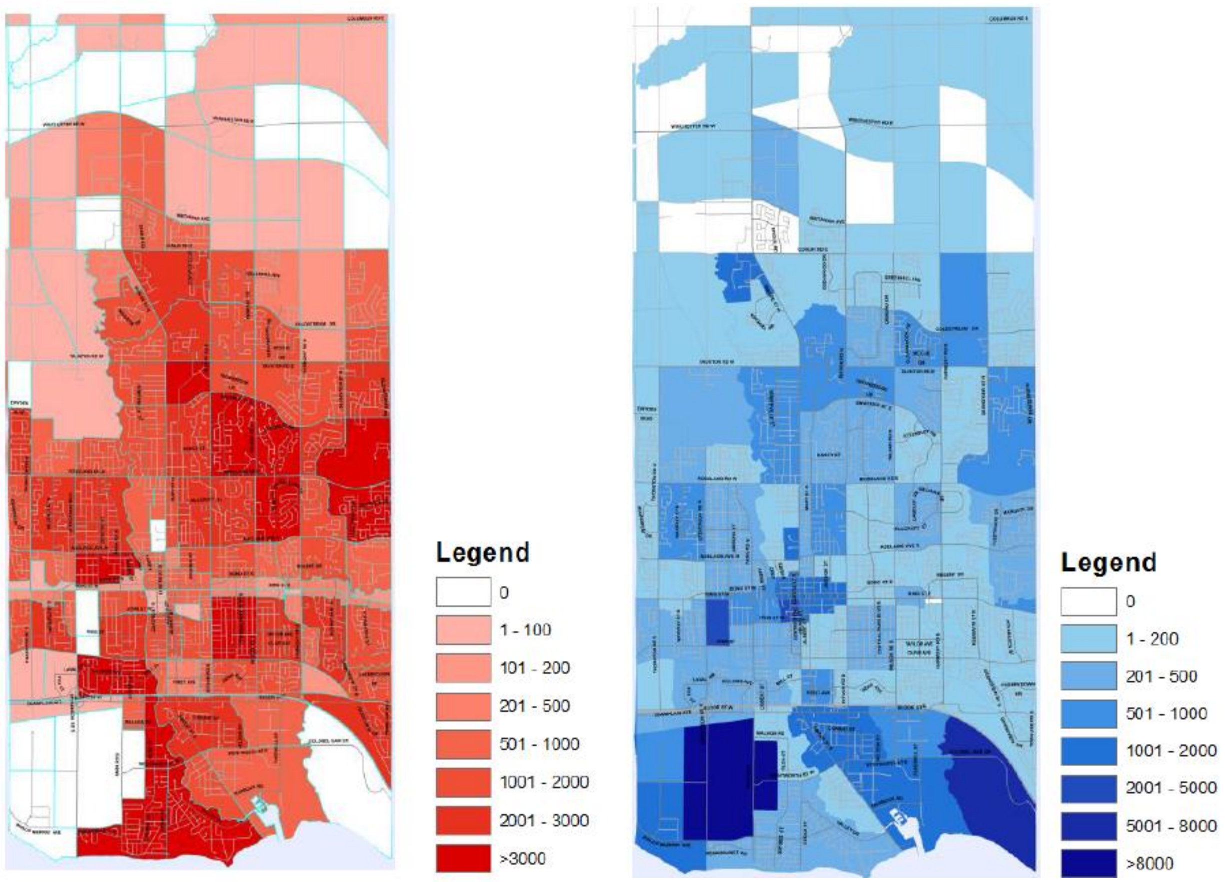
The multi-modal evaluation process aims to:

- Identify synergies, maximizing value and minimizing disruption;
- Integrate and encourage multi-modal planning;
- Mitigate the risk of new auto capacity being filled by induced demand; and
- Minimize subjectivity by relating the evaluation to independent plans and schedules.

Discussion

The performance of existing and future transportation networks can be evaluated by the use of travel demand modelling software such as EMME or TransCAD. The study area is broken down into transportation analysis zones (TAZs), as illustrated in Figure 1 below, and the level of population and employment for each zone is determined from census data for the existing scenario. The modelling of future time horizons is based on population and employment projections.

Figure 1: Example population (left) and employment (right) distribution by TAZ[1]



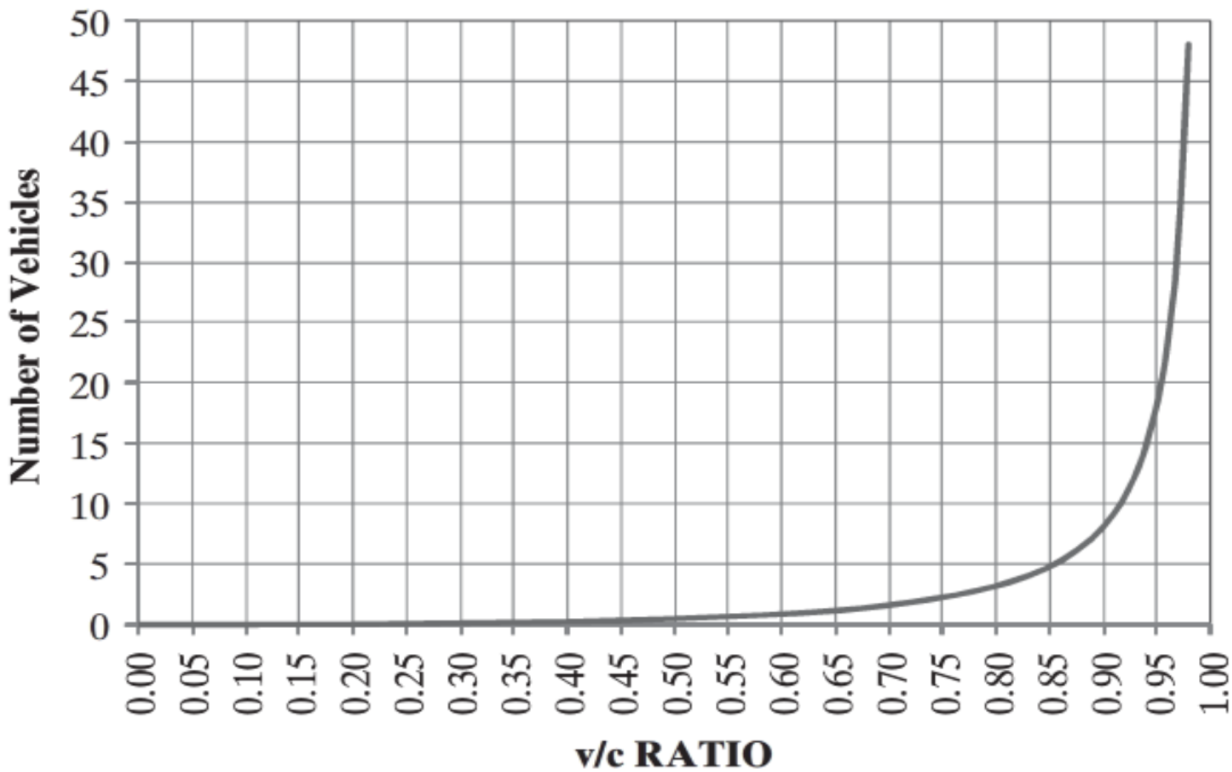
For each scenario in the travel demand model, the zones of population and employment are connected by links that represent the assumed roadway network. These links are assigned a throughput capacity in terms of vehicles per hour based on factors such as the number of lanes and operating speed. The software determines the most likely travel patterns associated with that combination of infrastructure and land use, and assigns traffic volumes (in both directions) to each of the links in the roadway network.

To determine the performance and potential for congestion for an individual link, it is necessary to compare the traffic volume assigned with the assumed capacity of that link to process those vehicles. This is known as the volume/capacity (v/c) ratio; a value of 1.0 indicates that the assigned volume is precisely matched by the capacity, and the link would be operating optimally under steady, consistent traffic flow conditions.

In practice, there is variability in vehicle arrival patterns, hence the link would oscillate between being under capacity when there are gaps in the traffic flow, and over capacity at other times when there are more vehicles arriving than the link capacity can accommodate. In the latter situation, a snowball effect may occur whereby the lack of spare capacity to absorb fluctuations in traffic flow can lead to the rapid formation of queues and the deterioration in the operation of the roadway.

To avoid this, it is recommended that the maximum hourly volume on a link be between 80% (v/c=0.8) and 90% (v/c=0.9) of its capacity, with the remainder acting as a buffer. As illustrated by Figure 2, queue lengths increase significantly for v/c ratios above this level under normal conditions where vehicle arrivals are random and there are no external controls on vehicle arrivals.

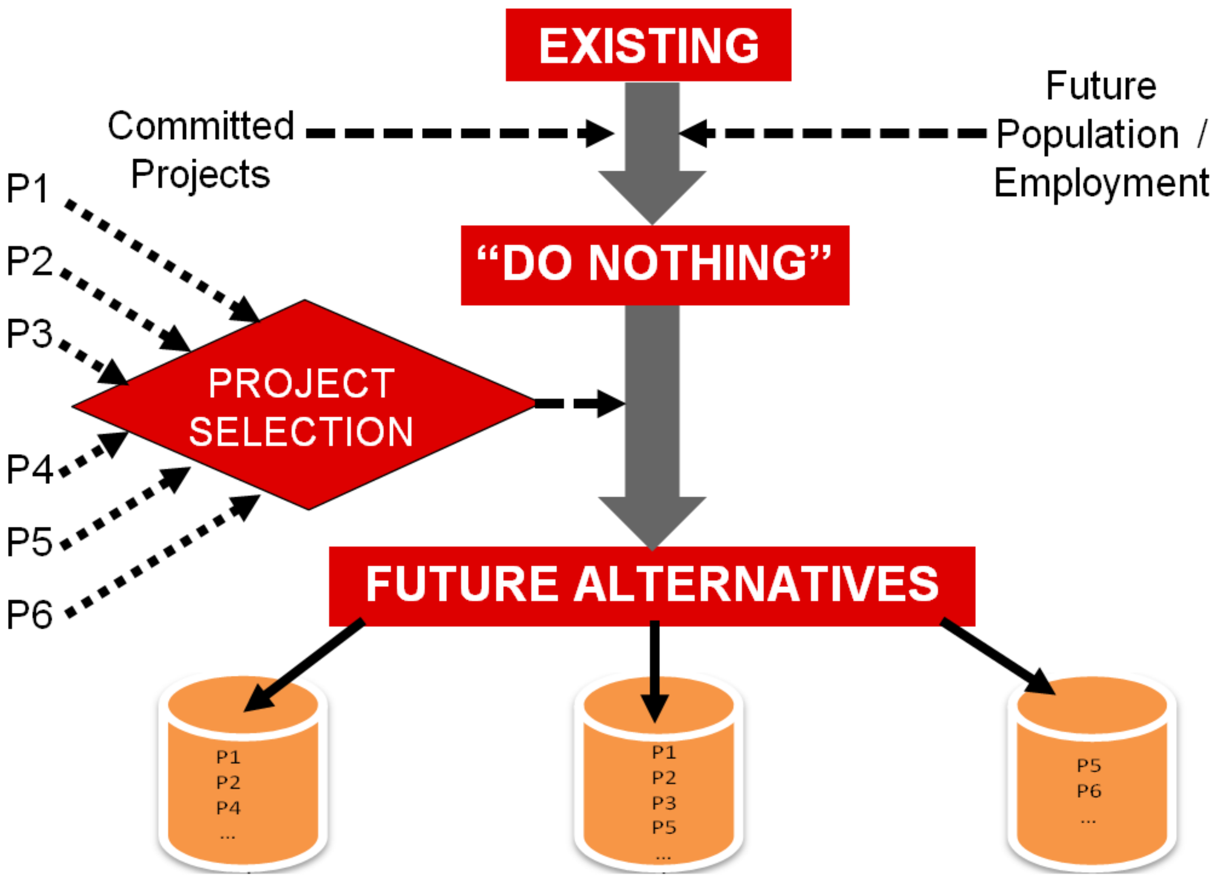
Figure 2: Expected Queue Lengths for Various Volume/Capacity (v/c) Ratios[2]



The transportation of people serves no purpose in and of itself; rather, it enables us to participate in activities at different locations. The most popular such activity is employment, hence overall travel demand is the highest during the weekday morning and evening rush hours, when the majority of office workers are driving from, and to, their homes. The other 158 hours of the week, the volume of traffic is typically lower and, in some cases, significantly so. However, this is the “worst case scenario” that is generally considered in modelling. If the network is able to manage the demand at these times, then it should operate acceptably the rest of the time.

Figure 3 illustrates the traditional approach to identifying the recommended network improvements. The 'Do Nothing' model, which includes population and employment projections, as well as road construction and widening projects that are expected to be in place at that point in the future, is run to identify the links with a high v/c ratio. The selected combination of improvement projects is typically one that reduces the v/c ratio of congested links by widening them to increase their capacity, or constructing new links that provide alternative routing options, thus reducing the traffic volume on the affected links.

Figure 3: Traditional Modelling Approach



The roadway network is commonly considered to operate like plumbing. When a pipe becomes blocked, the standard course of action is to locate the blockage and clear it. The expected result would then be a system that flows as well as it did before the problem arose. However, there is a key behavioural difference between the water molecules flowing through pipes and traffic flow on a highway. The former is governed by the laws of physics, whereas the latter is directed by human decision making.

Figure 4 shows example link structures representing a road network across three future scenarios. On the left side of the figure, the width of the lines signifies the number of lanes in each direction, and proposed improvements are highlighted in blue. On the right, the colours show the link volume/capacity ratios in the peak direction for each scenario, with red indicating that a link is expected to be congested.

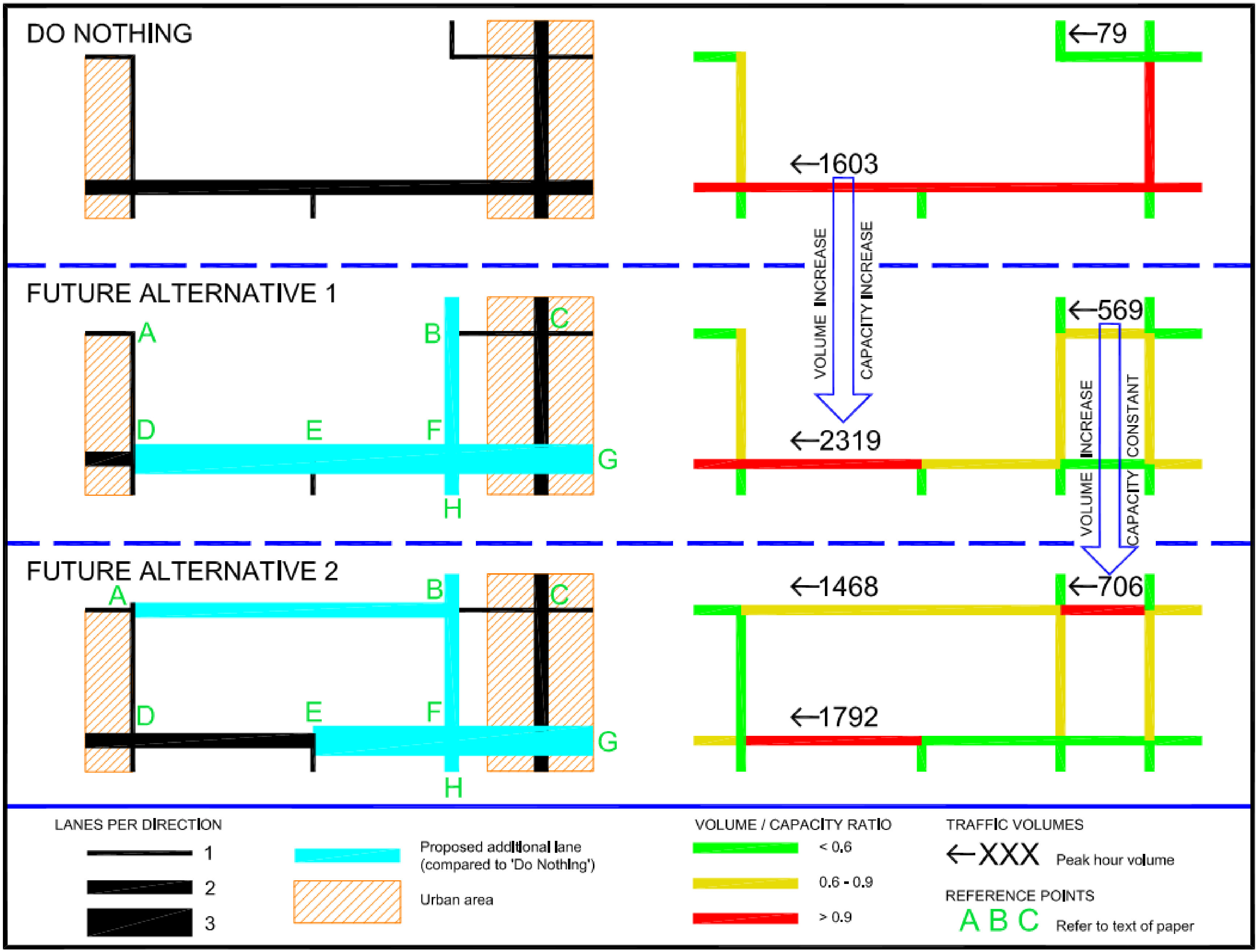
The top row of Figure 4 represents the Do Nothing scenario. The middle row relates to Future Alternative 1, in which an existing highway connecting two shaded urban areas is proposed to be widened from two to three lanes in each direction between points D and G on the figure. Since it is the only direct inter-city connection, the highway is expected to be congested in the Do Nothing scenario; however, following the proposed widening, parts of the roadway, EF and FG, will experience an improvement in performance and are respectively shown in yellow and green in the volume/capacity (v/c) plot on the right. On section DE this 50% increase in lane capacity, when combined with the construction of a perpendicular four-lane road BH, induces a 45% increase in volume from 1603 to 2319 peak hour vehicles. In this situation, almost all of the additional capacity provided by the road widening would be filled by the additional traffic volume.

The bottom row of Figure 4 shows Future Alternative 2, in which part of the existing inter-city highway, EG, is proposed to be widened. This leads to a significant improvement in performance on that widened section, with the v/c ratio dropping below 0.6 from a ratio in excess of 0.9 in the Do Nothing case. Although section DE is not proposed to be widened in this scenario, the additional demand attracted to the inter-city corridor results in a volume increase on section DE from 1603 in the Do Nothing scenario to 1792 in Future Alternative 2. This adds to a v/c ratio that is already above 0.9 in the Do Nothing scenario.

A second inter-city highway, AB, is proposed for construction in Future Alternative 2. The modelling indicates that, like on section DE, the through traffic pushes section BC, which would otherwise operate with a volume/capacity ratio below 0.9, into the red. Summing the inter-city volumes, it can be seen that there is more than double the demand (3260) than in the Do Nothing case (1603). Therefore, the new road AB in Future Alternative 2 will encourage more and longer commutes by car, requiring yet more infrastructure.

The significant investments associated with facilitating the movement of transportation network users are usually justified by the benefits that will result in terms of travel time savings. The assumption is that travel time is wasted and that commuters will always adjust their behaviour to minimize it. However, the logical extension to this is that workers would prefer to live as near to their work as possible, in which case most commutes would involve only a short walk from the closest residence. Figure 4 demonstrates that this is clearly not the case, hence the reality must consist of a balancing act between the competing desires to keep travel time as low as possible and the benefits that may be achieved from living some distance from work.

Figure 4: Example of induced demand affecting network performance following roadway improvements

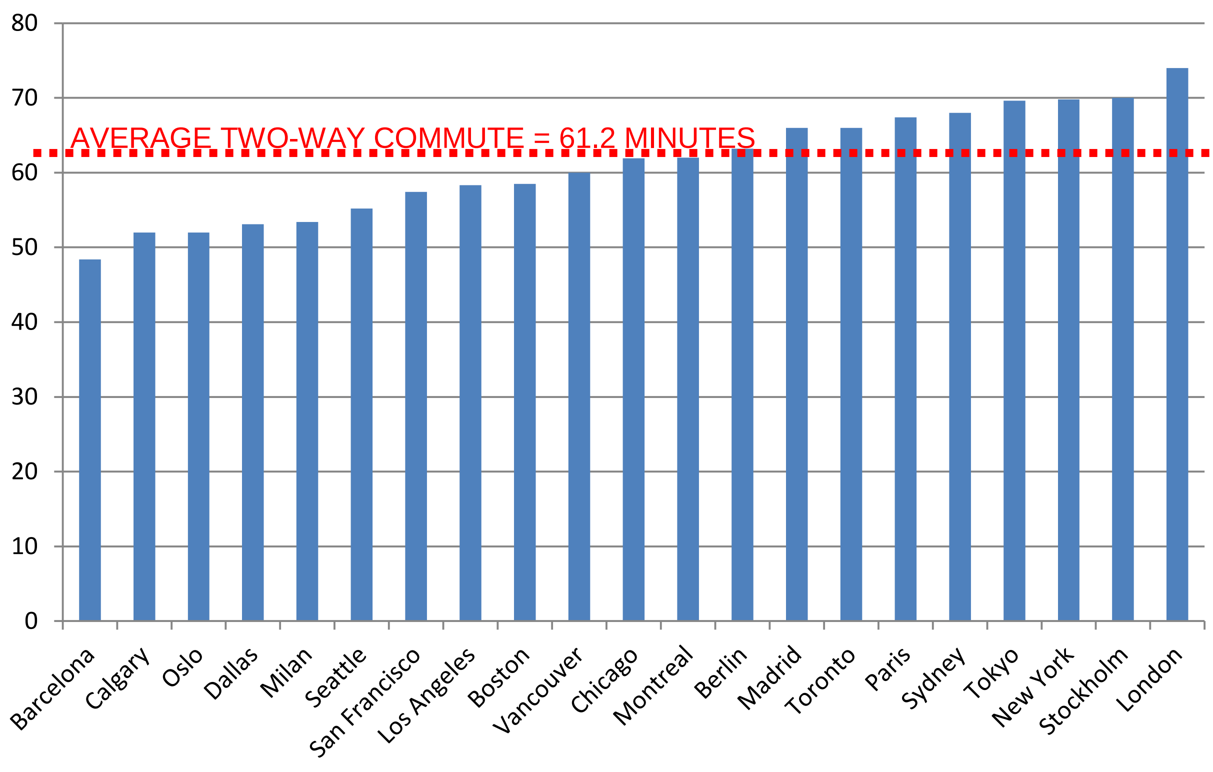


Like any product or service, demand for travel (and the activities to which it allows access) is sensitive to the associated costs incurred. Such costs can be measured in terms of money, time and other ‘disutilities’ that are traded off against each other.

It is hypothesized that there may be a fixed tolerance, or even a preference, for a certain quantity of travel time. This concept is known as a ‘travel time budget’ and can be represented by Marchetti’s constant[3]. This is based on primitive human psychology and estimates the optimum time for maintaining territory and gathering food, while limiting exposure to predators and other environmental threats, at approximately one hour per day.

Figure 5 below suggests that a similar timeframe applies to the modern day commute. This duration for the two-way travel time appears to be optimal when the associated perception of cost to the commuter is balanced against financial costs such as those related to accommodation, as well as individual lifestyle priorities.

Figure 5: Commute times for major cities (Two-way travel in minutes)[4]



So, if projects are not to be selected exclusively on the basis of volume/capacity ratios, then what criteria should be applied? The answer is to incorporate upgrades that make better use of the roadway by increasing its ability to move people. This means improving the infrastructure for transit and cycling, modes where each travelling person occupies a smaller area of road space than a solo driver.

This paper presents a methodology for identifying the projects that include synergies between modes, and free up the roads for other important functions such as freight movement. As well as the benefits of more efficient roadways, it also considers the costs of the improvement works in financial and environmental terms.

The project selection methodology is illustrated in Figure 6 overleaf. It relates to a system of evaluation that rates projects based on multiple accounts and then filters them according to their score. Selection criteria may include the following:

- **Support for Transit:** In rural communities, density and intensification targets can make the provision of express transit service between major settlements more feasible, in which case this account can recognize improvements on direct routes between primary settlement areas. In urban environments, where roadway and transit improvements overlap, points can be awarded to reflect potential running time savings along transit routes.

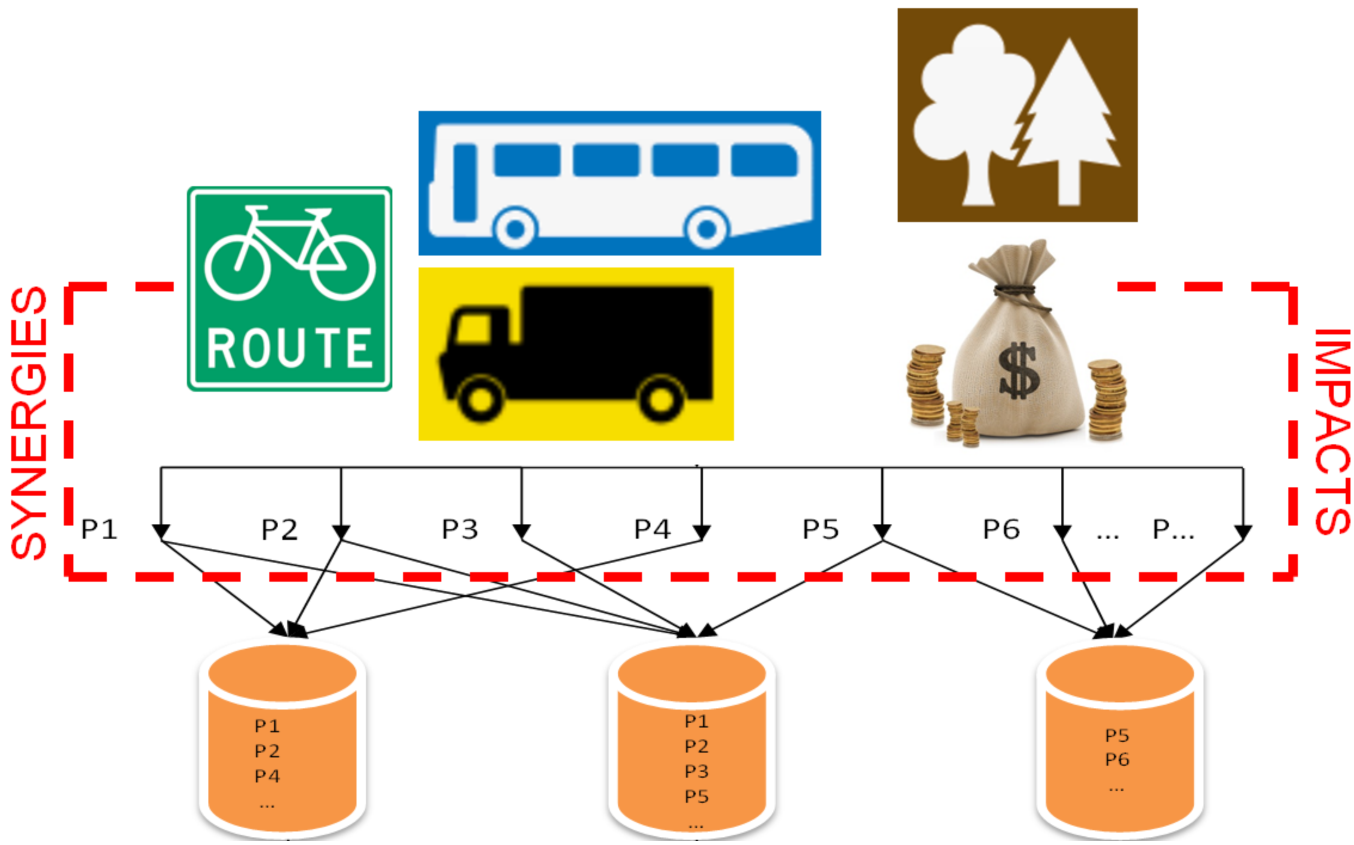
- **Active Transportation:** This identifies overlaps between road network improvements and active transportation projects, recognizing potential synergies by giving preferential scoring to road projects that have the scope to incorporate active transportation facility upgrades. Benefits may be found where on-road bicycle facilities are proposed and can be implemented at the time of the road widening, although these economies of scale may also exist for certain off-road sections.

- **Goods Movement:** This recognizes improvements that are proposed on roads identified as goods movement corridors, roads linking major settlements, or bypasses around smaller communities. Lower travel times for freight mean reduced overheads and benefits for the wider economy.

- **Environmental Impact:** This identifies the land use designations adjacent to the proposed improvements which may be affected by them. This may include, in decreasing order of environmental impact: settlements, economic/employment districts, rural/agricultural lands, areas that may carry a ‘greenlands’ or similar designation, and conservation areas.

- **Cost Effectiveness:** This is based on the implementation costs per kilometre. Although this will be a high level estimate, consideration should be given to the need for structures, large-scale earthworks and other aspects that may increase construction costs for certain routes.

Figure 6: Project Selection Methodology for Multi-Modal Evaluation



The choice of accounts will vary according to the local context and, before aggregating the scores, certain variables may be weighted if this is more reflective of stakeholder priorities. Potential improvement projects can then be evaluated based on these accounts. Candidate roads may be scored in blocks between major intersections, with values averaged across the length of the proposed project. Sections that form continuous routes may be grouped together as one project.

It should be noted that roads where Environmental Assessments (EAs) have been undertaken or are underway should be excluded from this evaluation, with decisions based upon the outcome of the more detailed EA process.

Table 1 below shows an example project scoring summary:

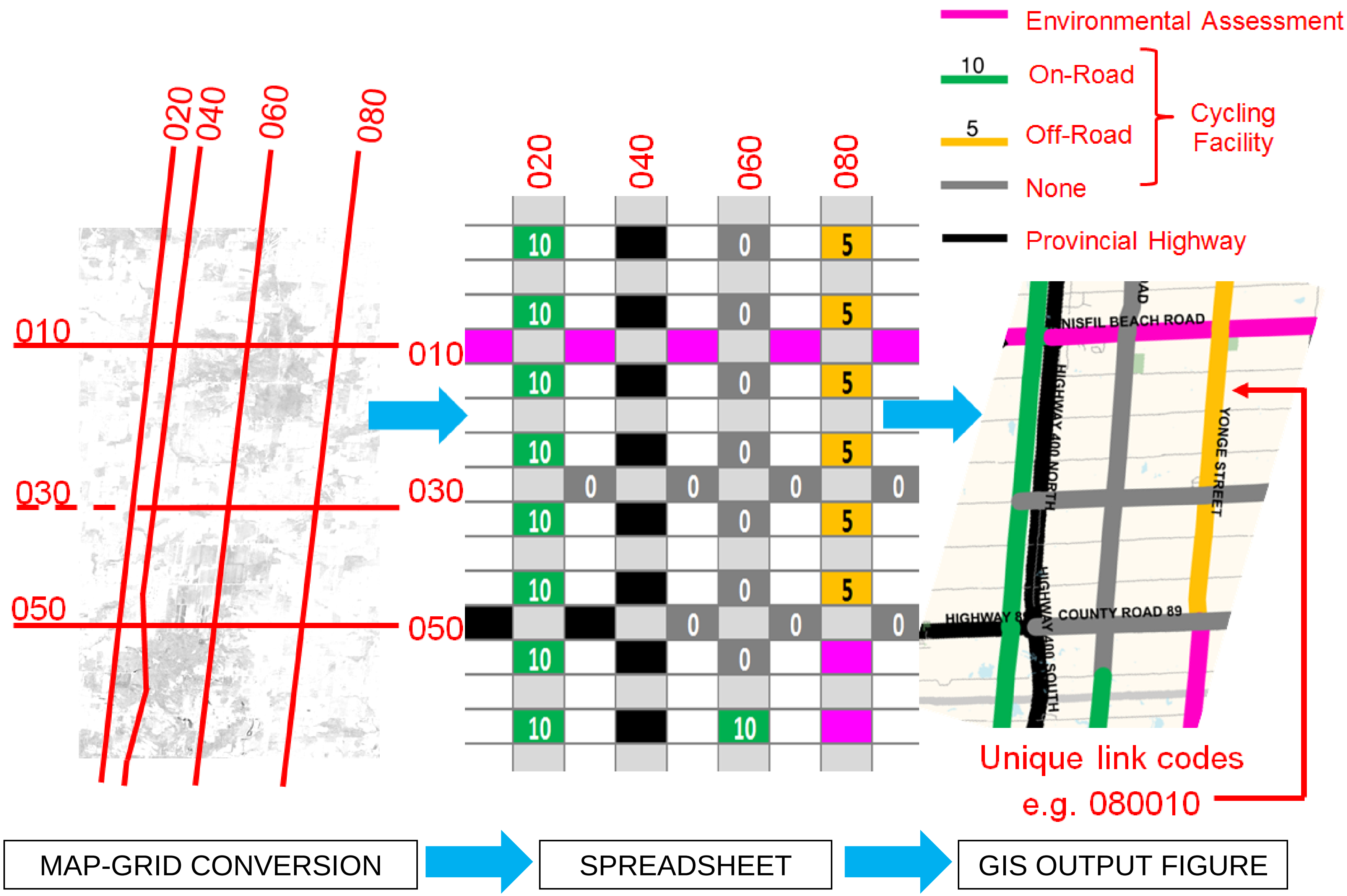
Table 1: Example matrix for multi-modal evaluation[5]

Road	Limits	Improvement 2011	Improvement 2031	Multi-Modal Evaluation GM	CON	AT	TRA	ENV	$	TOTAL
CR 44, Ramara	Highway 12 to Casino Rama	2	4	0	10	5	10	9.3	4	38.3
Line 7, Oro-Medonte	Highway 11 to CR 22	LOCAL	CR	10	10	0	1.7	5	8	34.7
Line 6, Oro-Medonte	CR 22 to Mt. St. Louis Rd.	LOCAL	CR							
Mt. St. Louis Rd, Oro-Medonte	Line 6, Oro-Medonte to Highway 400	LOCAL	CR							
CR 10, New Tecumseth	CR 14 to Highway 89	2	4	10	0	10	2	5.3	4	31.3
CR 27, Innisfil	CR 21 to CR 90	2	4	0	0	10	7	10	4	31
Flos Road 4 Springwater	Highway 93 to Springwater/ Clearview boundary	LOCAL	CR	0	4	10	0	6.2	8	28.2
CR 4, Innisfil	CR 89 to Barrie City Limit	2	4	0	1.6	5	9.4	6	4	26
CR 10, Clearview	CR 90 to CR 9	2	4	0	6	5	5	6	4	26
CR 10 Clearview	Highway 26 to 27/28 Sideroad/12 Conc.	2	4	0	0	10	5	6	4	25
CR53/Wilson Drive, Springwater	Ferndale Drive (Barrie City Limit) to Highway 26	2	4	0	0	10	1.5	10	3	24.5
12 Conc. Sunnidale Clearview	Springwater / Clearview boundary to CR 7	LOCAL	CR	0	4	10	0	5.7	4.7	24.3
5th Line, New Tecumseth/BWG	CR 10 to Highway 400	LOCAL	CR	0	4	10	0	6.3	4	24.3

To assist with the calculation process that arrives at an output like Table 1, a spreadsheet template has been developed. The methodology involves converting the road network into a grid layout that may be represented by the spreadsheet. Lines are drawn across the road map in two directions, predominantly horizontal and vertical, and grid reference numbers are attached as shown in Figure 7. Using a Geographic Information System (GIS) software package, the network is drawn with numbered links that are consistent with the grid references, and colours are assigned to point score ranges.

Scores for each link in the network are input on separate tabs of the spreadsheet file, and can be weighted, summed as in Table 1 above, and exported along with the unique link code based on the grid reference numbers. The table of codes and values can be imported into the GIS file, which will then be populated automatically. This process is illustrated in Figure 7.

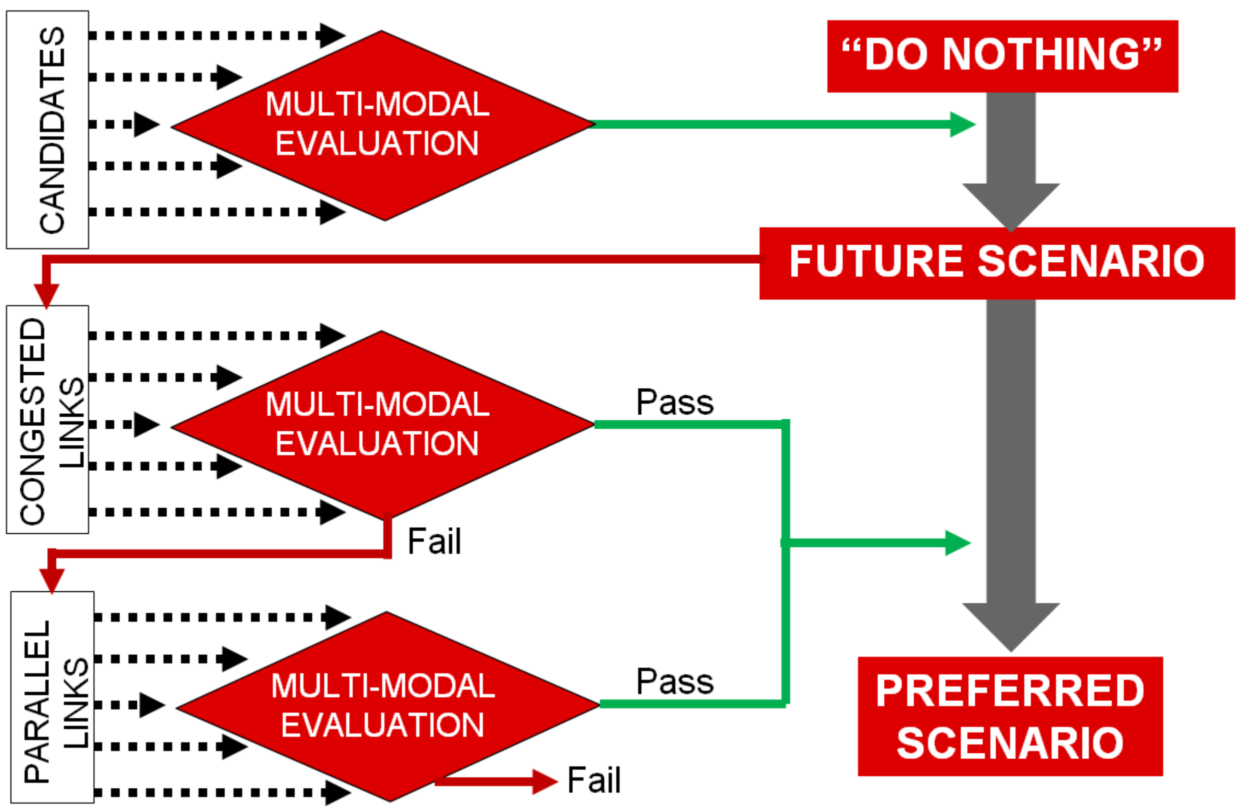
Figure 7: Score calculation and map production process (example: active transportation)



The projects selected by the aforementioned methodology can be incorporated into the Do Nothing model to create an alternative future scenario. This model can then be run to identify the links whose operation has improved, and those that will still experience congestion.

As previously described, the traditional approach to mitigating the congestion on links with volume/capacity ratios greater than 0.9 would be to simply widen the affected roads or construct new ones. The alternative methodology presented in this paper can be adapted as shown in Figure 8 to subject those red links to the multimodal evaluation. Those that score highly are recommended for widening. For those that score poorly, alternative improvements are investigated on nearby or parallel roads. Those alternatives that score highly can themselves be recommended for implementation in order to divert traffic away from the congested links while also improving the road network for other modes.

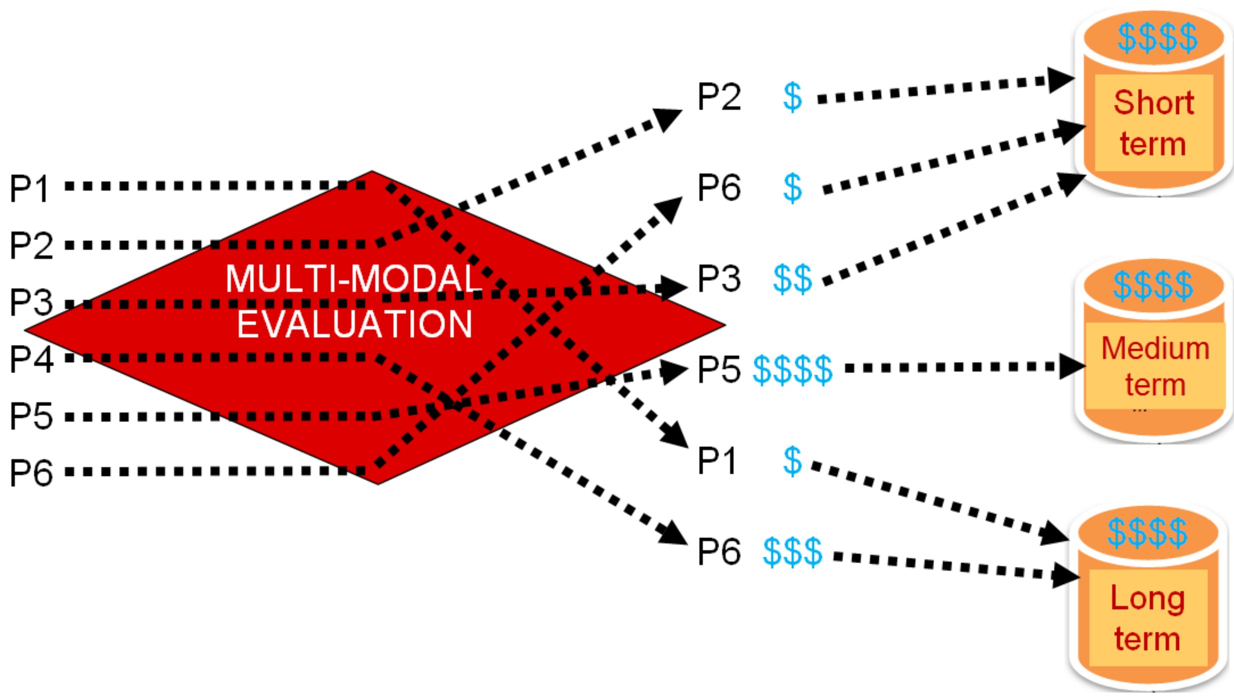
Figure 8: Project Selection Methodology incorporating multi-modal evaluation



Constrained resources and operational considerations mean that not all projects can realistically be implemented in the near term. Also, the need for network improvements will develop over time with changes in population and employment that influence travel patterns and demand volumes.

The set of recommended improvements may be broken down into short, medium and long term plans, with the cumulative value of the projects in each phase determined based on implementation budget projections. Projects can then be ranked according to their score from the multi-modal evaluation and their individual cost to implement. The highest scoring projects are assigned to the short term plan until the available funds for that phase have been exhausted. The remaining projects are deferred, first to the medium term plan and then to the long term plan, in accordance with the ranking of the projects and the budget for each phase.

Figure 9: Project Selection for Phased Implementation



The resulting groups of projects should be given a “sanity check” to ensure that inter-dependent projects are phased together or consecutively depending on their anticipated effects on traffic flow patterns on links elsewhere in the network. The review should also ensure that the size of individual projects or groups does not lead to an underspend in a particular period or result in significant gaps in the implementation schedule. Finally, projects should be appropriately distributed both geographically across the region, and in relation to the development of individual transit, active transportation and freight networks.

Conclusion

The common practice of trying to relieve congestion by widening roadways or building new ones can be self-defeating, encouraging people to drive further in order to meet their broader lifestyle objectives while maintaining a tolerable commute time. The roadway network may experience greater demand in terms of vehicle kilometres travelled, partially or even fully negating any benefits that may have been expected from the roadway improvements and the associated public investment.

As demonstrated by this paper and the accompanying presentation, more balanced and efficient roadway networks can be constructed by prioritizing projects that involve synergies with transit and active transportation improvements or free up capacity for freight movement, with due consideration for financial and environmental costs. The result will be effective and targeted investment in the development of sustainable transportation networks that operate efficiently for all modes and roadway users.

References

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