International Transport Forum

Performance Measurement in the Road Sector: A Cross-Country Review of Experience

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OECD

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INTERNATIONAL TRANSPORT FORUM

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1. INTRODUCTION

Road networks are important lifelines for modern societies. Social prosperity and economic development are directly related to mobility and accessibility of communities and are, therefore, highly dependent upon the existence of high quality road networks. Currently, roadways are the dominant mode of transport, particularly in developed countries. In Europe for instance, over 75% of ground freight transportation is by road, while road passenger transport exceeds 80% (Eurostat, 2012). According to Urban Audit (Urban Audit, 2012), private vehicle usage for work related journeys in major European cities exceeds 40% in most cases, while the same figure for US cities is over 70%. Further, despite worldwide efforts for promoting sustainability and environmentally 'friendly' modes, road users tend to increase on a global scale, as developing countries gradually enter the world of motorization (Pucher *et al.*, 2007).

Given the large amount of road transportation users globally, road networks are expected to offer safe, convenient and efficient transportation services as well as adequate accessibility to communities. As such, road operators and agencies focus on retaining the quality and performance of the network under their jurisdiction at required operational levels. In an era of economic recession, operators attempt to develop and deploy 'optimal' maintenance and operational policies and actions to manage with a constrained economic environment. Indeed, while road user needs increase and road infrastructures degrade, resource availability declines; such conflicting conditions are commonly faced by road agencies whose task of maintaining an efficient road network often becomes a challenge.

In this context, the concept of efficient road management has been introduced in the past two decades as the "process of maintaining and improving the existing road network to enable its continued use by traffic efficiently and safely, normally in a manner that is effective and environmentally sensitive; a process that is attempting to optimize the overall performance of the road network over time" (TRL, 1998). Road management involves a number of tools that include (Schutte, 2008):

- Policy Formulation: Definition of standards and policies for the road sector,
- Monitoring: Knowledge of the network extent, conditions and traffic characteristics,
- Needs Assessment: Determination of required expenditures for management and operations,
- Capital Budgeting: Appraisal and ranking of investment options,
- Project Programming: Programming of maintenance and improvement projects,
- Monitoring Maintenance: Monitoring of maintenance projects, and
- Monitoring Performance: Obtaining performance measures for operations.

These tools combined, aim for measuring the performance of road networks and planning their maintenance, comparing maintenance strategies against operational requirements, and for programming future maintenance and improvement activities based on available resources. These actions are also coupled by the need to select pre-

defined performance standards in order to maximize expected performance. In this sense, setting performance objectives and associated indicators is an integral element of road management tools; performance has to be measured in a systematic manner and must be compared against objectives set by road agencies.

While the use of performance indicators and thresholds (condition ratings and levels of service as examples), has been at the core of road management for decades, performance based management of roads has been introduced relatively recently. Indeed, in the past, maintenance and operations were assigned and/or contracted on the basis of design and material requirements, and were related to the amount of work undertaken as part of a maintenance project (Zietlow, 2004). Only in recent years has the concept of performance based management been exploited by authorities. Under performance based contracting, minimum performance standards (or targets) are set and reimbursement of contractors is related to how well they comply with these standards and not to the amount of completed work (Sultana *et al*. 2012).

Modern road management is performance based; both programming and implementation of maintenance and operational activities are driven by appropriately defined performance indicators. This report focuses on the review of performance requirements and indicators established by developed countries worldwide. Additionally, the concept of performance based maintenance and related contracts - closely linked to the selection of proper performance indicators – is presented, since it is the modern approach towards achieving sustainable financing of road maintenance and operations projects.

2. PERFORMANCE IN THE ROAD SECTOR

2.1 Performance Measurement: A General Overview

Performance assessment is commonly encountered in a number of activities and processes related to engineering, economics, health, and so on. Its definition in this context is straightforward, in that performance essentially refers to how successfully a task, system or operation functions. From this perspective, performance measurement is a task required for assessing and improving characteristics and operations of a system, process, or infrastructure. A comprehensive definition of performance measurement is offered by the US Federal highway Administration (Shaw, 2003)

"Performance measurement is a process of assessing progress toward achieving predetermined goals, including information on the efficiency with which resources are transformed into goods and services (outputs), the quality of those outputs (how well they are delivered to clients and the extent to which clients are satisfied) and outcomes (the results of a program activity compared to its intended purpose), and the effectiveness of government operations in terms of their specific contributions to program objectives."

In the road sector, performance can be measured from a number of different perspectives and for a number of reasons (Haas *et al*. 2009):

- To assess current and future conditions of road infrastructures,
- To evaluate road agency efficiency with respect to provided services, productivity, protection of the environment, cost-effectiveness and so on.

Indeed, the road sector involves a number of different stakeholders, often with contradicting interests and expectations. These lead to the need for assessing and measuring various dimensions of performance in this area. Figure 2.1 depicts these perspectives.

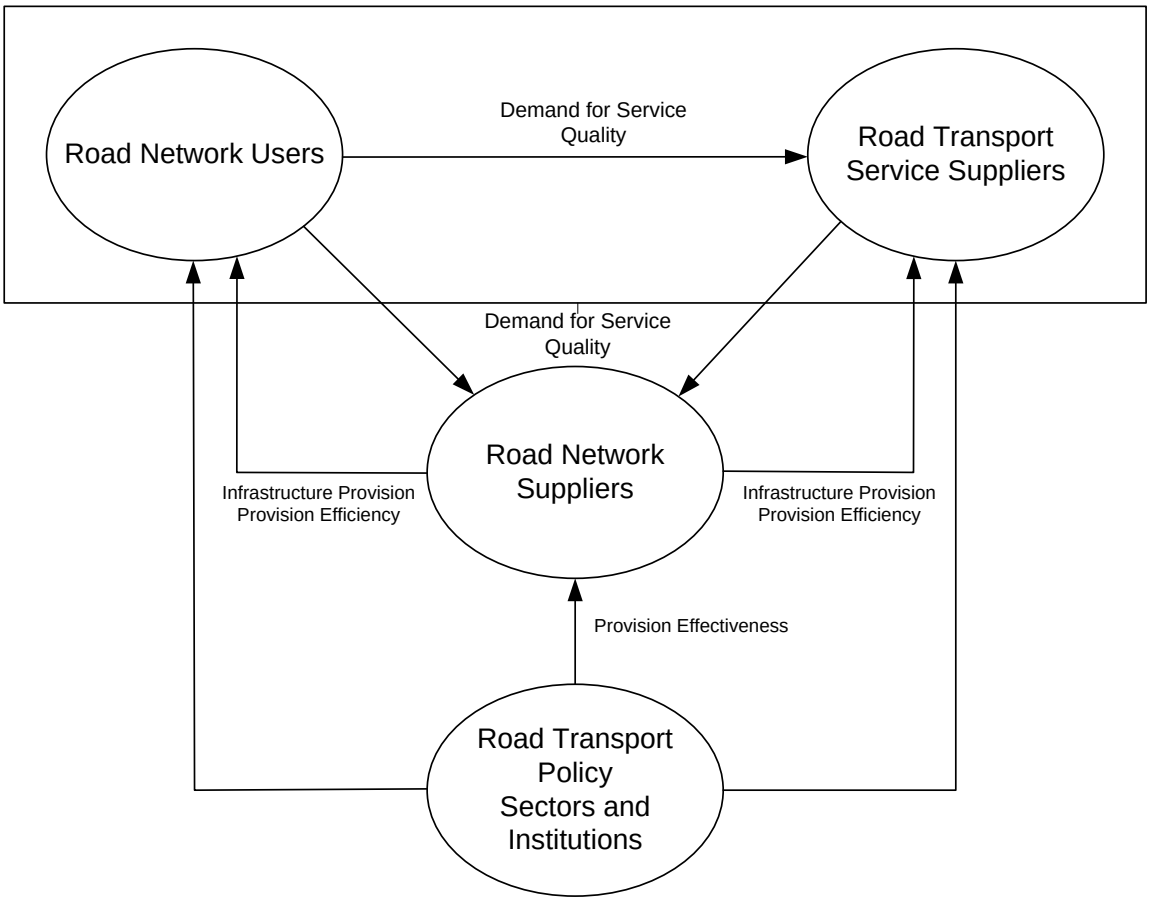

Figure 2.1. **Stakeholders in the road sector and performance measurement**
(adopted from Humplick and Paterson, 1994)

Road users and *service providers* (such as bus, coach, taxi, and road freight providers) require "service quality" in terms of comfort, safety, affordable usage cost, and an adequate driving environment (Humplick and Paterson, 1994). *Suppliers* of the road networks focus on efficiently satisfying user and service requirements and are therefore concerned with the productivity and effectiveness of their operations. *Policy makers* are primarily interested in the best possible allocation of resources among road network supplies, along with compliance with road network-related rules (Humplick and Paterson, 1994).

Road network suppliers (road administrators) play a central role towards measuring performance and exploiting relevant findings. As noted by Talvitie (1999), performance measurement encompasses three questions expected to be answered by road administrators:

- Is the road administration doing the right things? (this is frequently referred to as effectiveness in the performance measurement literature)
- Is the road administration doing things right? (termed efficiency)
- What external factors and to what degree affect the road sector?

Road authorities are those that set "goals" for managing the road network; these goals are motivated by the requirements posed by all stakeholders. Since "goals" define a generalized and ideal state for the road network, "objectives" are introduced in an effort to materialize a course of action towards reaching them (Talvitie, 1999). Achieving objectives is compared to "standards"; both objectives and standards are represented through performance measures (Thomas and Schofer, 1970). As noted by Haas *et al.* (2009), objectives set should consider the interests of all stakeholders, be quantifiable in the form of performance measures, and be related to achievable implementation targets (an example is presented in Figure 2.2).

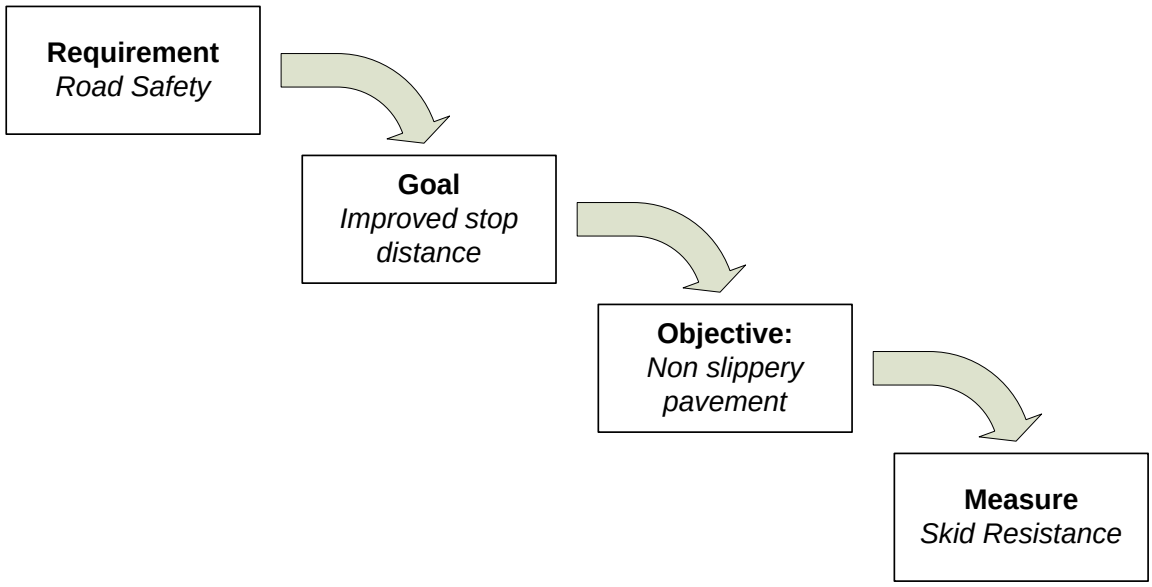

Figure 2.2. **Example relation of requirements, goals, objectives and performance measurement**

Given the above, performance measurement is linked to road authority goals and objectives, while it guides the authority towards prudent decision making. Indeed, performance measurement provides critical information for programming actions and, therefore, for meeting goals and objectives (Poster, 1997). Further, performance measurement is considered useful for reporting to, and communicating with, the users and the policy sector (Transportation Association of Canada, 2006). This is the case because, as noted by Pickrell and Neumann (2001), particularly publicly-funded authorities are under increasing pressure to be accountable to the public.

Finally, an important aspect of performance measurement is the clear distinction between the different types of potential measures involved in the road management process: (i) inputs; (ii) outputs; and, (iii) outcomes (Transportation Association of Canada, 2006). Input measures represent those resources needed for implementing a road management program, output measures reflect the product of that program, and outcomes focus on the agency's success in meeting their goals and objectives (Cambridge Systematics, 2000; Dalton *et al.*, 2005).

2.2 Performance indicators

Road network authorities collect and retain extensive datasets related to their services and the life-cycle of their infrastructures. It is important to note, however, that proper collection, analysis, refinement and presentation of that data is a prerequisite for using them and for proper reporting to a broader audience. As such, development of appropriate performance measures (or indicators) is required for linking transportation and infrastructure data for road management. OECD (1997) defines performance indicators as follows:

A tool enabling:

- The effectiveness of an operation or an organization to be measured; or,
- An achieved result to be gauged or evaluated in relation to a set of objectives.

Objectives related to introducing performance indicators may be the following (Humplick and Paterson, 1994; Haas *et al.,* 2009):

- *Physical condition assessment*, with respect to level of service offered, structural integrity and safety provision of infrastructures,
- *Support in management of the road network* in terms of decision making for investments, expenditures and operations,
- *Diagnosis of critical network elements* with respect to deterioration and remedial action related to decision making,
- *Tracking and monitoring of policies* with respect to their effectiveness and compliance with associated objectives,
- *Information provision* to road users and road service players,
- *Optimal allocation of resources* through the quantification of the efficiency of road investments and other road administrative activities,
- *Cost (and relevant data) tracking* with respect to construction and maintenance of road infrastructures and equipment.

Performance indicators can be exploited in a variety of manners, including in-house decision making and better communication between different road network stakeholders.

In this context, performance indicators are expected to measure, among other issues (Humplick and Paterson, 1994):

- Compliance with operational and policy objectives,
- Satisfaction of the road users with respect to network services,
- Efficiency of transportation service providers,
- The relationship between policy makers and the road administrator.

The NCHRP Report 446 (Cambridge Systematics, 2000) raises particular issues with respect to selecting performance indicators for a road network. First, performance indicators should be suitable for forecasting purposes in order to assess future conditions and characteristics of alternative road management programs. Second, indicators must be straightforwardly understood by stakeholders. Third, indicators should be useful; such measures should aptly reflect objectives and capture cause-effect conditions between the actions of administrators and their results. An indicator's ability to diagnose problems should be considered as well; the indicator should reflect those actions that affect it. Fourth is indicator selection process: temporal effects of the measure (is the measure comparable across time?), and compatibility to programming of actions (can the measure be used for developing a program of actions, budgeting and so on?). A summary of the most important properties of performance indicators are summarized in Table 3.1.

Table 3.1. **Major properties of performance indicators**

Property	**Description**
Relevance	The indicator must be relevant to the purpose it was developed for
Clarity	The indicator must be clearly defined
Reliability	Measurements for obtaining the indicator should not be affected from the process or person performing them
Precision	As precise measures as possible should be anticipated
Availability	An indicator should be… …readily available as long as the cost of obtaining them does not exceed their usefulness. …still useful and up-to-date when available to the road administrator

3. CROSS-COUNTRY ANALYSIS OF ROAD MANAGEMENT INDICATORS IN OECD COUNTRIES

Performance indicators in the road sector have been widely used by authorities worldwide both in developed and in developing countries. This review is largely based on available literature for OECD countries. This includes OECD's 1996 results of the Scientific Expert Group on Performance Indicators for the Road Sector (OECD, 1997) and the associated field test (OECD, 2000), COST 354 Action (focusing on pavements), a series of NCHRP Projects, as well as insights from Canada, Australia, New Zealand and Japan. It is noted that there exist a number of publications on performance measurement in developing countries, but these are not reviewed as part of this report (for performance indicators in developing countries see, among other reports, Zietlow, 2004).

3.1 OECD Scientific Expert Group on Performance Indicators for the Road Sector and Field Test

The OECD Scientific Expert Group on Performance Indicators for the Road Sector investigated performance measures for the road sector (OECD, 1997); following that, a field test was undertaken to define relevant indicators in detail (OECD 2000). A condensed version of that work was presented by Talvitie (1999); the author noted that the OECD expert group focused on: i) developing a conceptual model to be used by road authorities in order to set up their own indicators, ii) defining the most important performance indicators for the road sector, and iii) determining the manner in which performance indicators should be used to contribute to road authority network management. The group identified six categories of indicators that are most commonly used in OECD countries:

- Accessibility and mobility
- Traffic safety
- Environment
- Equity and community
- Road program development
- Road program delivery
- Road program performance.

The group concluded that road authorities had developed extensive data collection systems – inputs – along with analysis tools and procedures for deriving performance measures from their point of view (outputs). However, from the point of view of the remaining stakeholders (road users, policy makers and so on), findings on actual performance indicators that were used is practice were not very promising. As a result, the group's work was oriented towards developing a conceptual model which could support road authorities in developing and using performance indicators. The proposed model is depicted in Figure 3.1.

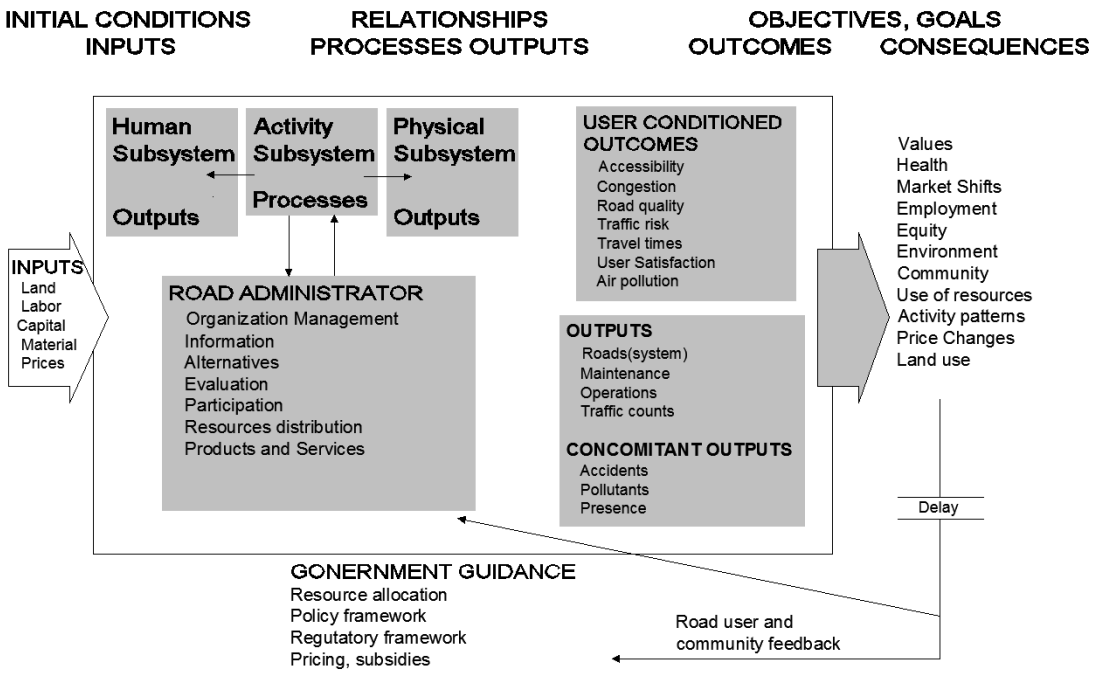

Figure 3.1. **OECD conceptual model for developing and using performance indicators**
(OECD, 1997).

Most important indicators identified - per category - by the OECD working group are presented in Talvitie (1999). These are organised according to categories and stakeholders and are presented in Table 3.2.

Table 3.2. **OECD 1997 expert group suggested performance indicators**
(Talvitie, 1999)

Category	Performance Indicator per Stakeholder		
	Road Policy Sector	**Road administration**	**Road user**
Accessibility mobility	✓ HCM Level of Service (percent) ✓ Average road user cost (car and truck) ✓ Composite access index ✓ Total transport cost/GNP	✓ Expenditures for maintenance and operation/veh-km ✓ ditto by functional class ✓ Travel time and its variability ✓ Quality of information to road users (from audit)	✓ Level of satisfaction regarding travel time, its reliability and quality of road user information ✓ Hours of congestion delay
Safety	✓ Accident risk: fatalities and injuries and/or fatal and/or injury accidents per veh-km ✓ Existence of National traffic safety program	✓ Method to assess the safety programs ✓ Percentage of traffic flow speeding (weighted) ✓ Percent of roads not meeting min design	✓ Unprotected road user risk ✓ Time from alert to treatment (medivac) ✓ Share of population that considers traffic accidents as a public

Category	Performance Indicator per Stakeholder		
	Road Policy Sector	**Road administration**	**Road user**
	✓ Percentage of accidents involving drunken driver	standards ✓ Exposure of pedestrians and cyclists to vehicle traffic	health problem
Environment	✓ Existence of air quality standards ✓ Cumulative land area taken by roads (%) ✓ New land area taken for roadway use ✓ Insp/maint prog'm for veh emissions	✓ Environment policy or program (y/n) ✓ Use of de-icing agents ✓ Emissions per capita for CO2, NOx, VOC, PM ✓ Pollutant concentrations in road run-off	✓ Percent of population exposed to noise levels > 65 db ✓ Percent of pop exposed to emission levels violating air quality standards
Equity	✓ Regional distbn of roads ✓ Laws for mobility limited, (y/n)	✓ Surplus (deficit) of road expenditures relative to road user charges collected by region	✓ Travel cost, travel time by user group ✓ Accident risk by user group
Community	✓ Processes for public participation and to reconsider prior decisions	✓ Processes in place for market research and customer feedback (y/n)	✓ Satisfaction with the number and types of feedback mechanisms
Program development	✓ Long-term programs for construction, maintenance, and operations (y/n) ✓ B-C analysis of the adopted road ✓ Program Projected level congestion	✓ Management systems for distribution of all the resources (y/n) ✓ B-C analysis of the (proposed) road program Quality Management Audit program (y/n)	✓ Satisfaction with the road program development process
Program delivery	✓ Sufficiency of maintenance funding ✓ Degree of completion of the long-term road program	✓ Forecast road costs vs. the actual ✓ Cost of operation/lane-km Overhead percent % construction materials recycled No. of staff/lane-km Percent of work by direct labor	✓ Satisfaction with the road program delivery ✓ Administration costs and user delay costs associated with maintenance
Program performance	✓ Value of assets ✓ Ex-post values of Benefit-Cost analyses ✓ Trends in road budget by program ✓ Return on assets Road exps/GNP	✓ Roughness (by road class) ✓ Bearing capacity (by road class) ✓ % Load posted bridges % ✓ Defective bridge deck area ✓ Congested roads – km ✓ Incidence of truck overloading ✓ Management system for road furniture	✓ Surface condition and satisfaction with road condition ✓ Rest areas/100 km % of ✓ Main roads lighted Quality of winter maintenance User info system (y/n)

3.2 COST Action 354

Organised in 2004 by the Forum of European National Highway Research Laboratories (FEHRL) and an additional 23 participants (delegates from European countries and the US Federal Highway Administration – FHWA), this four year COST action elaborated on unifying performance indicators for pavements in Europe. This was done by considering both users and authorities (Litzka *et al.*, 2008). Focus was given on the development of uniform indicators which would, in turn, be the basis for setting standards for pavements across Europe.

The Action defined a performance indicator for pavements as a measure representing a technical characteristic and indicating its condition, and introduced a performance index as its dimensionless equivalent. A consistent and robust procedure was developed within the Action for transforming indicators into indices. A number of individual performance indicators were identified for which indices would be developed, representing key pavement characteristics. Combined indicators were set up in more complex cases where pavement conditions were determined by a set of different characteristics (in the case of cracking and surface defects for example).

Four major Combined Performance Indices (CPIs) were the outcome of the action: the Safety Index, the Comfort Index, the Structural Index and the Environmental Index. The objective of each CPI was to determine the effect – contribution - of pavement condition into overall road network performance and not to become a comprehensive measure of road safety, comfort and so on. Next, a general performance indicator was developed as a combination of the individual and/or combined indicators. The role of that general indicator was to assist road network authorities in assessing their network's condition and into proceeding with programming maintenance and investment activities.

Part of the action was to set forth detailed tasks for deriving performance indicators. This included selection of input parameter, determination of appropriate functions for calculations, and estimation of weights for the composite as well as the general performance indicators. All processes were included in a spreadsheet-based software package which was custom created for this process. Performance indicators determined in the course of the COST action are presented in Table 3.3.

Table 3.3. **Performance indicators of the COST 354 Action**

Individual Performance Indicators	Combined Performance Indicators
1. Longitudinal evenness 2. Transverse evenness 3. Macro-texture 4. Friction 5. Bearing Capacity 6. Cracking 7. Noise 8. Air Pollution.	1. Safety Index 2. Comfort Index 3. Structural Index 4. Environmental Index.

3.3 Performance measurement in the USA

Performance measurement has been a topic of extensive discussion by road authorities in the USA since the mid 1990s. A series of National Cooperative Highway Research Program (NHCRP), AASHTO and Federal Highway Authority (FHWA), publications have investigated and presented performance measurement practice and trends in the USA. Interestingly, according to the NCHRP Synthesis of Highway Practice 243 (Neumann, 1997), among road authorities in the USA, "use of performance measures as a means of informing program goals and objectives is not widespread." At the same period, another NCHRP Report (Pointer, 1997), undertook a survey of state DOTs and described measures and techniques used for assessing functions of transportation organizations. The associated project's findings showed that performance measures were widely implemented for maintenance and safety, but the need existed for introducing measures oriented towards strategic decision making and outcomes. These measures would be directly linked to authority goals and objectives and explicitly consider quality and customer service.

NCHRP's guidebook for performance-based transportation planning – NCHRP Report 447 by Cambridge Systematics (2000) - aimed at establishing a rationale and providing practical guidance for performance-based planning and management. The objectives of the guidebook were to provide guidance and support to road authorities for:

1. Identifying needs and priorities and translating them into goals and objectives,

2. Deciding on a decisionmaking framework,

3. Determining the best manner for measuring performance in a specific organization, its network elements and systems, and,

4. Developing data collection processes and analytic methods for extracting useful performance indicators.

Besides the methodological approach which was presented in detail, the guidebook included a comprehensive presentation of performance indicators used in the USA; these were identified through a review of the literature, case studies and field visits. According to the goals and objectives of authorities, indicators were categorized as follows:

- Accessibility
- Mobility
- Economic Development
- Quality of Life
- Environmental and Resource Conservation
- Safety
- Operational Efficiency
- System Condition and Performance.
-

The guidebook focused on all modes of transport and therefore included performance indicators dedicated to rail and air transportation systems. The following Table (Table 3.3), presents examples of road indicators proposed by the NCHRP 447 report. It is noted that some indicators correspond to more that one of the aforementioned categories and are therefore repeated (Cambridge Systematics, 2000).

Table 2.3. **Example performance indicators for the road sector**
as proposed by NCHRP Report 447 (compiled by the author)

Category	Area of Application	Example Performance Indicators
Accessibility	Passenger or Freight Travel Time, Distance	✓ Average travel time from facílity to destination (by mode) ✓ Average travel time from facility to major highway network ✓ Accessibility index
	Passenger or Freight Roadway Condition, Capacity	✓ Total freeway lane-miles (or per capita or per measure of regional business volume or per square mile or fruck VMT)
	Passenger or Freight Customer Perception	✓ Perceived deficiencies ✓ User identification of access issues
	Freight Specific Roadway	✓ Average circuity for truck trips of selected O-D pattern, ✓ Number of truck-days of highway closure on major freight routes
Mobility	Passenger or Freight Travel Time, Speed	✓ Origin-destination travel times ✓ Total travel time ✓ Average speed
	Passenger or Freight Delay, Congestion	✓ VMT with congestion level ✓ LOS ✓ V/C ratio
	Passenger or Freight Amount of Travel	✓ VHT per capita, ✓ Total VMT ✓ Average daily traffic
	Passenger or Freight Reliability, Variability	✓ Percentage of on-time performance ✓ Minute variation in trip time ✓ Fluctuations in traffic volumes
	Passenger or Freight Customer Perception	✓ Customer perception of time it takes to travel to places people/goods need to go ✓ Customer perception of time it takes to drive through highway construction areas
	Passenger or Freight Financial	✓ Cost/benefit of existing facility vs. new construction, ✓ Number and dollar value of projects that improve travel time on key routes
	Freight Speciflc Roadway	✓ Delay per ton-mile traveled, ✓ Ton-miles traveled by congestion level, Capacity restrictions
	Passenger Specific Multimodal Travel Time, Delay	✓ PMT by congestion level, ✓ Origin destination travel times ✓ In-vehicle travel time
	Passenger Specific Multimodal Amount of Travel	✓ PMT per capita ✓ PHT, ✓ Passenger-trips per household
	Passenger Speciflc Automobile/Roadway	✓ Percent of lane-rniles of recreational routes operating below LOS D ✓ Vehicle ownership
Economic Development	Direct Impacts of Transportation	✓ Economic costs of pollution ✓ Economic costs of accidents ✓ Economic costs of lost time
	Transportation's Support of General Economy	✓ indirect jobs supported (or created)

Category	Area of Application	Example Performance Indicators
	Passenger or Freight	
	Transportation's Support of General Economy Freight Specific	✓ Economic indicator for goods movement ✓ Regional truck VMT per unit of regional economic activity/output
	Transportation's Support of General Economy Passenger Speciûc	✓ Economic indicator for people movement ✓ Percent of employers that cite difficulty in accessing desired labor supply due to transportation
Quality of Life	Accessibility, Mobility Related	✓ Customer perception of satisfaction with commute time ✓ Lost lime due to congestion
	Land Use Related	✓ Sprawl: difference between change in urban household density and suburban household density
	Safety Related	✓ Accidents (or injuries or fatalities) / VMT ✓ Accidents (or injuries or fatalities) / PMT ✓ Customer perception of safety
	Air Quality Related	✓ Tons of pollution (or vehicle emissions) generated ✓ Number of days that Pollution Standard Index is in unhealthful range ✓ Customer perception of satisfaction with air quality
	Noise Related	✓ Percent of population exposed to levels of highway noise above 60 decibels ✓ Number of residences exposed to noise in excess of established thresholds
	Other Environmental Related	✓ Customer perception of satisfaction with transportation decisions which impact the environment ✓ Customer perception of amount of salt used on trunk highways
	Project Delivery Related	✓ Customer perception of satisfaction with involvement in pre-project planning ✓ Customer perception of satisfaction with completed projects
	Employment Practices Related	✓ Compliance with affirmative action goals
Environmental and Resource Conservation	Air Pollution	✓ Tons of pollution (or vehicle emissions) generated, ✓ Highway emissions levels within non-attainment areas ✓ Tons of greenhouse gases generated ✓ Air quality rating
	Fuel Usage	✓ Fuel consumption per VMT ✓ Fuel consumption per PMT
	Land Use	✓ Sprawl: difference between change in urban household density and suburban household density ✓ Percent of region which is developed
	Salt Usage	✓ Amount of salt used per VMT or per lane-mile ✓ Customer perception of amount of salt used on trunk highways
	Government Actions	✓ Customer perception of satisfaction with transportation decisions which impact the environment ✓ Number of environmental problems to be taken care of with existing commitments

Category	Area of Application	Example Performance Indicators
	Miscellaneous	✓ Constraints to utilization due to noise (hours of operation) ✓ Constraints to utilization due to water (dredge fill permits) ✓ Number of accidents involving hazardous waste,
Safety	Number and Cost of Incidents	✓ Number of accidents per VMT ✓ Number of accidents per year ✓ Fatality (or injury) rate of accidents
	Infrastructure Condition Related	✓ Number of high-accident (or hazardous) locations, ✓ Accident risk index ('Safety Index')
	Incident Response	✓ Response time to incidents ✓ Average duration of incidents
	Customer Perception	✓ Percent of population which perceives that response time by police, fire, rescue/ or emergency services has become better or worse and whether that is due to transportation factors
	Motorist Behavior Related	✓ Number of accidents in which speed or traffic violation is a factor ✓ Number (or percent) of highway miles driven above speed limit
	Construction Related	✓ Construction fatalities/dollars of construction cost (or per 100 highway related crew) ✓ Number of accidents occurring in highway construction zones
Operational Efficiency	Financial Measures General	✓ Public cost for transportation system ✓ Private cost for transportation system
	Financial Measures Infrastructure Construction, Engineering and Administration	✓ Cost/benefit of existing facility vs. new construction ✓ Number and dollar value of projects that improve travel time on key routes
	Financial Measures Infrastructure O&M	✓ Infrastructure maintenance expense ✓ Maintenance cost of connector link ✓ Operational cost per toll transaction
	Financial Measures Vehicle, Traveler Operations	✓ Average cost per mile ✓ Average cost per trip ✓ Vehicle operating cost reductions
	Time, Speed Measures Infrastructure Construction, O&M	✓ Percentage of increase in number of days required for completed ✓ construction contracts over original contract days ✓ Units of work completed per hour worked
	Time, Speed Measures Vehicle, Traveler Operations	✓ Total travel time ✓ Average travel time from facility to destination ✓ Average speed
	Operational Measures Infrastructure Construction, O&M	✓ Percent of projects rated good to excellent in quality audits ✓ Percent of projects with no premature maintenance problems ✓ Percent of projects requiring few or no significant change orders due to plan
	Operational Measures Vehicle, Traveler Operations	✓ Number of projects (area and population) accessible to designated development centers ✓ VMT per mile of roadway ✓ Average daily traffic per freeway lane ✓ V/C ratio, V/C by route
	Perception Measures	✓ Management/employee satisfaction with progress

Category	Area of Application	Example Performance Indicators
	Infrastructure Construction, O&M	toward targeted focus area ✓ Management/employee satisfaction with diversity efforts
	Passenger or Freight Perception Measures Vehicle, Traveler Operations	✓ Customer perception of satisfaction with completed projects ✓ Customer perception of promises kept on project completion
	Passenger Specific Roadway	✓ Cost per vehicle for parking fees ✓ VMT/PMT Average vehicle occupancy ✓ Percent of vehicles using high-occupancy lanes
System Preservation	System Condition Roadway General	✓ Percent of VMT on roads with deficient ride quality ✓ Percent of roadway/bridge system below standard condition ✓ Remaining service life
	System Condition Roadway Pavement Details	✓ Percent of lane-miles by pavement condition ✓ Pavement quality index ✓ Remaining life of pavement ✓ New composite index incorporating roughness and distress (pavement), ✓ Roughness /ride index (IRI)
	System Condition Roadway Bridge Specific	✓ Percentage of highway mainline bridges rated good or better ✓ Scour criticality bridges) ✓ Frequency distribution of bridge element condition (Pontis)
	System Condition Roadway Freight Specific	✓ Percentage of state truck highway system rated good or better ✓ Miles of roadway not useable by certain traffic because of design or condition deficiencies
	System Condition Roadway Bicycle Specific	✓ Miles of highway rated 'good' or 'fair' for bicycle travel
	Program Delivery Time-Related	✓ Percent of contracts planned for letting that were actually let ✓ Number of lane miles let to contract for capacity improvements, Number of lane miles let to contract for resurfacing
	Program Delivery Cost-Related	✓ Net present value of future facility or bridge or pavement, equipment and facility capital, operating and maintenance costs, ✓ Percent of budget allocated to system preservation activities

Another NCHRP study (NCHRP Synthesis 311 by Shaw (2003)), focuses on performance measurement in highway operations in the USA. More than 70 performance measures were identified in the synthesis and their assessment was undertaken. Measures that straightforwardly report traveler experiences such as travel time, speed and delays, were recognized as the most successful for operations, while derived indicators were found to be more useful for policy makers (percent of network congested as an example). It was also suggested that the dimensions of operational performance most important for overall management were quantity and quality of travel (such measure were traffic volume, vehicle miles traveled and travel speed). Table 3.4 summarizes the operations-oriented performance measures discussed in the synthesis.

Table 3.4. **Performance measures for operations**
as determined by NCHRP Synthesis 311 (Shaw, 2003)

Performance Indicator	**Description**
Level of service (LOS)	Qualitative assessment of highway point, segment, or system using A (best) to F (worst) based on measures of effectiveness
Traffic volume	Annual average daily traffic, peak-hour traffic, or peak-period traffic
Vehicle-miles traveled	Volume times length
Travel time	Distance divided by speed
Speed	Distance divided by travel time
Incidents	Traffic interruption caused by a crash or other unscheduled event
Duration of congestion	Period of congestion
Percent of system congested	Percent of miles congested (usually defined based on LOS E or F)
Vehicle occupancy	Persons per vehicle
Percent of travel congested	Percent of vehicle-miles or person-miles traveled
Delay caused by incidents	Increase in travel time caused by an incident
Density	Vehicles per lane per period
Rail crossing incidents	Traffic crashes that occur at highway–rail grade crossings
Recurring delay	Travel time increases from congestion; this measure does not consider incidents
Travel costs	Value of driver's time during a trip and any expenses incurred during the trip (vehicle ownership and operating expenses or tolls or tariffs)
Weather-related traffic incidents	Traffic interruption caused by inclement weather
Response times to incidents	Period required for an incident to be identified, verified, and for an appropriate action to alleviate the interruption to traffic to arrive at the scene
Commercial vehicle safety violations	Number of violations issued by law enforcement based on vehicle weight, size, or safety
Evacuation clearance time	Reaction and travel time for evacuees to leave an area at risk
Response time to weather-related incidents	Period required for an incident to be identified, verified, and for an appropriate action to alleviate the interruption to traffic to arrive at the scene
Security for highway and transit	Number of violations issued by law enforcement for acts of violence against travelers
Toll revenue	Dollars generated from tolls
Travel time reliability	Several definitions are used that include (1) variability of travel times, (2) percent of travelers who arrive at their destination within an acceptable time, and (3) range of travel times

Further, the synthesis noted that measures referring to the number of persons or vehicles served (such as volume, VMT, PMT and Freight Volume), were the most important. These quantifiable measures were categorized as important since they were easy to collect and present, while other very useful measures could be derived from them (Fuel consumption, Noise impacts, and Air quality impacts as an example). It was also suggested that reported measures may be of lesser importance to stakeholders compared to derived measures.

Performance measures for asset management of roads were again investigated in NCHRP Report 551 (Cambridge Systematics *et al.,* 2006). The associated project focused on developing an understanding of the set of performance measures that can best serve

the principles of good asset management and to recommend procedures that can help an agency apply this understanding. The purpose of this study was to develop a methodology for:

1. Identifying performance measures appropriate for asset management. These measures would adequately cover investments for system preservation, operations and capacity expansion.

2. Determining specific indicators and setting associated targets for them. These targets would be compatible with authority needs and best practices.

The proposed framework for developing performance indicators is depicted in Figure 3.2.

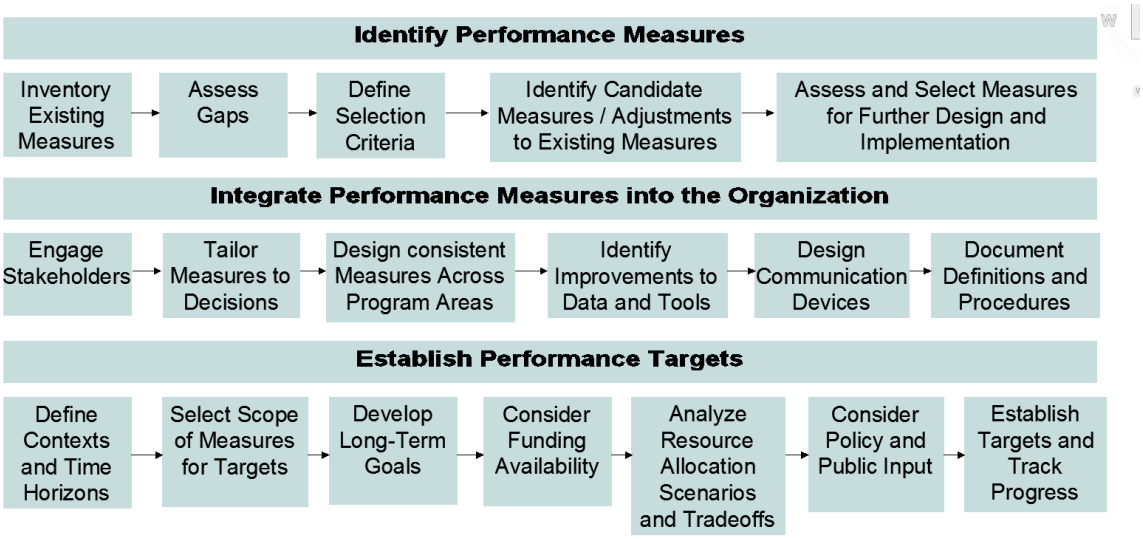

Figure 3.2. **Framework for performance indicator and target development,** as proposed by NCHRP Report 551 (Cambridge Systematics *et al.*, 2006)

The proposed framework consisted of three processes (also shown in Figure 3.2):

1. *Identifying Performance Measures:* Any existing indicators should be assessed, gaps in performance measurements should be pinpointed, and new indicators could be developed to complete these gaps.

2. *Integrating Performance Measures into the Organisation:* Involve stakeholders in performance measurement, organize groups of measures for different organizational levels and decision making, ensure measure consistency, identify possible enhancements in data collection and analysis tools, and improve documenting and reporting.

3. *Establishing Performance Targets:* these should be both long-term – desired or optimal – goals, as well as short- to medium-term (funding related) targets for performance measures.

Within this study, general categories of performance measures were defined as composites of previous categorizations found in NCHRP Report 446 (Cambridge Systematics, 2000), and the Federal Highway Administration report FHWA OP-03-080 (FHWA, 2003). They considered the potential relationship of indicators to authority goals and objectives (such as the use of the number of crashes to the goal of improving road safety), as well as the investment type relevant to them. The proposed categories are the following (Cambridge Systematics *et al.* 2006):

- *Preservation:* refers to the condition of the transportation system and actions to keep the system in a state of good repair,
- *Accessibility:* refers to the ability of people and goods to access transportation services,
- *Mobility:* refers to the time and cost of making a trip and the relative ease or difficulty with which a trip is made, essentially congestion and the trip measures related to congestion,
- *Operations and Maintenance:* refers to the effectiveness of the transportation system in terms of throughput and travel costs and revenues from a system perspective. Focus is also on maintenance level of service and customer experience with the system,
- *Safety:* refers to the quality of transportation service in terms of crashes or incidents that are harmful to people and damaging to freight, vehicles, and transportation infrastructure,
- *Environmental Impacts:* refers to the protection of the environment,
- *Economic Development:* refers to the direct and the indirect impacts of transportation on the economy,
- *Social Impacts:* refers to the effects of transportation on the broader society (for example neighborhoods adjacent to transportation facilities), or on different population groups (for example disadvantaged individuals),
- *Security:* refers to protection of travelers, freight, vehicles, and system infrastructure from terrorist actions,
- *Delivery:* refers to the delivery of transportation projects and services to the customer.

Based on that categorization, the report offers a number of example performance indicators that are shown in Table 3.5.

Table 3.5. **Asset management performance measures proposed by NCHRP Report 551**

Category	Area of Application	Example Performance Indicators
Preservation	Pavement Condition/ Ride Quality	✓ Average condition ✓ Percent miles in good/fair/poor condition
	Bridge Condition	✓ Average health index (0–100 scale) ✓ Percent with sufficiency rating less than 50
	Asset Condition (General)	✓ Percent length/count/area in good/fair/poor condition ✓ Percent length/count/area in "state of good repair"
	Remaining Life/ Structural Capacity	✓ Percent asset quantity with fewer than 5 years remaining service life (RSL) ✓ Average RSL
	Asset Value	✓ Replacement value ✓ Ratio of current value to replacement cost
	Backlog or Need	✓ Current value of cost to preserve assets in state of good repair over defined time horizon ✓ Ratio of deferred maintenance dollars to replacement value (facility condition index)
	Agency Financial Impacts	✓ Cost of emergency maintenance due to asset age or poor condition ✓ Agency cost due to deferred maintenance
	Customer Benefit or Disbenefit (or Surrogates)	✓ VMT-weighted average pavement condition ✓ Percent of VMT on roads in poor condition
	Customer Perception	✓ Customer rating of asset condition or agency preservation activities ✓ Customer satisfaction rating
Mobility and Accessibility	Congestion	✓ Level of service (LOS) ✓ Volume-to-capacity (V/C) ratio (facility-specific measure) ✓ Travel time index (ratio of peak travel time to free-flow travel time), Travel rate index (amount of additional time required due to congestion)
	Speed	✓ Travel rate (e.g., minutes per mile) ✓ Average speed for given roadway segment or origin-destination pair, Mobility index (VMT, PMT or ton-miles times average speed)
	Travel Time	✓ Average travel time (by mode or cross modes) for a given origin-destination pair or trip type 95-percent reliable travel time
	Travel Time Reliability	✓ Variation in average speed (location-specific measure) ✓ Standard deviation of travel time
	Delay	✓ Total hours of delay ✓ Relative delay rate (difference from target or standard) ✓ Congestion severity index (hours of delay per million VMT)
	Travel Cost	✓ Trip cost by mode for origin-destination pairs ✓ Vehicle operating cost increases due to congestion ✓ Travel time cost of congestion
	Accessibility to destinations	✓ Percent of target population that can conveniently reach a specific destination. ✓ Percent of working population within X miles of employment, PMT per capita

Category	Area of Application	Example Performance Indicators
	Accessibility to facilities and services	✓ Average time from snow event to bare pavement operations ✓ Percent of population within X miles or minutes of the state highway system
	Accessibility to different modes	✓ Modal split by trip purpose ✓ Average automobile ownership
	Backlog or Need	✓ Estimated cost to achieve a given performance level or to eliminate deficiencies ✓ Estimated cost of recommended work with benefit/cost ratio greater than 1
	Customer Perceptions	✓ Customer ratings of trip time, reliability, congestion severity, travel cost, travel time, and so forth ✓ Customer satisfaction with snow and ice removal
Operations and Maintenance	System operations efficiency	✓ See mobility measures (e.g., congestion and speed) ✓ VMT per lane-mile (per capita)
	Incident Response/ Winter Operations	✓ Average annual incident response time on limited access miles managed by ITS ✓ Average time to clear incident or percent of incidents cleared in less than X minutes
	Capacity and Availability	✓ Number of hours (or days) of road closure, ✓ Traffic signal malfunction rate
	Maintenance Level of Service	✓ Lineal feet of damaged guardrail ✓ Number of pieces of roadside litter per mile
	Cost Efficiency	✓ Average cost per lane-mile constructed ✓ Average operations and/or maintenance cost per lane-mile ✓ Construction and maintenance expenditures per VMT
	Occupancy	✓ Percent or number of multiple-occupant vehicles ✓ Average vehicle occupancy (by peak/off-peak, and location)
	Fuel Efficiency	✓ Average fuel consumption per trip by type (or shipment) ✓ Annual fuel consumption per VMT
	Backlog or Need	✓ Estimated cost to achieve a given performance level or eliminate deficiencies ✓ Estimated cost of recommended operational improvements with benefit/ cost ratio greater than 1
	Customer perceptions	✓ Customer ratings of facility operations and availability
Safety	Crashes	✓ Number of crashes by type, mode, system, location type, and so forth, Crash rates—number of crashes (by type) per 100 million VMT ✓ Percent reduction in crashes (by type)
	Crash Impacts	✓ Number of fatalities (or rate per amount of travel) ✓ Number of injuries (or rate per amount of travel) ✓ Hours of delay related to crashes
	Transportation Infrastructure	✓ Hazard index (location-specific measure) ✓ Number of locations with high crash rates or hazard indexes (exceeding defined threshold) ✓ Number of roadway sections (or percent of system miles) not meeting safety standards
	Need/Backlog	✓ Cost to implement identified safety countermeasures
	Customer	✓ Number of safety-related complaints

Category	Area of Application	Example Performance Indicators
	Perception	✓ Customer ratings of transportation facility safety or operational response to incidents
Economic Development	Economic Costs and Benefits	✓ Number of jobs within X minutes of population centers ✓ Transportation-related impacts: jobs created, percent of state or regional gross product, Economic costs of pollution
	Direct User Costs	✓ Average cost per trip ✓ Average cost per ton-mile
	Transportation Infrastructure Support for Freight Movement	✓ Road mileage converted to all-weather surfacing ✓ Road mileage upgraded to support truck traffic
	Support Improved Service to Existing Urbanized Area	✓ Extent to which projects fall within census urbanized area
	Support of Brownfield or Infill Sites	✓ Serves one or more Brownfield or infill sites (expressed as Yes/No on project basis; percent or qualitative measure on system basis)
	Customer Perceptions	✓ Percent of businesses that cite problems with transportation as a major factor in ✓ relocation, productivity, or expansion
Transportation Environmental Impacts	Vehicle Emissions	✓ Vehicular emissions by type—NOx, VOC, CO2, CO, ozone fine particulate matter (PM2.5) ✓ Tons of greenhouse gases generated
	Air Quality Standard Attainment	✓ Number of counties that experience isolated transport-related excesses over air quality standards ✓ Urban areas in nonattainment status
	Length or Extent of Air Quality Problem	✓ Number of days that pollution standard index is in the unhealthful range, Percent of time air quality is rated good at monitoring stations ✓ Number of days of air quality noncompliance
	Water Quality, Wetlands, Aquatic Life	✓ Acres of wetlands replaced or protected for every acre affected by highway Projects ✓ Level of fish habitat reduction as a result of new construction
	Hazmat Impacts	✓ Number of incidents involving hazardous materials (or rate per vehicle-mile of hazmat traffic)
	Energy Impacts	✓ Percent of vehicles using alternative fuels ✓ Average fleet-miles per gallon ✓ Fuel consumption per VMT, PMT, or ton-mile
	Noise Impacts	✓ Number of residences or percent of population exposed to highway noise ✓ exceeding established standards (or greater than X decibels) ✓ Percent of road network (including concrete sections) with quieter road surface by 2010
	Recycling	✓ Amount (or percent) of recycled material used in road construction
	Completion of Mitigation Steps	✓ Number of environmental impact analyses, conformity analyses, or environmentally friendly partnership projects completed
	Customer	✓ Customer satisfaction with transportation decisions

Category	Area of Application	Example Performance Indicators
	Perceptions	affecting the environment ✓ Customer perception of air quality
Social Impacts	Social, Societal, Neighborhood, Community Quality of Life	✓ Percent of projects in which community is actively engaged ✓ Number of archaeological and historical sites that are not satisfactorily addressed in project development before construction begins
	Customer Perceptions	✓ Customer perceptions of highway project impacts
Security	Incident Rates	✓ Number (or rate per capita or number of travelers) of crimes at rest areas, bus stops, highways, and so forth by type or severity ✓ Value of losses from theft per capita, person-trip, shipment value, ton
	Prevention Activity	✓ Percent of facilities with specific security features (e.g., cameras, lighting, and guards) ✓ Percent of facilities passing security tests
	Customer Perceptions	✓ Percent of customers identifying security as a concern ✓ Change in customer concern about security over time
Delivery	Accomplishment	✓ Quantity of work completed ✓ Dollar value of work completed by type
	Quality	✓ Quality index (based on materials testing, pavement smoothness and inspection results) ✓ Percent of material samples meeting specification
	Efficiency	✓ Cost per lane-mile constructed ✓ Design costs as percent of construction dollars let
	Schedule and Budget Adherence	✓ Unprogrammed costs as percent of total ✓ Number of projects let versus planned for letting, Number of projects certified versus scheduled for certification
	Responsiveness	✓ Average response time to emergency work request ✓ Percent of work requests closed within X hours or days
	Backlog	✓ Ratio of work under contract to programmed work ✓ Backlog of programmed construction work to be let
	Customer Impact and Safety	✓ VMT impacted by work zones ✓ Lane-hours restricted due to construction ✓ Hours of delay due to work zones

NCHRP Web Document 97 was produced by Cambridge Systematics et al. (2006b), as the final outcome of a relevant research project funded by the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA). Its objective was to develop a manual providing recommendations and guidance for managing a freeway performance monitoring system that emphasized operations (particularly congestion and mobility). Based on a survey of existing practice, the guidebook answered questions such as which measures should be used, how measures can be developed, how performance results on freeways should be communicated and used in decision-making. For that purpose, the guidebook offered step-by-step procedures for answering the aforementioned questions. Part of the report was devoted to presenting appropriate performance measures; some of these are briefly presented in Table 3.6.

Table 3.6. **Performance Measures for Operations in Freeways**
as proposed in the NCHRP Web Document 97

Area of Application	Example Performance Measures
Outcome measures	
Congestion	✓ Travel Time Index Total Delay ✓ Percent of Congested Traffic
Travel Time Reliability	✓ Planning Time Index, ✓ Buffer Index ✓ On-Time Performance
Incident Duration	✓ Incident Prediction, ✓ Total Incident Duration, ✓ Road Ranger Dispatch Time Period
Customer Satisfaction	✓ Satisfaction with ITS Program, ✓ Satisfaction with Road Rangers, ✓ Satisfaction with Work Zone Program
Benefit/Cost Measures	
Benefit/Cost Measures	✓ Total ITS program benefits divided by total program cost
Output Measures	
System Coverage	✓ ITS Miles Managed ✓ Percent Centerline Miles Managed ✓ Number of ITS Devices
Traffic Flow	✓ Average Volume ✓ Average Occupancy ✓ Average Travel Time ✓ Average Density
Incident Management	✓ Total Number of Incidents ✓ Incident Level ✓ Incident Delay Reduction
Freeway Patrol Service (FPS)	✓ Number of FPS Assists, ✓ FPS Assistance Duration ✓ FPS Response Time
System Performance	
ITS Field Equipment and Communications Equipment	✓ Operational Field Equipment Existing TMC Operators ✓ Mean Time to Repair ✓ Mean Time Between Failures
TMC Software and Hardware	✓ Device/Module Uptime Percentage ✓ Calls Sent to IT Helpdesk ✓ Helpdesk Calls Outstanding
Freeway Service Patrol Dispatch and Management	✓ Operator Man-Hours ✓ FSP Dispatch Man-Hours ✓ FSP Operator Man-Hours
Work Zone Management	✓ Average Volume ✓ Maximum Hourly Volume ✓ Capacity Loss ✓ Percent VMT through Work Zone
Road Weather Management	✓ Number of Weather Stations Deployed ✓ Number of Responses Due to Weather Detection ✓ Lane-Miles Affected
Traveler Information	
Web Site Operations	✓ Number of TMC Web Site Visits ✓ TMC Web Pages Visited ✓ Referring Web Sites
Dynamic Message Signs	✓ Number of DMS Systems ✓ Lane-miles of DMS Coverage ✓ Percent DMS Operational

Area of Application	Example Performance Measures
Call Center Operations	✓ Call Duration ✓ Call Answer Time ✓ Number of Calls Taken
Broadcast Media Operations	✓ Number of Radio, TV Stations Broadcasting Information
Call Box Usage	✓ Number of Call Boxes ✓ Call Box Usage
Freeway Management	
Ramp Meters	✓ Number of Ramps Metered ✓ Average Vehicle Delay
HOV Management	✓ HOV Lane-Miles ✓ HOV Lane Volume ✓ HOV Lane Speed versus SOV Lane Speed
Special Events Management	✓ Assistance to Police Managing Special Events
Other Systems	
Electronic Payment	✓ Traffic Volume through Toll Booth ✓ Number of Cruise Card Tolls ✓ Number of Cruise Card Lane Violations
ITS or CVO Operations	✓ Number Trucks Bypassing Weigh Stations Using Electronic Tags ✓ Number Trucking Companies Using Electronic Credentialing

AASHTO's report titled "Measuring performance across State DOTs" (AASHTO, 2006) investigated ways for state departments of transportation (DOTs) to increase their comparative performance through the use of performance measures. This was to be achieved by providing a basis for further collaborative development of comparative performance measures. According to AASHTO (2006), comparative performance measurement is defined as follows:

"The premise of comparative performance measurement among DOTs is that independent agencies in different states often share similar strategic goals with their peers, such as smoother pavement or improved mobility, but that in any grouping of peers, one or two agencies are likely to devise unique yet transferable business processes that enable better performance in these areas. The benefits of using more comparative performance measures include more communication among DOTs, greater awareness about best practices and innovations, improved business processes, superior performance, and increased responsiveness to customers' needs."

As part of the associated project, some comparative performance measures relevant to project delivery were tested with respect to their cross DOT acceptance and usability:

- *On-Time Performance:* Percentage of total projects finished on, or before, the original or currently scheduled completion date or duration,
- *On-Budget Performance:* Percentage of total projects for which actual final payments to the contractor lower than, or up to 110% of, the original bid level.

The report concluded "that small groups of state DOTs working together can successfully develop acceptable measures and compare performance in an area that is key to every DOT's mission." AASHTO goal was for the report to become a 'roadmap' for introducing comparative performance measurement in road agencies.

The most recent NHCRP report (Zietsman *et al.*, 2011) offers a practical approach and methodology for determining and applying sustainability oriented performance measures. In this manner it enables decision makers to address performance through a different perspective. The concept and principles of sustainability in transportation, related goals for road authorities, and associated performance measures are presented and discussed. The framework for developing sustainability related performance measures is depicted in Figure 3.3.

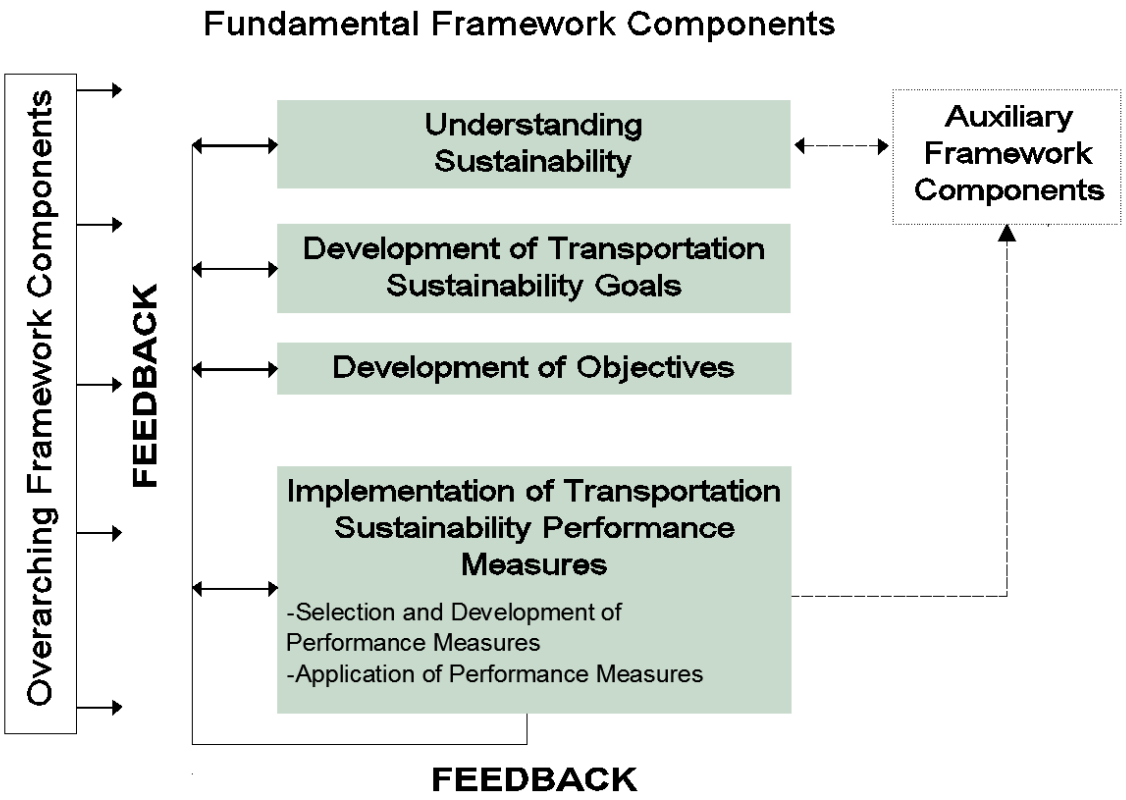

Figure 3.3. **Framework for developing sustainable performance measures**
(Zietsman *et al.*, 2011)

The framework consists of five steps part of a feedback loop; the first step involves understanding the concept and principles of sustainability. The second step is about developing relevant goals that are then translated into objectives in the third step. Examples of such goals are presented in Table 3.7. The fourth and fifth steps focus on developing and implementing related performance measures. Table 3.8 offers indicative objectives and performance measures that are among those presented in the report's compendium.

Table 3.7. **Proposed Sustainability Goals** (Zietsman *et al.*, 2011)

Goal	Description
Safety	Provide a safe transportation system for users and the general public.
Basic accessibility	Provide a transportation system that offers accessibility that allows people to fulfill at least their basic needs.
Equity/equal mobility	Provide options that allow affordable and equitable transportation opportunities for all sections of society.
System efficiency	Ensure that the transportation system's functionality and efficiency are maintained and enhanced.
Security	Ensure that the transportation system is secure from, ready for, and resilient to threats from all hazards.
Prosperity	Ensure that the transportation system's development and operation support economic development and prosperity.
Economic viability	Ensure the economic feasibility of transportation investments over time.
Ecosystems	Protect and enhance environmental and ecological systems while developing and operating transportation systems.
Waste generation	Reduce waste generated by transportation-related activities.
Resource consumption	Reduce the use of nonrenewable resources and promote the use of renewable replacements.
Emissions and air quality	Reduce transportation-related emissions of air pollutants and greenhouse gases.

Table 3.8. **Indicative sustainability objectives and performance measures** (Zietsman *et al.*, 2011)

Goal		Objective	Example Measures
Safety	Planning	Reduce the number and severity of crashes	*Change in the number and severity of crashes*
	Programming	Prioritize projects with explicit safety considerations	*Change in number of programmed projects with highest reduction in crashes out of all alternatives*
	Project Development	Develop projects that meet maximum safety requirements	Return on investment for individual project (reduction in the number and severity of crashes for the expenditure)
	Construction	Reduce crash risk in work zones	*Change in number of crashes per time unit within a particular work zone*
	Maintenance	Reduce crash risk in work zones	*Change in number of Crashes per time unit within a particular work zone*
	System Operations	Reduce crash risk on two- lane rural highways	Change in number of crashes by crash type on two- lane rural highways
Basic accessibility	Planning	Ensure accessibility to jobs	*Change in the number of jobs within reasonable travel time (by mode) for region's Population*
	Programming	Program projects that increase access to job opportunities	Change in the number of jobs within reasonable travel time (by mode) for region's population due to project

	Project Development	Develop projects that increase access to job opportunities	Change in the number of jobs within reasonable travel time (by mode) for region's population due to selected project alternative
	Construction	Reduce delay to commuters due to construction activities	*Change in travel time delay for commuters due to construction activities*
	Maintenance	Reduce delay to commuters due to maintenance activities	*Change in travel time delay for commuters due to maintenance activities*
	System Operations	Reduce travel time to jobs and other essential destinations through operational improvements	Change in travel time per mode per destination type
Equity/equal mobility	Planning	Ensure comparable transportation system performance for all communities	Change in level of service (LOS) for disadvantaged and nondisadvantaged neighborhoods
	Programming	Program transportation projects that improve transportation infrastructure equitably	*Change in ratio of Transportation disadvantaged to non-disadvantaged population benefitting from program*
	Project Development	Develop transportation projects that improve transportation infrastructure equitably	Change in ratio of Transportation disadvantaged to non-disadvantaged population benefitting from project
	Construction	Reduce delay due to construction activities equitably	*Ratio of disadvantaged to non-disadvantaged system users experiencing delay due to construction activities*
	Maintenance	Reduce delay due to maintenance activities equitably	*Ratio of disadvantaged to non-disadvantaged system users experiencing delay due to maintenance activities*
	System Operations	Reduce travel time to jobs and essential destinations through operational improvements equi tably and across all modes	Ratio of disadvantaged to non- disadvantaged system users experiencing reduced travel time due to operational improvements
System efficiency	Planning	Ensure that the transportation system is functional for all users	Change in volume/capacity ratio by functional class
	Programming	Program projects that maintain or improve the functionality of the transportation system for all users	Change in volume/capacity ratio [congestion reduction per unit (lane-mile)] due to program

	Project Development	Develop projects that maintain or improve the functionality of the transportation system for all users	*Change in V/C ratio [congestion reduction per unit (lane-mile)] due to project*
	Construction	Maintain the functionality of the transportation system during construction activities	Change in peak hour persons moved due to construction activities
	Maintenance	Maintain the functionality of the transportation system during maintenance activities	Change in peak hour persons moved due to maintenance activities
	System Operations	Implement operational improvements that maintain system functionality	Change in peak hour persons moved due to operational improvements
Security	Planning	Prevent incidents within a transportation agency's control and responsibility	Change in level of redundancy for critical passenger and freight infrastructure
	Programming	Program projects that prevent incidents within a transportation agency's control and responsibility	*Change in level of redundancy for critical passenger and freight infrastructure*
	Project Development	Develop projects that prevent incidents within a transportation agency's control and responsibility	*Change in level of redundancy for critical passenger and freight infrastructure*
	System Operations	Prevent incidents within a transportation agency's control and responsibility	Change in level of redundancy for critical passenger and freight infrastructure
Prosperity	Planning	Support growth in jobs and income by improving travel efficiency/reducing congestion	Change in average truck speed on major freight corridors
	Programming	Support growth in jobs and income by improving travel efficiency/reducing congestion through programming	Change in average truck speed on major freight corridors due to program

	Project Development	Develop projects that support growth in jobs and income by improving travel efficiency/ reducin g congestion	Change in average truck speed on major freight corridors due to project
	System Operations	Support growth in jobs and income by improving travel efficiency/reducing congestion	Change in average truck speed on major freight corridors
Economic viability	Planning	Ensure that the expected value of social and economic benefits created by proposed transportation projects exceeds their costs	Project-level cost/benefit ratio for proposed alternatives/policies, including freight
	Programming	Ensure that the expected value of social and economic benefits created by proposed transportation programs exceeds their costs	*Project-level cost/benefit ratio for proposed programs, including freight*
	Project Development	Ensure that the expected value of social and economic benefits created by major transportation projects exceeds their costs	*Project-level cost/benefit ratio for proposed projects and/or programs, including freight*
	Construction	Ensure that construction costs are within planned budget	*Proportion of projects with construction costs within planned budget*
	Maintenance	Ensure that maintenance costs are within planned budget	*Proportion of projects with maintenance costs within planned budget*
	System Operations	Ensure that operations costs are within planned budget	*Proportion of projects with operations costs within planned budget*
Ecosystems	Planning	Ensure that environmental and ecological systems function properly	Change in the number of formalized working partnerships (e.g., memorandums of understanding) with public and private environmental stakeholders
	Programming	Program projects that maximize ecological opportunities and ecosystem benefits	*Change in the percentage of projects programmed on the basis ofachieving priority ecologicaloutcomes*
	Project Development	Develop projects that maximize ecological opportunities and ecosystem benefits	Change in the percentage of project alternatives selected on the basis of achieving priority ecological outcomes

	Construction	Promote biodiversity during project implementation	Number of biological communities, species, populations, and genetic assemblages eliminated from effect zones due to construction
	Maintenance	Promote biodiversity during project maintenance	Number of biological communities, species, populations, and genetic assemblages eliminated from effect zones due to maintenance
	System Operations	Operate facilities to promote ecological opportunities, ecosystem benefits, and the building of natural capital	Change in number of projects using spatially related (i.e., GISbased) ecological condition inventories for managing healthy ecological systems
Waste generation Resource consumption	Planning	Reduce total waste created	Change in the amount of waste generated by type, weight, and/or volume
	Programming	Reduce total waste created by transportation projects	Change in the amount of waste generated by type, weight, and/or volume due to program
	Project Development	Reduce total waste created by transportation projects	Change in the amount of waste generated by type, weight, and/or volume due to project
	Construction	Reduce total waste created during construction	Change in the amount of waste generated byn type, weight, and/or volume duringconstruction
	Maintenance	Reduc e t ot al w ast e created during maintenance	Change in the amount of waste generated by type, weight, and/or volume during maintenance
	System Operations	Reduce total waste created due to system operations	Change in the amount of waste generated by type, weight, and/or volume due to system operations
	Planning	Maintain a sustainable Fleet	Change in the percentage of zero/low emissions vehicles in DOT fleet
	Programming	Encourage the sensible use of recycled materials in project programming	Existence of a policy or specification prioritizing the use of sustainablematerials in program
	Project Development	Develop projects that encourage the sensible use of recycled materials	Change in percentage of sustainable materials (by weight, volume, or dollar value) due to project
	Construction	Use biofuel for non-roadconstruction equipment	*Percentage of machine-hours or gallons of biofuel used during construction*
	Maintenance	Use biofuel for nonroad Maintenance equipment	*Percentage of machinehours or gallons of biofuel used during maintenance*
	System Operations	Maintain a sustainable Fleet	Change in the percentage of zero/low emissions vehicles in DOT fleet

Emissions and air quality	Planning	Reduce activity that generates pollutant emissions (travel, trip length, mode split, emissions)	Change in trips, vehicletrips, vehicle miles traveled (VMT), percentnon-driver, tons ofemissions per day
	Programming	Program projects that reduce pollutant emissions (travel, trip length, mode split, emissions)	Change in trips, vehicle trips, VMT, percent nondriver, tons of emissions per day due to program
	Project Development	Develop projects that reduce pollutant emissions (travel, trip length, mode split, emissions)	Change in trips, vehicletrips, VMT, percent nondriver,tons of emissionsper day due to project
	Construction	Reduce construction activity that generates pollutant emissions (engine operation, engine emission rates, idling time, emissions)	Engine hours of operation, emission rates, idling hours per day, tons of emissions per day due to construction
	Maintenance	Reduce maintenance activity that generates pollutant emissions (engine operation, engine emission rates, idling time, emissions)	Engine hours of operation, emission rates, idling hours per day, tons of emissions per day due to maintenance
	System Operations	Reduce congestion related Emissions	Change in the percent of VMT at low emission speed ranges, total vehicle delay, percent of approaching traffic that is stopped, multimodal level of service (by mode)

3.4 Performance measurement in Canada

Performance measurement usage in Canada is surveyed in two studies (Transportation Association of Canada, 2006; Haas et al. 2009). As noted by the Transportation Association of Canada (2006), most Canadian transportation authorities have introduced concepts of performance based planning and management. In some cases, authorities have incorporated performance measurement in their business plans, using indicators to evaluate their compliance to goals and targets and communicating them to various stakeholders. Based on a survey of authorities in twelve Canadian provinces and territories, the Transportation Association of Canada (2006) indicated five categories of outcome-oriented performance measures that were used by Canadian Authorities; these are summarized in Table 3.9.

Table 3.9. **Performance measures for Canadian Authorities**
(Transportation Association of Canada, 2006)

Area of Application	Performance Measures Used
Safety	✓ Accident rates per million vehicle kilometers (MVK) – most commonly used indicator ✓ Fatalities per MVK, Injuries per MVK ✓ Property damage only incidents ✓ Percent of incidents involving trucks per MVK ✓ Rail grade crossing incidents.
Transportation system preservation	✓ Pavements: Riding comfort (RCI), Surface distress (SDI), Structural adequacy (SAI), Pavement condition (PCI), Roughness (IRI), Pavement quality (PQI). ✓ Bridges: Bridge condition index, live load rating factor, Sufficiency rating index
Sustainability and environmental quality	✓ Noise, Environmental Evaluations
Cost effectiveness	✓ Net present value ✓ Net benefit/cost ratio ✓ Internal rate of return
Reliability	✓ Level of service ✓ Percent delay experienced in the system ✓ Percentage of urban vehicle-kilometers travelled in ✓ Congested conditions ✓ Annual total duration of unplanned highway closures greater than half an hour
Mobility/accessibility	✓ Average Speed, Traffic Volume

A subsequent 2008 project undertaken by Engineers Canada and the National Research Council Canada on "Development of a Framework for the Assessment of the State, Performance and Management of Canada's Core Public Infrastructure" (CPI) developed 32 key performance indicators in the road sector, using a slightly different categorization of objectives compared to the 2006 survey (Haas, 2008); these are shown in Table 3.10.

Table 3.10. **Performance measures for the Canadian road sector**
(Haas *et al.*, 2009)

Area of application	Performance measures used
Public Safety	✓ Condition rating ✓ Number of fatalities and injuries per million vehicle kilometers ✓ Number of accidents per million vehicle kilometers
Public Health	✓ Noise: actual dBa vs. acceptable level ✓ Emissions of GHGs, NOx, SOx, VOC
Mobility	✓ Actual traffic volume/design capacity ratio (congestion level) ✓ Average speed/ posted speed ✓ Number of restricted/closed lanes ✓ Number of load restricted roads ✓ International Roughness Index ✓ Comprehensibility of markings, signs and messages ✓ Percent of population within 1 km of surfaced road ✓ Number of days of snow and/or ice free surface ✓ Condition rating
Environmental Quality	✓ Vehicle emissions ✓ Emissions of GHGs, NOx, SOx, VOC, ✓ Energy use ✓ Vehicle noise (dBa vs. time) ✓ Protection against climate change impacts ✓ Use of recycled materials ✓ Materials consumption
Social Equity	✓ Percent of population within 1 km of surfaced road (Accessibility by road class) ✓ Vehicle operating costs ✓ Annual accident costs
Economy	✓ Benefit/cost ratio ✓ Total costs/capita ✓ Average cost per vehicle-km or per tonnes-km ✓ Cost-Effectiveness of programs ✓ Impact on business relocation, productivity or expansion ✓ Asset value
Public Security	✓ Protection against deliberate acts ✓ Response time to incidents

3.5 Performance measurement in Australia and New Zealand

Austroads has been developing and implementing performance indicators for Australia and New Zealand since the mid 1990's (Austroads NPI, 2011). Indicators cover the areas of economic, social, safety and environmental performance of road administrators in Australia and New Zealand. Since then, there have been 17 national performance indicator publications (the latest in 2011). These publications support road administrations in Australia and New Zealand in benchmarking themselves in the national

and international levels, and in identifying and implementing best practices when managing their road network (Austroads NPI, 2011). Austroads suggests ten sectional headings for organising performance indicators:

- Road safety
- Registration and licensing
- Road construction and maintenance
- Environmental
- Program/project assessment
- Travel time
- Lane occupancy rate
- User cost distance
- User satisfaction index
- Consumption of road transport, freight and fuel indicators.

Performance indicator information and values are available on-line at http://algin.net/austroads/site/index.asp, with some examples provided in Table 3.11.

Table 3.11. **Austroads Performance Indicators**

Area of Application	Performance Indicators
Road safety	Serious Casualty Crashes (Population Basis) Serious Casualty Crashes (Veh-km Travelled Basis) Road Fatalities (Population Basis) Road Fatalities (Veh-km Travelled Basis) Persons Hospitalised (Population Basis) Persons Hospitalised (Veh-km Travelled Basis) Social Cost of Serious Casualty Accidents (Population basis) Social Cost of Serious Casualty Accidents (Veh-km travelled basis)
Asset management	Smooth Travel Exposure
Program assessment	Return on Construction Expenditure
Travel speed	Actual Travel Speed (Urban) Nominal Travel Speed (Urban) Congestion Indicator (Urban) Variability of Travel Time (Urban)
Lane occupancy rate	Lane Occupancy Rate (Persons) Car Occupancy Rate
Congestion	Traveller efficiency Average travel time per 10 km performance indicator Average travel time per 10 km performance indicator (based on floating car survey data) Variation from posted speed performance indicator Variation from posted speed performance indicator (based on floating car survey data) Reliability (variability of travel time for a typical trip) performance indicator Reliability (variability of travel time for a typical trip) performance indicator (based on floating car survey data) Productivity Speed and flow performance indicator Speed and flow performance indicator (based on floating car survey data)
User satisfaction index	User Satisfaction Index

3.6 Performance measurement in Japan

Performance measurement in the Japanese road sector is presented by Nishio *et al.* (2006); the paper investigates improvements in road management in Japan by the introduction of outcome oriented performance measures along with performance based budgeting. Performance measurement was arranged in seven themes consisting of 17 indicators summarized in Table 3.12.

Table 3.12. **Performance indicators in the Japanese road sector**

Theme	**Performance Indicators**
Reducing traffic congestion - Smoothing traffic flows and countermeasures against global warming	✓ Time loss by traffic congestion ✓ Hours of road work ✓ ETC utilization rate ✓ Time loss due to interception at railroad crossings ✓ Quantity of CO2 emission in the transport sector,
Improving the environment - Conserving the environment along roadside	✓ Rate of achievement of NO2 environmental target ✓ Rate of achievement of SPM environmental target ✓ Rate of achievement of nighttime noise limits
Reducing traffic accidents - Creating safe and worry-free roads	✓ Rate of traffic accidents with death/injury ✓ Rate of barrier-free major roads around travel facilities used by an average of at least 5000 people/day
Linking regions - Improving freight transport and interregional co-ordination	✓ Rate of traffic on high standard roads ✓ Rate of major airports and ports with highway access
Preparing against disasters - Disaster prevention and maintenance	✓ Rate of cities where wide area rescue routes are ensured during disasters ✓ Rate of bridges with preventive maintenance
Improving regional attractions - Tourism Promotion	✓ Rate of trunk roads in urban areas without power/telephone poles
Reforming road administration – Improving accountability	✓ Degree of satisfaction of road users ✓ Number of website hits ✓ Rate of comprehensive cost reduction of road projects

4. PERFORMANCE TARGETS

As earlier discussed, among the objectives of performance indicators is their comparison with target values (requirements) introduced by road authorities. While target values may be case specific and often decided at a road authority level, some cases are found in the literature where performance targets for indicators are proposed at national levels. A categorization offered by NCHRP Report 551 (Cambridge Systematics *et al.*, 2006), is frequently used for providing cross-country information on performance targets; the categorization is the following:

- Pavement preservation
- Structure preservation
- Authority operational efficiency
- Capacity expansion
- Safety
- Environmental impacts.

4.1 Pavement and structure preservation

NCHRP Report 551 offers information on performance targets set by a number of states in the USA. Most states use composite performance measures which integrate different pavement characteristics (ride smoothness, cracking, rutting etc), such as the distress rating in Alabama (≥75), highway adequacy in Maine (≥60) and the maintenance assessment program in Texas (≥80% for interstate roads, ≥75% for other roads). Some states use the international roughness index (IRI) but do not keep any consistent values with respect to their targets.

Haas *et al.* (2009) report that IRI is used in Canada for pavement performance asessment, with pavement serviceability being excellent for values under 1, good for values between 1.5 and 1, fair for values between 2 and 1.5, and poor for values over 2. Further, 90% of the network is expected to have an IRI≤2. In addition, Haas *et al.* (2009) report some target information from pavement maintenance contracts awarded by New South Wales; these include a 4% increase in asset value, an IRI of under 4.5 for flexible and 5 for rigid pavements, limits on the extent of fatigue cracking (10% at the most for 10%-15% of the road network depending on the road type), an upper limit of 12-15 mm for rut depth on arterials and collectors, and road segments with remaining service life under 10 years.

As for structural preservation, information for a number of states is also given in NCHRP report 551; targets are applied for typical ratings such as the National Bridge Inventory (NBI) appraisal rating, the health index, and the sufficiency rating. These targets are commonly set as follows: a specific percentage of structures should exceed a lower value for the associated performance measure. For example, 75% of bridges in Delaware should have a NBI rating of at least 6, while only 10% should have a value lower that 4 for the same rating. In Japan, performance of structures is linked to

preparation against disasters; the rate of bridges with preventive maintenance would be approximately 100% for year 2007 (Nishio *et al.*, 2012).

4.2 Operational Efficiency

Some DOTs in the USA set targets for benchmarking operational efficiency. For example, in Florida the target cost for toll operations is set to 0.16$ per service. In Minnesota, average incident clearance time is set to 35 min and snow removal time for major arterials to 2-4 hours (Cambridge Systematics *et al.*, 2006). In Japan, the rate of cities with rescue routes in cases of disasters is set to 75% (Nishio *et al.*, 2012).

4.3 Capacity Expansion

With respect to capacity expansion, example targets include congestion, travel speeds, and the level of service (LOS). In the US for instance, Minnesota sets a maximum limit of 21% for congested urban freeways and a target of 90% of roads were minimum speeds are achieved. The state of Washington allows for a 'D' Level of Service for urban roads and a 'C' Level of Service for rural roads. Florida and Maryland set upper limits for traffic density (Cambridge Systematics *et al.*, 2006). Time loss due to congestion is an indicator considered in Japan, with a target of 10% annual decrease along with a "traffic rate" of 15% on high level roads (the traffic rate is defined as the ratio of vehicle-km in high standard roads to vehicle-km in the rest of the road network) (Nishio *et al.*, 2012).

4.4 Safety and the Environment

Japanese authorities have set some standards for both safety and the environment; these include (Nishio *et al.*, 2012):

- Environment
  - Quantity of CO2 emission in the transport sector: 250 million tons of CO2
  - Rate of achievement of NO2 environmental target: 90%
  - Rate of achievement of SPM environmental target: Maintain current target
  - Rate of achievement of nighttime noise limits: approximately 72%.

- Safety
  - Rate of traffic accidents with death/injury: approx. 108 accidents/100 million vehicles/km
  - Rate of barrier-free major roads around travel facilities used by an average of at least 5000 people/day: approx. 50%.

With respect to safety, US DOTs use mostly crash rates (0.73 for a three year average in Minnesota), fatalities (550 for a three year average in Minnesota, reduction by 10% by year 2010 in Pennsylvania), and fatality and injury rates (1.8 deaths and 10.22 serious injuries per 1,000,000 VMT in Idaho over a five year period). Example environmental targets set by Maryland include the maximum rate of transportation related emissions to total emissions (33.9% for NOx and 40.2% for VOC).

5. PERFORMANCE-BASED CONTRACTING

Performance based contracting is among those approaches currently promoted for maintaining and managing road networks. Contrary to traditional road maintenance approaches where contractors are reimbursed based on the amount of work undertaken, performance based contracts (PBC) relate payments to contractors according to the outcome of their work and achievement of targets. Such contracts could potentially include management of infrastructures and activities such as drainage system, pavements, traffic and roadside assets, bridges, tunnels, traffic services, emergency response and snow & ice control (AASHTO, 2006).

Advantages of PBCs include transferring risk and responsibility of successful management to contractors, reducing maintenance costs, and providing motives for innovation and work quality (Sultana *et al*., 2012). However, these advantages cannot be achieved directly since, initially, levels of service decrease as contractors need to get acquainted with developing effective methods for maintaining the road network (Hyman, 2009). In the medium-term though, performance is improved to pre-PBC levels. The literature has discussed some successful cases of performance based contracts in Europe, Canada, Australia, Latin American and African countries since the late 1980's (Zietlow, 2004; Stankevich et al., 2005). In the USA, pioneering states in the field of PBC are Virginia, Florida and Texas (Hyman, 2009).

Performance measurement and selection of appropriate indicators is critical for successfully organizing and implementing PBC, since performance indicators and associated targets guide contractors towards providing expected maintenance results (Zietsman, 2004). Sultana et al. (2012) stress the importance of setting up proper indicators for assessing PBC contracts. They note that there are cases that road administrations set inappropriate performance measures for evaluating the effectiveness and efficiency of contractors. Performance measurement themes for PBCs have been proposed by de la Garza *et al.* (2009):

- Level of Service Effectiveness: The extent to which performance targets are met.
- Timeliness of Response: The response time to service request or maintenance needs is evaluated.
- Safety Procedures: The implementation of a safety program by the contractor
- Quality of Services: Customer perception with respect to the condition of the assets and contractor performance.
- Cost-Efficiency: Cost savings, if any, accrued as a result of engaging a contractor to perform PBC services.

Indeed, with respect to PBC, performance measures and targets should correspond to all aspects of the contract (The World Bank, 2006). According to the World Bank (2006), selected PBC performance indicators should address the following themes:

1. Road User Service and Comfort:
   - Road Roughness
   - Rutting
   - Skid resistance
   - Vegetation control
   - Lane-km availability for traffic
   - Response times to restore defects
   - Attendance at road accidents
   - Drainage off the pavement.

2. Road Durability:
   - Longitudinal profile
   - Pavement strength
   - Permissible extent of repairs before a more extensive periodic maintenance treatment is required
   - Degree of sedimentation (obstruction) in drainage facilities.

3. Management:
   - Regular progress reporting
   - Inventory updating
   - Maintenance history recording.

Zietlow (2004) reports that performance indicators for PBC should have particular characteristics including:

- Reflecting minimization of total system and user cost
- Satisfying comfort and safety of users
- Clearly defining and measuring a process objectively.

Commonly used performance indicators for PBC are presented by Zietlow (2004), Sultana *et al.* (2012); these indicators are shown in Table 4.1.

Table 4.1. **Example indicators used for PBC**
(Zietlow, 2004; Sultana *et al.* 2012)

Indicator	**Area of Influence**
International Roughness Index (IRI)	Vehicle operating cost
Absence of potholes Control of cracks and rutting	Safety and pavement performance
Friction between tires and the pavement	Safety
Siltation or other obstruction of the drainage system	Protection of pavements and Infrastructure, safety
Retro - reflexivity of road signs and markings	Safety

With respect to services, some examples of performance standards for paved roads are given by the World Bank (2006).

Table 4.2. **Typical LOS for paved roads** (World Bank, 2006)

Performance Standard	**Fair**	**Good**	**Very Good**	**Excellent**
Typical Traffic Volumes (Vehicles/day)	Less than 250	250 – 1000	1000 - 5000	5000 - plus
Potholes (Max Dia of any single pothole)	400mm	300mm	200mm	None allowed
Potholes(max number in any 1000m with diameter greater than 100 mm	10	5	1	None allowed
Patching (Response time)	28 days	28 days	14 days	7 days
Cracking (Response time)	28 days	28 days	28 days	28 days
Cleanliness of pavement surface and shoulders response time for safety related matters	8 hrs	4 hrs	2 hrs	1 hr
Cleanliness of pavement surface and shoulders response time for all other matters	14 days	7 days	5 days	3 days
Typical Traffic Volumes (Vehicles/day)	Less than 250	250 – 1000	1000 - 5000	5000 - plus
Rutting	4 cm	4 cm	3 cm	2 cm
Rutting (Response time)	56 days	56 days	28 days	28 days
Patching (Response time)	28 days	28 days	14 days	7 days
Raveling (Response time)	28 days	28 days	14 days	7 days
Loose Pavement edges (Response time)	28 days	28 days	14 days	7 days
Height of Shoulders vs. Height of pavement	7.5 cm	5.0 cm	5.0 cm	5.0 cm
Height of Shoulders vs. Height of pavement (Response time)	56 days	56 days	28 days	14 days
Paved shoulders (Response time)	56 days	56 days	28 days	28 days

Overall, PBC is a particular area or road management where indicators are introduced as a tool for determining and controlling the relationship between road administrators and service contractors. Given the penetration of PBC in modern road management, the need to define appropriate indicators by road administrators that are tailored for specific authorities is evident. Authorities should carefully select appropriate measures (potentially different than those already in use), in order to capture the efficiency and effectiveness of contractors undertaking PBCs.

6. CONCLUSIONS

Modern road management is performance based; both programming and implementation of maintenance and operational activities are driven by appropriately defined performance indicators. This report focused on reviewing performance requirements and indicators established by developed countries worldwide. Additionally, the concept of performance based maintenance and related contracts was presented as a modern approach for achieving sustainable financing for road maintenance and operations projects.

A review of major documents on performance measurement and indicators in the road sector in developed countries revealed a richness of information and proposed indicators. OECD has suggested a comprehensive yet relatively small group of indicators. These indicators should be accompanied by field tests to examine applicability and harmonization. Interestingly, indicators on economic development and security are not clearly defined within the existing categorization. On the other hand, reports by US organizations focus on methodological aspects and to a lesser extent on particular indicators. Example measures are frequently given as a result of surveys of departments of transportation of different States. Proposals for indicators for different performance categories are numerous; but, performance measures for operations exist only for specific road types (most commonly for freeways).

To this end, a report by AASHTO discusses the importance of comparative performance measurement among different road administrations. The Canadian and Australian-New Zealand experience suggests a restricted number of categories and straightforward performance indicators. Interestingly, for the case of Australia and New Zealand, environmental and equity indicators for the road sector are not provided. Finally, in Japan, a small set of performance indicators is reported; interestingly, some indicators focus on issues such as preparation against disasters; also, indicators on pavement preservation are absent.

Overall, taxonomy of indicators remains, to a large extent, similar for most parts of the World: infrastructure preservation, safety and security, environmental sustainability, mobility and accessibility and economy. Performance targets on the other hand are set on a case-by-case basis; each road administrator sets road network requirements at a national or a local level based on specific experiences, expectations, resource availability, and knowledge of local conditions and needs. A convergence between road administrations worldwide on both performance indicators and targets could be a difficult task, but it could be useful for benchmarking and resource allocation (EU funding for example).

Requiring specific performance targets could offer the basis for improved road maintenance by authorities. They could compare their performance against benchmarks and peer groups, and potentially revise procedures and approaches accordingly. In addition, PBCs is a particular area of road management where indicators are introduced as a tool for determining and controlling the relationship between road administrators and service contractors. Given the penetration of PBC in modern road management, the

need to define appropriate indicators by road administrators is evident. Authorities should carefully select appropriate measures - potentially different than those already in use - to capture efficiency and effectiveness of contractors undertaking PBCs.

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