Planning and Transport Research Centre (PATREC)

CONGESTION ABATEMENT THROUGH TRAVEL DEMAND MANAGEMENT (TDM)

PHASE 1: REVIEW OF INSTRUMENTS AND TOOLS

REPORT B: REVIEW OF TDM APPRAISAL AND EVALUATION TOOLS

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1 INTRODUCTION

1.1 Background

The Transport Portfolio responded to the PATREC Strategic Business Plan 2013-2016 by identifying a range of research priorities, one of which was “Demand Management”, with the following component questions:

DM1: *What are the key demand management instruments available for managing transport congestion in Perth? What is the relative contribution that each of these instruments can make to reducing congestion?*

DM2: *What are the broader economic and social costs associated with demand management instruments (e.g. impact on CBD retail and social equity from implementation of congestion pricing schemes)?*

DM3: *What are the key lessons that Perth can learn from other jurisdictions regarding community acceptance and the successful implementation of demand management instruments?*

In response PATREC proposed a first phase of a broader project to study the relative importance of the range of factors that affect congestion, developing and applying a decision tool for decision-makers to assess the relative cost and benefits of a range of Travel Demand Management (TDM) measures in the abatement of congestion in Perth.

The goal of **Phase 1** of the project is to review the literature on TDM practices and tools employed in Australian cities and a selection of global case study cities. The objectives of the review are:

- **Report A** aims to develop a working definition of TDM, capturing various perceptions on what travel demand management is thought to be and compile a matrix of measures being implemented, including the circumstances and contexts of implementation and evaluation in various jurisdictions
- **Report B** (this report) aims to identify approaches to assess TDM policies targeted at congestion mitigation including measures of congestion.

Both parts of the review will lay the foundation for further analysis of TDM and its applicability to Perth in the proposed Phase 2 of the study.

1.2 Terminology

A number of terms are used throughout the report, each with a specific meaning:

- **TDM instrument** is a general term for a type of TDM policy that could be implemented by way of a specific TDM project or program.
- **TDM Project** is the implementation of a TDM instrument for a particular purpose, having a dedicated budget and a predetermined scope and end date in mind. After the project is implemented funds are spent on monitoring. At some time the project will be evaluated against anticipated outcomes.
- **TDM Program** is the ongoing effort to manage travel demand. A TDM program may be thought of as a series of TDM projects that include a cycle of appraisal, implementation, monitoring, evaluation and updating. An example of a TDM program is *TravelSmart* which has an ongoing budget for delivering personalised marketing projects.
- **TDM Policy** is the strategic targeting of an instrument or portfolio of instruments.
- **TDM Initiatives** is a generic term including TDM instruments, projects, programs and policies.
• **Appraisal**: The determination of the anticipated impacts, effectiveness and value of a TDM project or program. An *economic appraisal* is the processes of calculating monetary equivalents to the benefits delivered by the TDM project and comparing these with the implementation costs.

• **Assessment**: The comparison of more than one appraisal with the aim of recommending which to implement when (prioritisation).

• **Decision**: A commitment of funds and other resources to implement the chosen projects or programs.

• **Evaluation**: The measurement of the actual outcomes of an implemented TDM project against the stated targets.

### 1.3 Purpose

The purpose of this report is to give an overview of the possible appraisal tools, evaluation procedures, performance measures and congestion measures that may be used as the basis for selecting, implementing and reviewing TDM initiatives. This report provides an international review of the tools used to appraise the potential effectiveness of employing a particular TDM instrument (or suite of instruments) to a specified market, route or area. In addition, the report examines a number of evaluation cases where the actual performance of a TDM instrument was reviewed after its implementation.

This report concludes with an overview of congestion indicators and congestion measures used in TDM appraisal and evaluation to measure performance against the objective of congestion reduction. The report does not recommend an appraisal tool or an evaluation strategy, nor does it indicate which congestion indicator is appropriate to guide assessment of TDM projects. Phase 2 is aimed at making appropriate recommendations for the Perth context.

### 2 AUSTRALIAN NATIONAL GUIDELINES FOR TRANSPORT SYSTEM MANAGEMENT

#### 2.1 The Eight Process Decision Model and Transport performance procedure

The *National Guidelines for Transport Systems Management in Australia* (ATC, 2006) set out a decision framework which is top-down or strategy led. The guidelines aimed to provide a consistent framework and procedures to assist and guide transport planning. The eight process model can be broadly segmented into three stages of a top-down decision process:

**Strategy and Policy**

1. **Strategic Objective Setting** identifies the broad societal goals along with the contribution of transport objectives towards achieving good social outcomes. By setting targets and transport indicators the decision makers create a map between transport outcomes and the broadly defined objectives.

2. **Policy Choices** — perhaps not appropriately named — refers to the development of strategic priorities. For example are non-infrastructure investments preferred to infrastructure investments or ‘is private funding of transport infrastructure a priority?’. These policy directions guide assessment of transport initiatives at later stages in the decision making process.

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1 The Australian Transport Council no longer exists. In December 2013, the Council of Australian Governments (COAG) agreed to a new Council System, the Transport and Infrastructure Council.
3. *System Planning* is a long term vision of the way any investment will fit into the transport network. In general it is a strategic decision on what links, corridors or areas should take priority.

4. *Identifying Infrastructure and Non-Infrastructure Initiatives* is a process in which possible transport investments are brought to the table. The TDM review - Report A - is an example of identifying possible policy instruments which can be developed further to be proposed TDM projects.

**Appraisal and Assessment**

5. The *appraisal* process has three stages. At first a strategic merit test is used to identify projects that align with the strategic policy priorities (formed at the policy choice phase). This is a filtering process whereby some proposals are rejected without advancing to an elaborate and often expensive business case appraisal. The rapid appraisal stage is a preliminary cost benefit analysis with rough estimates of the costs, behavioural responses and the social benefit valuations. If a project is advanced beyond this phase a full cost benefit analysis should be undertaken and a business case is developed.

6. The *assessment* of the project proposals is a formal prioritisation of the projects by reviewing each case. Smaller initiatives may only include the strategic merit test. A schedule of investments takes into account urgency, budgets and funding opportunities.

**Implementation and Review**

7. The *project delivery* phase requires detailed planning. The planning should address the resourcing and funding of the project. The guidelines do not provide advice on project implementation.

8. *The review* of the project is a formal process of measuring the outcome of the project against the stated aims and forecasts. Whilst a review may look at the decision and implementation process, this is not the focus of this report. Reviewing the impact of a TDM initiative means measuring the observed outcomes against the strategic targets and transport indicators set in phase 1.

The review of TDM appraisal tools (Section 4) concentrates on the appraisal and assessment stages of the overall decision framework. However, policy support is considered (Section 5) and – based on the external review undertaken by Graham Currie – it is suggested that qualitative tools may support policy setting. A short review of monitoring and evaluation (Section 6) and the valuation of benefits and congestion indicators (Section 7) complete the report.
3 A GENERIC TDM DECISION FRAMEWORK

The primary focus of this report is to review a number of tools used to appraise TDM initiatives. However, the appraisal component sits within a broader decision-making framework that commences with the identification of priorities for the transport system framed as strategic or policy directions. These directions set the agenda for the appraisal and assessment efforts and inform the appraisal team of what nature of TDM projects are to be considered. At the appraisal stage an estimate of travel behaviour response is used to determine an anticipated effect on the performance of the transport system and subsequently the value of any benefits incurred. The assessment compares projects and helps prioritise projects in terms of their net benefits. While the assessment is limited to a recommendation, the decision is a commitment of funds to implement the project.

The effect of the TDM project is played out in the transport system in much the same manner as is modelled by the TDM appraisal. At the primary level travellers respond to the incentives or penalties introduced by the TDM instrument, in turn these choices affect the performance of the network and this change in performance yields the benefits to the affected parties. Whether or not the TDM project has the desired effect – meets the anticipated targets forecasted at the appraisal stage – is only known through some form of measurement in the change of the system’s performance. At the appraisal stage, specific metrics to be monitored need to be considered. Post implementation a monitoring phase needs to be undertaken. Evaluation is a comparison between the anticipated benefits and the realised benefits.

The generic TDM decision framework is presented in Figure 1 and its components are discussed below.

Setting the agenda through broad policy directions

Travel demand management instruments are implemented through particular projects. A TDM project involves a commitment of resources to either change the transport and land-use system or to affect travellers’ decisions through a marketing or information initiative. Proceeding the implementation phase there needs to be a policy commitment to employ one or more TDM instruments. For example a policy agenda may be to restrict parking supply in the CBD or to encourage cycling.

Examining the expected benefits through project appraisal, assessing the proposals and selecting projects

Following setting policy priorities, projects that contribute to the policy directions are identified. Each project is appraised by estimating the impact on the transport function. Firstly, the implementation of a travel incentive, disincentive or behavioural change intervention will cause some – a very small proportion in most instances – to change their travel patterns. Whilst the number of people affected may be a small proportion of the targeted community, their changes will have an effect on the overall performance of the system. If the response should be to cut one or two car trips per week, the system benefits from reduced emissions, noise, accident rates or congestion. The size of the impact depends on two things. Firstly, the magnitude of impact is due to the number of people that choose to change their travel behaviour (the demand response) and, secondly, the value of each behavioural change (the valuation of benefits). The aggregated benefits are compared to the implementation costs (cost-benefit analysis).
Assessment of the appraised projects may support a go/no go decision. In this case a single project is assessed and based on the project appraisal a judgment is cast on whether to implement the project. Alternatively, a number of potential projects drawn from the same policy direction (e.g. parking supply restrictions) may be assessed with the view to choosing the most cost effective alternatives. Finally, the assessment may aim to compare projects across policy directions. In this case, assessment may be thought of as allocating a finite budget to competing alternatives or TDM instruments. Assessing the projects provides a recommendation of which project to implement, or in which order to implement (prioritisation). The decision is a commitment of funds to implement projects.

Project Implementation
The implementation of the project is to deliver the TDM incentives, taxes and charges or behaviour change and information program. From an appraisal and evaluation standpoint, this represents the cost of implementation.

Response, System Effects and Benefits Realisation
TDM initiatives foster behaviour change, shifts in departure time, change of mode, shorter trips or telecommuting. In the longer term a TDM initiative may change vehicle ownership or workplace and residential location choices. Changes at the level of the individual lead to system performance improvements through the effect on aggregate travel. For example, the implementation of a TDM instrument may increase public transport ridership, improve the level of congestion in a part of the network or foster economic development at activity centres. The measurement of the direct physical effect support evaluation of the project, but they are not the benefits. The benefits are realised through improved economic outcomes to travellers (e.g., reduction in travel time and an improvement to transport system reliability), health outcomes (e.g., improved fitness levels and lower incidence of cardiovascular disease or type 2 diabetes), environmental outcomes (e.g., noise, pollution and greenhouse gas reductions) or wider economic impacts (e.g., improved business productivity). Economic appraisal is based comparing benefits and costs after converting benefits into monetary equivalents. However, quantifying benefits is an involved investigative process on measuring peoples’ willingness to pay. TDM appraisal may sometimes proceed without quantifying benefits and using subjective assessments or setting priorities.

Monitoring and Evaluation
Appropriate performance metrics are established prior to program implementation and monitoring is the mechanism of measuring the performance of the network in relation to those metrics. Evaluation is the comparison of the observed performance with the expected outcomes reported at the appraisal phase. Feedback to strategy and policy direction setting and appraisal is critical to reinforce or alter TDM approaches on the basis of evidence of actual achievements of TDM initiatives on the ground.
The following section provides a review a range of tools developed to support different critical stages of the Generic TDM Decision Framework - strategic policy direction setting, appraisal and evaluation tools.

**Figure 1: Generic TDM Decision Framework**

## 4 TDM APPRAISAL TOOLS

The descriptions of these tools are ordered by their level of sophistication in terms of estimating the impact of travel behaviour response and changes to the performance of the network. Participatory models and subjective assessments (Section 4.1) that apply subjective assessment are not evidence based tools. The impact on behavioural change and transport network effects is based on the opinions of the group of stakeholders brought together to assess the potential TDM projects. However, as is discussed when presenting short listing and rapid appraisal, the method can be coupled with evidence-based tools. Sketch models (Section 4.2) are evidence based, but most rely on elasticities from literature reviews or from locations other than the one in being analysed in the appraisal. Two of the sketch models only provide estimates for the number of targeted individuals that adjust their travel (behavioural response) and the other two models go onto compute the associated benefits in terms of emission reductions or monetary equivalents. Sketch models do not investigate the effects on the performance of the transport system. Two further models -- 4 step transport model and activity based model -- are considered in Sections 4.3 and 4.4. Each model imbeds the TDM benefits calculations into existing transport models for the site of the analysis. These models are superior to sketch models in two important ways. The first is that the behavioural responses are calibrated to data collected in the location under review and each computes any network affects, which takes into account congestion at the traffic assignment step.

**Valuation of TDM benefits:** Most of the TDM appraisal tools reviewed here do not provide a full cost-benefit approach which is most commonly employed for road and rail investment; the exception being TRIMMS which includes valuations for emissions, congestion abatement, health...
impacts and noise. That is not to say that the benefits due to the estimated travel behaviour change cannot be calculated in a subsequent phase. However, the conversion of benefits into monetary equivalents is not part of the models. The review extends to identification of benefits as well as some monetary values for the more commonly used benefits identified for transport investment appraisal (Section 4). The review covers nine benefits in which appraisals may be based.

**Cost-Benefit analysis in TDM appraisal:** Cost-benefit analysis quantifies and then compares the cost and benefits of the TDM project. The analysis incorporates non-market benefits and costs such as safety improvements, environmental pollution and increased accessibility. The monetary equivalents are estimated using marginal willingness to pay (WTP) measures – usually derived from discrete choice models. A review of the relevant willingness to pay measures is given in Section 4. The cost-benefit approach makes use of appraisal tools as described earlier to estimate the behaviour change and its impact on the network performance. This impact is then converted into dollar amounts using marginal WTP values.

As benefits accrue at different rates for each project a present value for costs and benefits is calculated. The present value (PV) or present worth of a future benefit or cost is its discounted value at the present day. The discount rate used for economic appraisal by state governments in Australia is around 7%.

Cost-benefit discounting is a way of organising and reporting the value of the project. On its own it is not a TDM appraisal tool as the full analysis needs to provide estimates of behaviour change and the impact on the transport network. The NZ Transport Authority requires cost-benefit analysis and provides agencies with a sketch model similar to (New Zealand Transport Agency 2010).

**Assessment and decisions:** The review does not extend to detailing and comparing transport authority manuals on appraisal. However, should Phase 2 of the project extend to suggesting a decision framework, the most advanced appraisal manuals are Volume 2 of the Economic Evaluation Manual, New Zealand (New Zealand Transport Agency 2010) and the Transport Business Case, United Kingdom (Department for Transport, UK 2011). The Australian Transport Council issued a set of decision framework recommendations (ATC, 2006 Vol 2) and appraisal standards (ATC 2006 Vol 3). The national standards for New Zealand, the United Kingdom and Australia follow the generic decision framework as outlined in Figure 1.

It must be noted that some of the tools included in this section on appraisal tools, are actually named as “evaluation” tools. In accordance with the terminology used in this report, clarified in Section 1.2, if the tool is aimed at determining the anticipated impacts, effectiveness and value of a TDM project or program, it is considered an appraisal tool.

### 4.1 Community Participatory Models and Subjective Assessments

#### 4.1.1 Importance-Performance Analysis (IPA)

Selection of relevant TDM instruments may be performed through subjective assessment of the importance of the attributes delivered to the community by a specified TDM instrument (Ko et al., 2009), i.e. experts and citizen groups rate the importance of the instrument components. Whilst the survey instrument does not explicitly relate travel behaviour change with importance, it can be reasonably argued that the transport expert group would equate importance with effectiveness (to induce travel behaviour change) and the community respondents would see importance as being a measure of desirability. Performance refers to the current assessment with a particular aspect of the transport network (e.g., the level and distribution of congestion charges). The IPA tool appears to rely on a notion of satisfaction in which the community express their desire to see improvement in
an aspect of the transport system (this may be loosely thought of as expectations) and their assessment of the current performance of that aspect (related to experience). Satisfaction is equated to the difference between expectations and experience.

The importance-performance analysis (IPA) highlights that TDM effectiveness is sometimes explored by asking stakeholders (transport experts and citizens alike) their opinion on what TDM they consider to be most effective. In the Seoul case study (Ko et al., 2009) it is clear that investment in improving the transport services or reducing the cost of public transport were preferred by experts and the community. Conversely, the provision of cycling facilities was the lowest on their list of priorities.

4.1.2 Short-Listing

In a similar way to IPA, Rose (2007a, b) suggested an approach to short-list the possible solutions to a transport problem. The assessment technique asks stakeholders to identify TDM instruments that they believe to be effective (at creating the desired travel behaviour change or achieving a specified benefit). The tool is not strictly evidence based as they rely on expert opinion and community priorities. However, it is thought that the short listing tools can be a first step in the process in that it identifies a number of TDM candidates that warrant further analysis by way of rapid appraisal (or rough cut cost benefit analysis). Short listing and rapid appraisal approaches differ from the top down approach outlined in Figure 1, as problem identification rather that policy guidance is the starting point for the use of the tool.

Short-listing potential TDM projects requires a subjective rating of the potential outcome from employing the instrument, as well as their confidence that implementation will be achieved. While the method is a subjective appraisal, it is meant to ‘reveal a number of candidates that warrant further analysis’ (Rose 2007b, p. 11). The outcome criteria is scored at two levels, firstly at how effective the TDM instrument is at managing demand (e.g., shifting car travel to other modes or time of the day, or optimising existing infrastructure). At the second level the contribution of the initiative towards achieving economic, environmental or social aims is queried. For example, improving traffic efficiencies by means of an active traffic management initiative may score highly on the economic scale, but poorly on the environmental and social scales.

The shot listing method outlined by Rose (2007) does not detail a way to prioritise social, environment and economic outcomes in order to provide the rankings of alternative TDM projects. It is assumed that decision makers are relying on subjective weights to prioritise the broadly specified goals (social, environmental and economic outcomes) as well as subjective assessments on how well each alternative performance on each goal. The branch of decision science that details this method into a mathematical model of priorities and performance is known as multi-criteria analysis (MCA) and is outlined below in Section 4.1.3. Rose’s (2007) paper suggests that each of the short listed alternatives could be examined further by a rapid appraisal analysis. The rapid appraisal approach makes us of a cost benefit analysis.

4.1.3 Normative Group Techniques and Delphi

The normative group technique (NGT) and the Delphi method are group decision tools that aim to improve inclusive decision making. For each technique participants are offered the opportunity to contribute their ideas without having to speak up in a group setting.

NGT sets aside time for participants to write their ideas or solutions before these are shared with the group. Anonymity is encouraged. The individual contributions are discussed and general themes or solutions are formed. The themes are prioritised by way of voting. Currie and Tivendale (2010)
applied NGT to intermediate stakeholder engagement exercises within a broader effort to reorganise Melbourne’s 330 bus routes. The engagement exercises helped set policy priorities, such as providing public transport services in the evening and on the weekend. However, analytical and demand forecasting techniques were used to establish the revised bus routes.

The Delphi method uses repeat questionnaires to gather considered opinions and forecasts from a panel with expertise in a particular field. After each round of survey responses, panellists may adjust their opinion based on their reading of other panel members’ contributions. The panellists are usual not identified and the responses in each round can be the unedited versions of all contributions or a moderated summary of the responses. The process aims to reach a consensus between the experts. Unlike NGT, short listing or IPA, the participants in the Delhi panel are not necessarily part of the decision making organisation or within the community affected by the decision.

Delphi is often used in long term decision contexts where the outcomes are ambiguous and not easily modelled by quantitative techniques, such as land-use feedback to transport infrastructure (Schuckmann et al., 2012). However, Still et al. (1999) found that planners were unconvinced by the outcomes of the Delphi method and trusted the output of a land-use transport interaction model. It was also noted that the Delphi panel exhibited personal bias against certain policies. Despite the drawbacks of community engagement or expert opinion approaches, Lemp et al. (2008) concede that these techniques have a place in settings where the analytical models are based on weak behaviour evidence or the planning horizon is for the long term.

4.1.4 Multi-Criteria Decision Analysis

Multi-Criteria Analysis accounts for the trade-offs inherent in complex decisions. The methodical contribution of MCA tools is to elicit priorities from decision makers with the aim to uncover decision weights that accurately reflect the decision maker’s priorities. A number of methods have been proposed to elicit priorities and to score alternatives. The simplest being the additive utility method. Whilst being easily understood by decision makers the additive utility model is often criticized because the both the priority weights and the performance measures are subjective. However, despite their overwhelmingly complex mathematical presentation, the advanced decision models – like analytical hierarchical processing, AHP – calculate the decision scores using subjective priorities and performance measures. Berrittella et al (2007) report the use AHP to the prioritisation of TDM policies aimed at addressing climate change. The policy alternatives, such as “tax schemes aiming at promoting environmental-friendly transport modes”, are too broad for appraisal. The outcome of the exercise is to identify which policy areas require further investigation.

Multi criteria decision tools – including short listing and importance performance analysis – rely on subjective assessment and expert opinion. These are not evidence based tools and should not be used to appraise individual TDM projects. Currie and Tivendale (2010) show that the group decision techniques are appropriate tools to facilitate stakeholder engagement, but these exercises would fit into a wider assessment of transport alternatives. The brief review of community participation models and subjective assessment indicates that these tools may play a role when identifying decision makers’ policy priorities (i.e. at the upper level of the decision framework in figure 1.) but are not necessarily appropriate to appraise individual travel demand management initiatives.

4.2 Sketch Models

For TDM instruments that have a low cost of implementation (when compared to road or rail expansion), a sketch model may be appropriate. Sketch models aim to provide decision makers with a rough estimate of travel behaviour change in response to the implementation of a TDM
instrument. The models import behavioural parameters from reviews of TDM studies. In many cases these parameters are transferred from other settings, and as such, have not been calibrated to the region in which the model is to be applied. Whilst all sketch models provide estimates of travel behaviour responses, they vary in the level of detail used for the base case. The TDM Evaluation Model (section 4.2.1), COMMUTER (4.2.2), and The Trip Reduction Impacts of Mobility Model (TRIMMS, Section 4.2.4) were developed primarily for workplace TDM project and usually require the baseline data of current commuter pattern of affected employees. The TDM Evaluation Model may be extended to local area analysis, in which case, zone-to-zone trips by mode split describe the base case. Washington State’s TDM Effectiveness Estimation Methodology (TEEM, Section 4.2.3) incorporated integrated land-use and transportation initiatives, in which case the base case scenario required information about land-use patterns (employment density, provision of parking etc.).

The second difference between models is the extent to which the benefit calculations are embedded into the models. The TDM Evaluation Model and TEEM provide estimates of behavioural response, leaving it to the user to compute any benefits associated with this change using another platform. COMMUTER imputes the reduction of total emissions for a number of pollutants based on travel behaviour change estimates. TRIMMS provides the most flexible platform for including benefit calculations. However, it does require the user to import the benefits (negative costs as savings per vehicle trip).

The development of sketch models appears to have been principally undertaken in the US and the tools are tailored to workplace incentives for employees to choose alternate commuting modes to the car. The earliest of such models is the US Federal Highway Association’s TDM Evaluation Model.

**4.2.1 Rapid Appraisal**

The rapid appraisal method is adopted from a part of the three-stage filtering process as outlined by ATC (2006). At the first stage the *strategic merit test* determines whether a proposed TDM project aligns with the strategic priorities of the relevant decision authority. A rapid cost-benefit analysis (CBA) is applied to the alternatives that pass the strategic merit test. Whilst not stated it appears that Rose’s (2007) short-listing of alternatives acts as the strategic merit test and TDM candidates that pass onto the next phase can be analysed using rapid CBA. At the time of the article Rose indicated that there had been little experience with applying CBA to TDM projects. However, sketch models as described below could be used to undertake rapid CBA.

**4.2.2 US Federal Highway Association’s TDM Evaluation Model**

Developed by the COMSIS Corporation in 1993, the TDM Evaluation Model provided support to employers to appraise workplace TDM project such as carpooling programs or flexitime. The model was also designed to support local government decision on instruments such as parking regulations, HOV lanes or improvements to public transport.

The model used a baseline travel matrix. For local government the baseline travel data would be traffic generated from a specified origin arriving at a particular destination (O-D pairs) by mode. Workplace baseline matrices record the commuting trips made by employees to the site. Strategies that affect either travel time or travel cost are examined by way of logit pivot tables. These make use of the current trip times and cost for all travel modes and estimate the mode shift due to the changes in trip conditions that are attributable to the TDM instrument. Responses to workplace initiatives that do not directly affect travel times or costs are computed by way of a look-up table that matches the type of TDM instrument with an appropriate response parameter (elasticity).
Summary information for the TDM Evaluation Model

**Strategies Addressed** - Improved transit; HOV lanes; carpooling and vanpooling promotion; telecommute and work hour strategies; pricing and subsidies.

**Methodology** - Strategies that affect the time and/or cost of travel are evaluated using a "pivot-point" mode choice model. It requires information on baseline mode shares and changes in travel time or cost. Other strategies, such as employer-based support programs and work hour shifts, are evaluated using lookup tables based on empirical evidence.

**Data Requirements** - Baseline travel data requirements include zone-to-zone person and vehicle trip tables for the analysis area. Default parameters model impacts TDM instruments. The user has the option to change default parameters affecting strategy effectiveness.

**Outputs** - Changes in modal share, vehicle-trips, VMT, average vehicle occupancy and ridership.

**Limitations** – Transferability of parameters are not tested. Program does not provide valuations of terms business, social or environmental benefits.

**Level of Effort** - The TDM model is easy-to-use, off-the-shelf software. Some effort is required to develop inputs in the form of matrices showing the number of trips by mode and the distance between each pair of zones.

Source: [http://www.fhwa.dot.gov/environment/air_quality/conformity/research/transportation_control_measures/emissions_analysis_techniques(descriptions_tdm_evaluation_model.cfm](http://www.fhwa.dot.gov/environment/air_quality/conformity/research/transportation_control_measures/emissions_analysis_techniques(descriptions_tdm_evaluation_model.cfm)]

### 4.2.3 COMMUTER

The US Environment and Protection agency’s (EPA) COMMUTER model is designed to evaluate workplace or local government area TDM programs. The model provides an estimate of the behavioural shift away from SVO commute resulting from the implementation of a TDM instrument, as well as a calculation of emission reductions. The model does not take into account any network effects – such as induced traffic – and is generally applied to a single worksite or an employment centre.

The model is based on broad categories, considering whether the instrument/strategy affects employees’ travel costs or travel times or refers to ‘soft’ (non-financial) changes. For changes to travel times or costs the model uses a logit pivot table and for ‘soft’ changes the model uses look-up tables:

- **Logit pivot table:** is a multinomial logit model based on imported parameters. The travel cost or travel time changes are applied to each commute and probabilities of choosing a new mode or other travel arrangement are computed.
- **Look-up-tables:** The change associated with a particular intervention. The response parameter is also dependent on the level of intensity.

The model applies at the work setting whereby the decision maker:

- Provides the current commuting information, such as mode split;
- Chooses a TDM from the available menu;
- Computes the expected behavioural change based on the logit model or the look-up table parameters;
• Calculates the benefits associated with this change (i.e. change in emissions).

**Summary information for the COMMUTER Model**

**Strategies Addressed** - Improved transit; HOV lanes; carpooling and vanpooling promotion; bicycle and pedestrian programs; telecommute and work hour strategies; pricing and subsidies.

**Methodology** - The data and methodologies used to estimate travel impacts are similar to (the same as) those in the TDM Evaluation Model. Emission changes are based on changes in trip s, vehicle miles travelled (VMT), and speed, using lookup tables derived from MOBILE5a.

**Data Requirements** – baseline population and trips by mode. Estimated changes in travel time and cost by mode; and description of other (non-time/cost-based) TDM programs. The user has the option to change default parameters.

**Outputs** - Changes in modal share, vehicle-trips, VMT, and emissions.

**Limitations** - Transferability of parameters are not tested. The software does not address a portfolio of TDM’s. The ability to manage scenarios is also limited.

**Level of effort** – Relatively easy to use.

**Source/Availability** - The EPA TCM/Commuter Choice Model was developed in 1998. The COMMUTER 2 was released in 2002. It appears that the model is no longer supported. The model was interfaced with EPA’s current MOBILE6.2 emission factor model.

### 4.2.4 TDM Effectiveness Evaluation Model

TDM Effectiveness Evaluation Model (TEEM) was developed by the Washington State Department of Transportation as an analytical tool to assess the impact of TDM and land use strategies in the Central Puget Sound Region (Winters, Hillsman et al. 2010). The TEEM model uses local data sources and is able to assess the effectiveness of 20 TDM and land-use strategies applied to activity centres in a corridor of planned highway reconstruction. Potential changes in vehicle trips due to these strategies are separately estimated by different methodologies. Using the assumption of interaction the model is capable of evaluating the combined impacts of different strategies. However, this has to be done by incrementally applying the sensitivity factors to the base mode shares. This elasticity-based spreadsheet model is very simple and user-friendly tool. However, it can mask real complexities of some inter-related strategies and therefore the users of the model need to be aware of when such interaction may be occurring and readjustment in the base mode shares are needed.
Summary information for the TEEM Model

**Strategies Addressed** – It measures the effectiveness of 20 TDM and land-use strategies applied to activity centres in a corridor of planned highway reconstruction.

**Methodology** - TEEM is a post-processor spreadsheet-based model, which includes price and service point elasticities of demand to estimate potential changes in vehicle trips from the TDM measures.

**Data Requirements** – It uses elasticity parameters from case studies.

**Outputs** - Potential changes in vehicle trips.

**Limitations** – The evaluation of joint impacts of different strategies has to be done by incrementally applying the sensitivity factors to the base mode shares.

**Level of Effort** - Very simple and user-friendly tool. However, the users of the model need to be aware of interactions between strategies and readjust the base mode shares.


### 4.2.5 Trip Reduction Impacts of Mobility Management Strategies (TRIMMS)

The National Centre for Transit Research and the Centre for Urban Transportation Research at the University of South Florida developed the TRIMMS (Trip Reduction Impacts of Mobility Management Strategies) model to evaluate the full benefits and costs associated with the TDM projects that particularly focused on mobile source ozone reduction strategies (Concas and Winters 2012). The TRIMMS development project was funded by the Florida Department of Transportation and the US Department of Transportation to enable transit agencies and location communities to quickly estimate the impacts of TDM projects, including support initiatives such as rideshare matching services, employer-based subsidies to promote public transport (alternative work schedules), parking pricing, pay-as-you-go pricing, and other financial incentives.

TRIMMS estimates changes in mode share, trips, VMT, and changes in relevant cost externalities associated to a TDM project (noise and air pollution, added congestion, excess fuel consumption, global climate change, health and safety). Changes in mode share, trips, and VMT are estimated using constant elasticity of substitution parameters obtained from past empirical evidence. However, the social costs associated with the changes in the externalities are estimated using a spreadsheet-based sketch-planning model. In order to evaluate the cost effectiveness of the project, TRIMMS produces a benefit-cost ratio (BCR). The total annual benefits from a TDM project are calculated by summing the daily reductions in the social costs over the number of working days (235 days) in a year. To transfer all input costs in current dollars TRIMMS uses the Consumer Price Index (CPI) and a discount rate of 4%.

The NZ Transport Authority has adopted a sketch model similar to TRIMMS (New Zealand Transport Agency 2013). However it is not always clear that the spreadsheets offered provide an estimate of travel behaviour change or whether the user must import these estimates from another analysis. The spreadsheets do provide benefit valuations and a cost benefit analysis.

The latest version of the TRIMMS has functionality to conduct a sensitivity analysis. TRIMMS uses a Monte Carlo simulation technique to provide more robust estimates of the benefit-to-cost ratio. Using the simulation technique, TRIMMS is able to provide statistical confidence of obtaining a certain benefit-to-cost ratio in case the project is repeated over and over again.
### Summary information for the TRIMMS Model

**Strategies Addressed** - Alternative work schedules include compressed workweek, flexible working hours, and telework. The rideshare and vanpool initiatives offer a guaranteed ride home. Worksite amenities refer to the provision of childcare facilities and the presence of sidewalks connecting transit stops to the worksite. Further policies for analysis include employer-based subsidies to promote public transport use, parking charges, pay-as-you-go pricing, and other financial incentives.

**Methodology** – From entering the year of analysis and the metro statistical area, TRIMMS updates all input cost parameters in time and based on the geographic area of the project. Users have to select one of the 85 metropolitan statistical areas from the U.S. census region. Next, the users define the project characteristics, the baseline mode shares and trip length. American Community Survey three-year average (2005-2007) and trip length by mode from the National Household Travel Survey offers the default values but users can input their own values. Users select any employer support instruments and if public transport access and changes to travel times. The behavioural response level is estimated monetary equivalent benefits are computed. The cost effectiveness of the project is evaluated using a benefit cost ratio: the sum of the daily benefits for 235 working days over the project costs. The Consumer Price Index (CPI) and a discount rate of 0.4% is used.

**Data Requirements** – The changes in mode share, trips, and VMT are estimated using trip demand functions that rely on constant elasticity of substitution parameters. The elasticity parameters were obtained from past empirical evidence. The social costs associated with the changes in the externalities are estimated using standard unit cost of those externalities that were obtained from different sources.

**Outputs** - TRIMMS provides three different output tables. The first output is about the changes in travel behaviour due to a project: changes in mode shares, the number of round trips, miles of travel between baseline and final values. The second output table shows changes in social costs generated by a project and its impacts on single occupancy vehicle (SOV) travel behaviour. Finally, it provides annualised costs, benefits, net program benefits, global climate change, and BCR to evaluate project’s cost effectiveness.

**Limitations** – Like other sketch-planning tool, TRIMMS has limitations. One limitation is the use of elasticities to measure travellers’ responsiveness to price and travel time changes. Another limitation is in the estimation of global climate change impacts. It only considers the marginal damage costs associated with CO₂ emissions, while other authors provide more comprehensive estimates of greenhouse emission costs.

**Level of Effort** - TRIMMS simplifies the quantification requirements for TDM programs by making careful simplifications, as well as enhancements.


### 4.3 Four-Step Travel Modelling

The sketch planning tools presented above (TDM, COMMUTER, TEEM, and TRIMMS) do not use the full advantage of four-step transport planning models within their frameworks. However, it was recommended by the TRIMMS developers that four-step models should be incorporated into the assessment process to assist transportation planners in estimating the impacts of TDM on traffic flows and traffic congestion in corridors where TDM is to be implemented (Concas and Winters 2012). Following this recommendation, Winters, Hillsman et al. (2010) developed Transportation Demand Management Assessment Procedure (TDMAP) that integrate four-step model with TRIMMS.
to produce estimates of changes in travel behaviour at the traffic assignment stage. TDMAP does so with the following steps:

- First it extracts the origin/destination (O-D) tables by modes from the modal split model of the four-step regional travel demand model and then aggregates the modes with compatible modes in TRIMMS (Car–Drive Alone, Car–Rideshare, Vanpool, Public Transit, Cycling, Walking, and Other);
- In the next step, TRIMMS estimates the mode shares in the TDM affected zones and calculates the changes in mode shares in the zones;
- Finally, the estimated changes in mode shares are distributed over associated origin zones and initial O-D tables are updated. The updated O-D tables are then fed back into the regional travel demand model to be used for traffic assignment (Winters, Hillsman et al. 2010).

4.4 Activity-Based Models

Activity-based models showed a significant improvement to the traditional four-step travel demand model by providing a deeper insight into individual decision-making process. These models consider travel as being derived from the demand for personal activities. Travel decisions, therefore, become part of a broader activity scheduling process based on modelling the demand for activities rather than merely trips. Past studies have shown that these models have a significant advantage in analysing the impact of TDM strategies as they predict a wider range of impacts, including secondary and synergistic effects of the strategies under consideration (Jones 1983; Shiftan and Suhrbier 2002; Shiftan 2008). For example, a commuter may shift from use of car to public transit for the trip between home and work because of an employer trip reduction strategy. The shift in travel mode is the direct effect of the TDM strategy. As the person stopped driving to work he/she might not stop on way home to buy groceries as he/she used to do while driving to work. Therefore, he/she returns home by transit and then takes car to go nearby grocery stores, which is a secondary effect of the strategies. Activity-based modelling is capable of account for such secondary effect.

Using Portland’s activity-based transportation models Shiftan and Suhrbier (2002) evaluated the impact of three TDM strategies (pricing of automobile travel, telecommuting, and public transport improvements) separately and their combined impacts. While adding up the reduction in drive alone trips for the three individual policies show a reduction of 1.89% trips, the combined policy shows a reduction of 1.86% drive alone trips which indicates the marginal interaction effects of the three strategies. Shiftan (2008) assessed the impacts of several land use policies using a residential choice and activity-based models within the Washington County Urban Growth Area boundary. The policies include improvement in land-use by providing bicycle paths, upgrading the level of local shops, and providing a community square; improvement in transit service; and increasing safety and school quality in the city centre. With the stated improvement in land uses, the residential choice model showed an increase in the number of households in the Urban Growth Area by 13%. Moreover, 4.2% of the total metropolitan households moved from the suburb to the urban growth area reducing the suburban population by 6.1%. The activity-based model showed that public transport tours increased by 5.2%, walking tours by 7.2%, and bicycle tours by 7.8% with a slight increase in car tours by 2.5%.
5 STRATEGIC POLICY ASSESSMENT TOOLS

Strategic and policy direction setting is supported by tools such as the abatement tool, which does not target a particular problem or area in the network but is rather focussed on predicting aggregate effects of alternative portfolios of TDM instruments at the transport systems level. Reports of these quantitative, strategic policy decision-support tools, as oppose to project appraisal tool, particularly in relation to transport, let alone TDM, are less evident in the literature and present a substantial opportunity for innovation. They are not, however, unrelated to project appraisal tools. Learning from a review of the wider application and reporting of experiences in developing and using project appraisal and evaluation tools can be brought to bear in developing an appropriate strategic TDM policy assessment tool for Perth. The learning is twofold: firstly, continuous project monitoring and evaluation will yield a database of evidence in terms of TDM elasticities and secondly, project appraisal tools or components of tools together with impacts and effectiveness measures and project-level valuations, provide inspiration for upscaling to the strategic policy level.

In the emission context, the Marginal Abatement Cost Curve (MACC) is a function that shows the cost of implementing an emission abatement measure per unit reduction of emissions. The approach may be used for evaluation of technology adoption (e.g. electric vehicles).

Adopting this method for the problem of congestion will require an appropriate measure of congestion. For example annualised congestion cost – being the additional travel time due to congestion multiplied by the value of time plus additional fuel expenditure. The MACC approach is a cost-benefit calculation of identifiable projects aimed at achieving lower congestion at some time in the future. A base case projection of congestion (i.e. traffic growth on the existing or planned network) is compared to a variety of TDM projects. The need to identify how the measure is implemented (i.e. what projects will be undertaken) is essential for calculating the cost and benefit of the TDM. For example “improve public transport” is an identified TDM instrument, but analysis on its effectiveness would require scoping a project. A TDM project is a defined policy intervention with an implementation budget and an identified target population.

MACC approach to evaluating TDM:

1) Base projections of population and distribution/cost of transport system. It may need to take into account the strategic direction papers for 2031.
2) Cost TDM projects (capital and operating) as well as any social welfare savings (i.e. could include externalities).
3) Measure the behavioural response to TDM – reduction of private or commercial vehicles on road at time of day (i.e. the where and the when). Calculate the impact on congestion (or other criterion).
4) MAC = $ / unit reduction in congestion measure.

Note: Using abatement curves to analyse congestion differs substantially from emissions. This is due to step 3. The technology (TDM measure) potential is due to the behavioural response. In emissions the technology potential is the reduction in pollutant or GHG if the technology is adopted.

5.1 Marginal Abatement Tools for Policy Analysis: Reviewing Evidence

A possible way to use marginal abatement cost curve to support policy is to use a rough estimate based on a review of programs. The review would need to identify the costs of each program as well as a measure of congestion reduction. A source for these cases is the review of Congestion Mitigation and Air Quality Improvement (CMAQ) program, United States (Transportation Research Board, 2002).
The Congestion Mitigation and Air Quality Improvement (CMAQ) program was allocated $14.1 billion for programs other than vehicle technology improvement to reduce emissions: “while congestion mitigation was a goal of CMAQ, the primary policy focus since the program’s inception has been on achieving the air quality goals” (Transportation Research Board 2002, p.1). As a consequence the report did not provide an impact measure on congestion. Figure 2 is extracted from the report and shows the range of marginal costs for abating one ton of emissions. The figure is added here to illustrate an exercise that could be undertaken should the data, on which the CMAQ review was based, still be available.

![Figure 2: Range of Marginal Costs to remove one ton of emissions. Source: Transportation Research Board 2002, p. 127](image)

5.2 Marginal Abatement Tools for Policy Analysis: Generating a database of TDM project appraisals

An alternative strategy to create a marginal congestion abatement cost curve is to build an appropriate sketch model for Perth. The tool would be based on TRIMMS as it includes a number of benefit measures, whereas the other sketch tools only report changes in travel behaviour or the reduction in emissions. To generate a marginal abatement cost curve a database of TDM projects could be generated by applying the tool to suggested projects and programs.

Over time monitoring and evaluation records could be added to the database to provide more accurate accounts of the effects of the projects. Whilst the development of the tool would take many years it would be in addition to the implementation of TDM projects and an effective monitoring and evaluation process.

5.3 Concerns Expressed by External Reviewer

The Marginal Abatement Cost Curve (MACC) represents a start of the art tool. However, the emphasis on quantitative policy support tools may be overly optimistic. It is considered misguided to emphasise quantitatively strong methods in a field which has very little detail and performance data available. This is why many of the ‘practical’ tools available emphasise broad estimation methods. This review suggests PATREC re-orient towards tools with less quantitative...
rigour where broad estimations can be made. In our view this reorientation will become essential when the quantitative data from actual performance of TDM measures is assembled.

PATREC will investigate a decision making process whereby participatory tools and subjective assessment may help set the policy agenda. However, phase 2 will pursue appraisal tools that are evidence based.

6 MONITORING AND EVALUATION

Monitoring and Evaluation is more than an afterthought or a post project review. Evaluation is an integral part of TDM projects and programs. Each project has specific policy objectives and appropriate performance measures should be developed in order to decide project’s achievement towards the policy objectives. Establishing appropriate performance measures prior to program implementation will provide practitioners with consistent and accurate results. Depending on the chosen performance measures and supply of data through project monitoring, the evaluation can take many forms from simple calculations to complex transport models. It is however essential that practitioners allow an adequate amount of time for the project to fully develop before they evaluate the possible changes in individual travel behaviours or impacts on the existing transport system as a result of its implementation. The cyclic nature of TDM projects indicates that once a project is evaluated, the practitioner should go back to planning stage to either improve or alter the TDM project using the information gathered during the evaluation stage or use the information for future TDM projects.

The European Union developed the MOST-Monitoring and Evaluation Toolkit MOST-MET to provide guidance to practitioners to measure the impact of various Mobility Management (MM) programs (e.g. mobility centres, mobility management for companies, schools, leisure sites and tourist destinations) against the program’s goals and objectives, using carefully chosen indicators. Changes in the target group members due to the project are measured by the indicators. MOST-MET follows a seven-step methodology as follows:

- Formulation of objectives;
- Specification of target groups;
- Choosing Mobility Management instruments and services;
- Applying of assessment level;
- Specification of indicators;
- Monitoring;
- Evaluation.

Sweden developed its own evaluation framework, namely SUMO (System for Evaluation of Mobility Projects) (Hylenius, Ljungberg et al. 2004). SUMO is also based on MOST-MET that was adapted to Swedish conditions to evaluate the impact of transport projects on individual attitudes and behaviours. However, SUMO is unique in how its targets, indicators, and results can be specified at different levels (e.g. number/percentage of people aware, people that show an interest, people satisfied with the services offered). Campaign Assessment Guidance (CAG) is another evaluation tool developed under the TAPESTRY (2003) of European Union. CAG offers an ex-post comparison of the situation before and after the implementation of a campaign. Nonetheless, the European Union is now using a new tool for systematic evaluation of mobility projects and programs, which is known as Max-SUMO. This new tool was developed under the project MAX - Successful Travel Awareness Campaigns and Mobility Management Strategies and is based on the existing tools (SUMO, MOST-MET, and CAG) where it uses the concepts of travel awareness aspects from CAG, the empirical
research conducted within the MAX project, and practical hands-on experience learned from the application of SUMO and MOST-MET (Trivector 2009).

Canada has recently developed a new evaluation framework based on the above two approaches, namely TDM Measurement Toolbox (Transport Canada 2012). The strength of this Canadian Toolbox is that it contains detailed evaluation indicators for 46 TDM measures along with their possible data collection tools at different assessment levels.

In general, the impact of TDM initiatives is evaluated by measuring the change in travel behaviour, for instance a reduction in vehicle miles travelled, modal shift from the solo car driving to the use of sustainable transport (public transport, walking, and cycling) and/or increase in the share of multi-occupant vehicles (e.g. carpool and vanpool). These changes are measured by counting traffic on the target area and by surveying individual’s travel behaviour before and after implementation of the initiatives. In order to avoid high cost of data collection, MOST suggests combing the data collection program with existing surveys, by adding some additional questions, instead of carrying out an extra survey. Moreover, in case data were not collected before the implementation of the project, retrospective questions about people’s travel behaviour at a point of time before the implementation may at least provide the general idea of the changes and gives hints about the reasons for these changes.

7  MEASURING IMPACTS ON THE TRANSPORT SYSTEM

Appraisal of TDM initiatives involves measures relating to two components. Firstly, a TDM project is appraised on its effectiveness in enacting travel behaviour change. The second component of TDM appraisal models is measuring the value or benefit of the behaviour response with four broad classes of impact having been identified: travel time and reliability, environmental benefits, fitness and well-being and wider economic impacts. With a primary objective of TDM being to reduce levels of congestion, measurement of congestion impacts is pivotal in TDM appraisal. A range of congestion indicators have been developed but are all essentially some form of a composite measure using travel time savings

7.1 Effectiveness

Effectiveness of a TDM initiative is measured by the level of travel behaviour change. Often the impact is measured as the reduction of SOV car trips during peak hour – essentially with the view that the TDM outcome is to reduce congestion. However, other objectives such as air quality and environment may not necessarily focus on trips during peak hour, but rather on total travel (aggregate vehicle kilometres, VKT). Alternatively, when focusing on health and fitness, TDM effectiveness may be measured in terms of increased public transport use or increased travel by active modes. The dimensions of TDM effectiveness listed below form a truncated list of that given in Rose (2007b):

- Reduction in car use: A primary measure of TDM effectiveness. If the TDM is aimed at commuting trips, the measure may be in terms of reduced number of SOV trips. If the application for the TDM instrument is for a school, the effectiveness may be determined by the reduction of service trips by car;
- Increased public transport ridership: Whilst this is a complement to reduced car dependency, the measure is relevant to public agencies interested in the impact of cost recovery from public transport initiatives;
• Increased travel by walking or cycling: Most commonly used metric if a principle aim of the TDM is to promote health and fitness.

7.2 Valuation of Benefits

The second component of TDM appraisal models is measuring the value or benefits of the behaviour response in terms of one or more measures. Whilst effectiveness indicators are useful for monitoring, any appraisal based on cost-benefit analysis will need to make use of economic indicators. The performance of the network is summarised as the economic values of travel time savings, system reliability, vehicle operating costs, improvements to air quality and greenhouse gas emissions and noise. The marginal willingness to pay values for each are reviewed in the next section. In addition, the review includes public transport measures of crowding and comfort because these outcomes may be affected by TDM’s that shift car travellers onto mass transport. Finally, the benefits related to health, fitness and safety are viewed as complimentary benefits.

7.2.1 Travel Time Savings

Values of travel time savings (VTTS) dominate benefit calculations used in assessing transport policy and infrastructure projects. Monetary valuations are often differentiated by the travel purpose (work vs. non-work), transport modes (car, bus, rail, walking, cycling), length and/or duration of the travel. The components of the total (door-to-door) travel time, such as access/egress, transfer, in-vehicle and waiting time, have been found to have different VTTS, reflecting the different utilities/disutilities experienced by travellers between the origins to the destinations of their trips. Additionally, the method of calculation may depend on the transport setting.

• Time savings valuations are generally based on whether the trip is within the ‘working hours’ or outside them (Mackie and Worsley 2013). Empirical evidence shows that VTTS within working time vary substantially across countries and continents: VTTS was estimated as £34.12/hour in UK in 2010; €23.50 in Germany in 2008; 247 SEK for trains and 291 SEK for all other modes in Sweden; $23 for car, bus, and train and $57 for air, and high speed rail in USA; A$44 in NSW Australia;

• In contrast, VTTS for commuting shows some similarities: was £6.46 per hour in UK; €9-10 in the Netherlands; $12 for local commute and $17 for intercity commute in USA; 87 SEK for car, 53 for bus, and 69 for train, and 108 for air in Sweden for trips shorter than 100km.

• Evidence from revealed and stated preference work showed that people are willing to pay more for reductions in waiting time and walk time than for in-vehicle time (Gühnemann, Kelly et al. 2013). As a result, the value of wait time is factored by 2.5 of in-vehicle time saving and walking time by a factor of 2 in the UK, however, the factors are slightly lower for USA and NSW, Australia.

• Using a behavioural model that accounts for income differences, in the UK it was found that the time saved on commuting was 10% more ‘valuable’ than the time saved on non-work related travel; the percentages are even higher in The Netherlands and Sweden.

• Whilst Mackie, Wadman et al. (2003) suggest that a lesser value of travel time savings for small time savings should apply, the UK appraisal did not differentiate between small and big travel time savings. Sweden and Germany however, have taken some steps in this direction. For instance, in Germany, in case of savings below 5 minutes, VTTS are calculated at 70% of the ‘nominal’ value.
New Zealand and Sweden apply mode-specific estimates for VTTS (Eliasson 2013, Mackie and Worsley 2013). When evaluating VTTS for commercial travel, the driver’s time and vehicle operating cost changes are accounted for in the UK (Guhnemann et al. 2013). In addition, Swedish appraisal standards consider the interest payable on the value of goods in transit (Mackie and Worsley 2013). The Netherlands use a stated preference survey of shippers and carriers to determine their willingness to pay for any delay (de Jong 2013).

7.2.2 Reliability
Reliability has recently been included as a performance measure in some transport policy manuals, based on evidence that showed willingness of trip makers to pay for decreasing the travel time variability in addition to travel time savings (Hensher 2001, Bhat and Sardesai 2006). Reliability is studied based on the repeated journeys along a route and hence it is usually measured by the variance (or standard deviation) of travel time (Li, Hensher et al. 2010). Travel time variability can be categorised into three types: i) day-to-day variability (due to weather condition, fluctuations in traffic, accidents, road construction, events and so on), ii) day-of-week variability (weekdays versus weekends), and iii) inter-vehicle variability (due to personal driving behaviours and traffic signals) (Bates, Dix et al. 1987, Bates, Polak et al. 2001). However, incorporating reliability or travel time variability in appraisal (more generally) within cost-benefit analysis (CBA) is yet to become a common practice and appropriate methods for valuation of reliability are still considered in the state-of-art sphere (Batley, Grant-Muller et al. 2008). In UK, reliability impacts are not directly taken into account in the initial benefit-cost ratio (BCR) i.e. BCR at the time of project appraisal, rather they are added in the final BCR calculation i.e. BCR at the time of project evaluation.

Reliability Ratio (RR) is a widely used valuation approach in practice in UK and USA for incorporating reliability into the appraisal. RR represents the ratio of standard deviation of travel time over value of travel time, or for rail, RR = value of standard deviation of lateness/value of lateness, where value of lateness = factor (3-4)* value of in-vehicle travel time. By contrast, in Sweden, standard deviation of travel time variability for car is valued by 0.9*VTTS and long unexpected delays on car and average delays on public transport are valued at 3.5*VTTS. A 25% surcharge is added on the time benefits in the Netherlands. In NSW, Australia, the value of travel time reliability is equal to the value of in-vehicle time savings.

7.2.3 Vehicle Operating Costs
A review of valuations for vehicle operating costs is not offered because of the differences between countries due to technical and engineering standards. Any TDM tool developed for Perth will need to use local standards. The Cost Benefit Appraisal manual published by Austroads does not include valuation of vehicle operating costs however RTA Road Evaluation Manual includes a set of economic parameters that provide values on vehicle operating costs (Douglas and Brooker 2013).

7.2.4 Air Quality and Climate Change
Both local and regional pollutants are quantitatively measured to assess the impacts of air quality in transport project appraisal. Particulate matter (PM10) and nitrogen dioxide (NO2) are the primary sources of local air pollution and road transport is one of the major generators of the pollutants (Department for Transport 2014). Changes in concentrations of the pollutants in local areas as a result of a transport scheme have been quantified. In the UK, a combination of two approaches is used for monetary valuation of changes in PM10 and NO2 concentrations. A damage cost approach is used when the changes in concentrations are within the European Union (EU) limits and a marginal abatement cost approach is used when it is expected that the proposed scheme would exceed EU
limits on NO\textsubscript{x} (nitrogen oxides NO and NO\textsubscript{2}) concentrations. NSW, Australia uses the damage cost approach for the valuation, incorporated in the Air Quality Appraisal Tool (AQAT) for the valuation of air quality impacts of transport and land use development. The AQAT estimates hot running emissions, cold-start emissions and non-exhaust PM\textsubscript{2.5} (particulate matter with diameter of 2.5 micrometres or less) emissions for the damage cost calculation. In addition to quantification and valuation, the tool also accounts for other planning measures that are designed for trading-off negative impacts i.e. improvement in air quality. Unit damage cost (in A$ per tonne of PM\textsubscript{2.5}) was calculated as a function of population density at Significant Urban Areas (SUA) across Australia (NSW Environment Protection Authority 2013). In a recent study by the OECD (2014), the cost of 2010 health impacts (both deaths and illness) due to air pollution from road transport was estimated at about USD 1 trillion across OECD countries. Table 1 shows the estimated cost of location pollution across four countries.

Table 1: Costs of Local and Global Pollution in Four OECD Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>England</td>
<td>Global pollution €420 per tonne for NO\textsubscript{x} in 2008</td>
</tr>
<tr>
<td></td>
<td>Local air quality €3.37 per resident equivalent</td>
</tr>
<tr>
<td>Sweden</td>
<td>Costs for PM\textsubscript{2.5}, Volatile Organic Compounds (VOCs),</td>
</tr>
<tr>
<td></td>
<td>SO\textsubscript{2}, NO\textsubscript{x} per exposed person varies</td>
</tr>
<tr>
<td></td>
<td>with the ventilation zone</td>
</tr>
<tr>
<td>NSW, Australia</td>
<td>Pollution cost = 0.001 * change in PM\textsubscript{10} concentration</td>
</tr>
<tr>
<td></td>
<td>due to the project * population exposed * normal death rate * value</td>
</tr>
<tr>
<td></td>
<td>of life</td>
</tr>
<tr>
<td>New Zealand</td>
<td>Same as NSW Australia</td>
</tr>
</tbody>
</table>

For the valuation of the impacts of climate change, the UK uses marginal abatement cost approach for the non-traded sector (as defined by the EU Emissions Trading System). A cost of £53.58 per tonne of CO\textsubscript{2} was estimated in 2010 in UK, whereas it was €70 per tonne in Germany and €62.66 per tonne in The Netherlands. The estimated cost in the USA and New Zealand was much lower than the European countries, at $19-21/tonne in USA and $40/tonne in New Zealand.

### 7.2.5 Noise

Transport-related noise pollution produces ‘a feeling of displeasure’ to individuals (WHO 2007). It brings discomfort by interrupting communication, concentration and activities (Miedema 2007). It is therefore necessary to assess the level of noise causing annoyance to people. The UK has clear guidelines for valuation of transport-related noise, based on a study by Bateman, Day et al. (2004). A hedonic pricing approach was used in the study to estimate willingness-to-pay for a peaceful and quiet environment in the housing market in Birmingham. The Birmingham based model was then updated by Nellthorp, Bristow et al. (2005) to be used across UK; the model was included in their WebTAG toolkit (Transport Analysis Guidance). There is no monetary value placed for noise level below 45 decibels (dB L\textsubscript{Aeq, 18h}) and the value remains constant above 81dB L\textsubscript{Aeq, 18h}. Annual value of a 1dB change in noise level between 45 and 81dB is estimated from £10.91 to £127.24 per household. In Germany, the willingness-to-pay to achieve low noise levels at night (<37dBA) was estimated at €67.68 per resident in 2008. In the USA, the valuation of noise annoyance is based on the cost of sound barriers or land value impact, whereas in NSW, Australia, it is calculated based on a prediction of change in property values (0.9%) by a 1dB increase in noise level above 50 dBA. However, hedonic pricing method for the valuation of noise annoyance has been questioned on several grounds, including multicollinearity of explanatory variables, spatial heterogeneity, or other market imperfections. Therefore, there has been an increasing interest in the use of stated preference methods for valuation of traffic related noise annoyance (Wardman and Bristow 2004).
7.2.6 Crowding and Comfort

Crowding and comfort are important factors in project appraisal for public transport. Whereas crowding can be measured quantitatively (density of passengers on vehicles, access ways and stations) (Tirachini, Hensher et al. 2013), comfort reflects several qualitative aspects of a journey including the quality of seats, and the smoothness of the ride. Occupancy rate or load factor is the most common metric for measuring crowding. It is measured as a ratio of actual in-vehicle passengers and the number of seats (Whelan and Crockett 2009) or as the ratio of in-vehicle passengers and the nominal capacity of the vehicle (seating and standing capacity) (Jara-Díaz and Gschwender 2003). A load factor over 80% is indicative of overcrowding and, in most countries, multipliers (1.03-3) are used to adjust for in-vehicle travel time and whether the person is sitting or standing. For instance, in the UK, a multiplier of between 1.03 and 1.16 is used for someone sitting in a crowded train, whereas the multiplier is increased to 1.65 for short distance and 2.11 for long distance standing. Sweden uses a ‘comfort’ multiplier of 1.5 for driving on a congested road and a factor of between 1 and 3 for public transport, depending on the level of crowding. New Zealand uses a different valuation where they increase the value of travel time by 40% for standing passengers compared to sitting passengers in public transit. A recent study by Tirachini, Hensher et al. (2013) found that a model that ignores crowding overestimates the VTTS for low occupancy rates and underestimates VTTS in case of substantial crowding.

7.2.7 Complementary Benefits

Despite travel time being considered the first benefit of any TDM measure, in recent times, safety, health outcomes and regeneration impacts, have been highlighted as integral part of TDM benefits.

Fitness and Health

Fitness and health is a relatively newer addition to transport appraisal. The World Health Organization (WHO) pioneered the approach by incorporating the health effects of transport interventions or infrastructure projects into CBA. It is easier to estimate the cost of infrastructure provided to increase the level of walking and cycling, than the direct benefits of walking and cycling. WHO (2007) provided guidance in the form of an harmonised method for the economic appraisal of health effects. Although their Health Economic Appraisal Tool (HEAT) was particularly developed for cycling, the method also allows for assessment of the health benefits of walking. The tool helps to answer the question “If x people cycle y distance on most days, what is the value of the improvements in their overall mortality rate?” (WHO 2007, p13). Most of the European countries use HEAT for their economic appraisal of cycling. New Zealand uses their own developed tool (New Zealand Economic Evaluation Manual) for the valuation, with separate estimates for walking and cycling (New Zealand Transport Agency 2010). Past studies also estimated the monetised benefits of active transport to health and found that each additional cyclist may add a benefit of £22 to £498 per year depending on a number of factors including age (Fishman, Garrard et al. 2011). Boarnet, Greenwald et al. (2008) developed a methodology to quantify monetised values of increased walking. Most evaluation approaches, for either TDM or construction projects, use improvements in mortality rate as the primary indicator of health performance. The Active Transport Quantification Tool developed by the International Council for Local Environmental Initiatives (ICLEI), however incorporated additional factors in their valuation including savings from reduced driving and consequently decreased congestion, pollution, and crash risk, along with increased fitness and wellbeing (ICLEI 2010).

Safety
Appraisal of transport safety deals with monetised value of a statistical life (VSL) to estimate total benefits and then uses the valuation in the appraisal of investments aimed at preventing road accidents. Total direct and indirect costs of accidents are considered (Milligan, Kopp et al. 2014). VLS in general is the amount of money individuals are willing to pay for improvements in safety (i.e. to avoid the risk of fatalities) with the expectation of saving a life (Miller 2000). Different ways of determining the willingness to pay WTP were put forward: USA uses a hedonic wage model for their estimation of VSL. From empirical analyses by a panel of expert economists, $9.1 million was determined as the value of a statistical life in 2012 and is being used by the US Department of Transportation with an annual growth rate of 1.07 over the next 30 years (2013-2043). They are also using relative disutility factors (Table 2) based on injury severity level (AIS).

Table 2: Relative Disutility Factors by AIS

<table>
<thead>
<tr>
<th>AIS Level</th>
<th>Severity</th>
<th>Fraction of VSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIS 1</td>
<td>Minor</td>
<td>0.003</td>
</tr>
<tr>
<td>AIS 2</td>
<td>Moderate</td>
<td>0.047</td>
</tr>
<tr>
<td>AIS 3</td>
<td>Serious</td>
<td>0.105</td>
</tr>
<tr>
<td>AIS 4</td>
<td>Severe</td>
<td>0.266</td>
</tr>
<tr>
<td>AIS 5</td>
<td>Critical</td>
<td>0.593</td>
</tr>
<tr>
<td>AIS 6</td>
<td>Fatal</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Source: U.S. Department of Transportation (2013)

Other monetary values used for transport project appraisals are provided in Table 3.

Table 3: Monetary Values in Five Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>England</td>
<td>VLS £1.65m, Serious injury £0.186m, Light injury £0.014m</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Fatal €2.744m, Serious injury €0.282m, Light €0.005-0.009m</td>
</tr>
<tr>
<td>Sweden</td>
<td>Fatal 23.7m SEK, Serious injury 4.4m SEK, Light 0.02m SEK</td>
</tr>
<tr>
<td>NSW Australia</td>
<td>Fatal A$6.3m, Serious injury A$0.467m</td>
</tr>
<tr>
<td>New Zealand</td>
<td>Speed limit 50km/hour: Fatal NZ$3.798m, Serious injury NZ$0.401m, Light NZ$0.021m Speed limit 100km/hour: Fatal NZ$4.560m, Serious injury NZ$0.486m, Light NZ$0.029m</td>
</tr>
</tbody>
</table>

Regeneration

Regeneration by transport improvement projects may affect the economy of the whole area of the project and its surroundings. The impacts include: changes in employment/labour market and impacts for business activity. Therefore, the purpose of the assessment of regeneration impacts under transport project appraisal is to show how a proposed transport project will influence the economy in the regeneration area (Department for Transport 2014). For instance, improvement in accessibility by means of improved transport networks and connectivity will change travel time, cost, and reliability. The improvement would probably attract more businesses, and/or expand existing businesses and hence create more employment opportunities in the area. However, there are no general guidelines across countries on how to incorporate the regeneration impacts in transport appraisal. In the UK, local benefits associated with changes in target areas (i.e. regeneration areas) are considered as a regeneration impact. The UK Department for Transport (2014) proposed that potential regeneration impacts of transport should comprise: ‘Impacts for business activity via such
changes in travel conditions such as costs of access to customers and costs of access to supplies; Labour market impacts through access to a larger pool of labour, and access of workers to a wider range of jobs; Access to and from the regeneration area by visitors’ (Department for Transport 2014, pp. 3-4). The USA however does not include regeneration impacts in its CBA, instead, regeneration is considered as a separate entity in a multi-criteria analysis in which projects are ranked based on a variety of qualitative and quantitative factors. An overall score is calculated for each project and the project with highest score is selected. In NSW, Australia, changes in population and employment at corridor level are attributed to the regeneration impact of transit-oriented development (TOD).

Wider Economic Impact

There are broader benefits and costs related to transport projects that are not incorporated in traditional evaluation frameworks. These additional potential sources are grouped under as the “Wider Economy Impacts” of transport projects (Joint Transport Research Centre 2008). A recent guideline provided by the Department for Transport, UK (2014) identified three sources of impact – agglomeration impact, output change in imperfectly competitive markets and tax revenues arising from labour market impacts (from labour supply impacts and from moves to more or less productive jobs). Agglomeration impact occurs when a transport project affects the cost of trips to, from or within the locations of agglomeration and hence is measured as a function of elasticity of total productivity with respect to the job density, change in the effective job density and GDP in the area (Department of Transport 2005; UK Department of Transport 2005). Output change in imperfectly competitive markets occurs when firms can increase their profit due to a reduction in unit cost of transport (to business and/or freight), as those firms frequently require the use of transport in their production and distribution. A simplified approach is used to estimate the impact of this benefit in the UK. ‘It is estimated as a proportion of total user benefits for business journeys, calculated as a 10% uplift to business user benefits’ (Department for Transport 2014, p.4). Finally, tax revenues arising from labour market impacts occur when a transport scheme influences labour market decisions. The change in tax revenues as a result of labour market impacts is estimated as a function of the change in GDP from the labour supply impact, and from the move to more or less productive jobs impacts. In UK practice, it is estimated that the change in GDP from the labour supply impact is 40%, and the change in GDP from the move to more or less productive jobs impact is 30% (Department for Transport 2014).

The New Zealand Transport Agency published a detailed report on quantifying and estimating the wider economic impacts of transport investments in 2011 which is somewhat similar to the UK approach where they divided wider economic impacts relating to: imperfect competition benefits, increased competition benefits, labour supply benefits, and job relocation benefits (Kernohan and Rognlien 2011). Other approaches include: input/output models, used in The Netherlands and the USA (Netherlands: REMI; USA: TREDIS). In the USA, the logistics and supply chain impacts are also considered.

7.3 Congestion Impacts

Three broad definitions of congestion exist in the literature. The first two are engineering based: throughput or demand/capacity relationships; and travel delay. The economic perspective relates to the impact imposed on other commuters by additional vehicles sharing a congested link. It is recognised that no single definition of congestion applies. The European Conference of Transport Ministers (2007, p.10) acknowledges this by offering three broadly different definitions based on:

- The demand capacity relationship: congestion is a situation in which demand for road space exceeds supply,
• The travel delay or impedance: congestion is the impedance vehicles impose on each other, due to the speed-flow relationship, in conditions where the use of a transport system approaches capacity and
• The user’s perspective “congestion is essentially a relative phenomenon that is linked to the difference between the roadway system performance that users expect and how the system actually performs.

The gap between user expectation and system performance is a measure of user satisfaction. In order to report an indicator of user satisfaction policy agencies would need to survey the road users. User surveys may be undertaken after the implementation of a TDM instrument. Phase 2 aims to develop a tool to appraise the effectiveness of a proposed TDM initiative. Any survey undertaken would be aimed at eliciting perceived effectiveness or determining the community’s level of acceptance rather than to gauge the level of satisfaction and, as such, user satisfaction is not considered further.

Measurements of traffic congestion are usually based on a traffic volume to road capacity ratio (V/C). A V/CR of 1.0 or more indicates that the traffic level has exceeded the design capacity of the road at this point. However, the point in which vehicles slow each other down occurs around a V/C of 0.75 to 0.80 (Boarnet et al., 1998). Litman (2012, p. 3) suggests that a “V/C less than 0.85 is under-capacity, 0.85 to 0.95 is considered near capacity, 0.95 to 1.0 is considered at capacity, and over 1.0 is considered over-capacity”. As indicated in Figure 1 as V/C approaches 1.0, small changes in traffic volume lead to large changes in congestion delays. For V/C greater than 1.0 not only is there a slowdown in the speed of vehicles on the congested link or route, there is also a reduction in vehicle throughput.

To calculate the impact due to a time delay, a reference travel time is needed. The reference travel time is the anticipated time a vehicle would take to complete its journey is conditions were uncongested (Luk et al., 2009). It is also valid to make the comparison between congested and uncongested conditions by referring to speed. However, to calculate the economic impact, speed needs to be converted back to travel time by taking into account the distance travelled. It is generally thought that Free-Flow and posted speed limits overvalue the delay, and therefore the benefits of congestion relief. Socially optimum travel time is favoured. The socially optimal travel time correlates with a vehicle to capacity ratio of about 85-90 per cent or to travel times that are 65-80 percent of the free flow speed (van den Bossche, Certan et al. 2001).

Selection of reference travel times:
1) Free-Flow time: travelling at speeds that are considered to be safe if conditions mean that no vehicle interacts with another vehicle.
2) Signed speed limits: approximately equal to Free-Flow time.
3) Social optimum: if a tax was imposed such that the private costs = the social costs (i.e. efficient charging).
4) Pre-congestion levels: approximately 85% volume to capacity ratio or 70% free-flow speed.

Economic indicators of congestion convert the travel delay into a monetary amount either by way of value of travel time savings or as a direct calculation of additional fuel costs incurred due to congestion. Table 4 details the broad classifications of congestion indices. For a complete list of indices see Litman (2012).
Table 4: Broad Categories of Congestion Indicators

<table>
<thead>
<tr>
<th>Indicator Classification</th>
<th>Description and Measurement</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delays</td>
<td>Compare the congested travel time to a reference travel time. Indicators include annual hours of delay, delay per capita, delay per road user. The indicators are sensitive to the choice of a reference travel time.</td>
<td>Litman (2012) Grant-Muller and Laird (2006)</td>
</tr>
<tr>
<td>Ratios</td>
<td>Measure the ratio of congested periods to uncongested periods. Travel time rate and travel time index measure the proportion of time a route, link or area is in congested condition. The proportion of road mile under congestion indicates what fraction of the network is under congestion during peak times.</td>
<td>Litman (2012) and Grant-Muller and Laird (2006)</td>
</tr>
<tr>
<td>Economic</td>
<td>Convert delays into a generalised cost of congestion. Annual or per capita costs of congestion sum time money value of travel time losses and are dependent on the measure used to compute the loss. The travel time valuations are often split between private and commercial travel. Excess fuel costs compares running cost under congested conditions to the running costs under non-congested conditions using standards.</td>
<td>Litman (2012) and Grant-Muller and Laird (2006)</td>
</tr>
</tbody>
</table>

8 CONCLUSION

Report A presented a review of the various TDM instruments that are available to policy makers. This report – Report B – complements the review by presenting the typical tools used for appraising TDM initiatives at various stages of the generic TDM decision framework. TDM project and program appraisal are the most commonly described tools presented in the literature. Sketch tools developed in the United States dominate the findings. The most commonly used tools were developed to assess workplace TDM projects. However, the general approach of estimating the effect of behaviour change and its impact on the transport network is a common theme throughout all the models reviewed. Whilst cost-benefit analysis is a preferred appraisal methodology in transport appraisal in general, it has not been widely adopted in tools designed specifically for TDM appraisal, although its potential for this has been recognised. The most promising of the appraisal tools reviewed is TRIMMS because it extends the basic estimation of behavioural response to include a calculation of the private benefits as well as externalities. Also, TRIMMS has a cost-benefit analysis module. Tools can be used in combination to improve efficiency. Subjective assessment tools such as short-listing and rapid appraisal (Rose 2007a, b) offer a method whereby short-listing limits the number of initiatives to be appraised and a sketch model such as TRIMMS can be used for the rapid appraisal.

At the level of support for strategic and policy direction setting, where portfolios of TDM initiatives need to be assessed, there are fewer tools reported in the literature, particularly in relation to transport and TDM, presenting a substantial opportunity for innovation. Marginal abatement cost curves are borrowed from climate research. These tools cannot be readily transferred to congestion analysis because the basis of the change is behavioural; in climate science the basis of the change is usually an improvement in technology. However, marginal abatement is effectively another way of reporting a cost-benefit result. In addition to the learning from cost abatement curves applied in other field such as in climate science, learning from this review of the wider application and reporting of experiences in developing and using project appraisal and evaluation tools, can be
brought to bear in developing an appropriate strategic TDM policy assessment tool for Perth. The learning is twofold: firstly, continuous project monitoring and evaluation will yield a database of evidence in terms of TDM elasticities and secondly, project appraisal tools or components of tools together with impacts and effectiveness measures and project-level valuations, provide inspiration for upscaling to the strategic policy level.

Travel demand management is the application of demand strategies to improve the efficiency of the transport system. A primary focus of demand management is to encourage alternatives to the use of single occupancy vehicles on the journey to work, with the primary aim of reducing congestion. In addition to reviewing TDM appraisal tools, this review has considered the range of impact measures used to determine the expected and actual effects of TDM on the transport system and benefits to travellers. Key measure of TDM effectiveness on the transport system are: reduction in number of car (in particular, SOV) trips; increased public transport ridership; and increased number of trips by walking or cycling. Whilst indicators that measure change in aggregate number of trips per mode per time of day are useful, any appraisal based on cost-benefit analysis will need to make use of economic indicators which considers the economic value of the benefits to travellers. Key indicators of value are the marginal willingness to pay for: travel time savings, system reliability, vehicle operating costs, improvements to air quality and greenhouse gas emissions and noise. Public transport measures of crowding and comfort can also be included because these outcomes may be affected by TDM’s that shift car travellers onto public transport. Benefits related to health, fitness and safety can be included as complimentary benefits.

With a primary objective of TDM being to reduce congestion levels, this review specifically considered measures of congestion used to monitor change. A range of congestion indicators have been developed but are all essentially some variation of a composite measure using travel time saving.

9 Acknowledgements

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