CHAPTER 1

Introductory Concepts in Transportation Decision Making

The beginning is the most important part of the work.
—Plato (427–347 B.C.)

INTRODUCTION

The transportation system in many countries often constitutes the largest public-sector investment. The economic vitality and global competitiveness of a region or country are influenced by the quantity and quality of its transportation infrastructure because such facilities provide mobility and accessibility for people, goods, and services, and thereby play an important role in the economic production process. The new millennium is characterized by continued growth in commercial and personal travel demand, and transportation agencies and providers strive to keep their assets in acceptable condition so as to offer desirable levels of service in the most cost-effective manner and within available resources. Consistent with such efforts is the need for best-practices evaluation and monitoring of the expected impacts of alternative investment decisions, policies, and other stimuli on the operations of existing or planned transportation systems and their environments. Such impacts may involve economics (such as quantified benefits and costs); economic development (such as job increases); environmental or ecological impacts (such as air, water, or noise pollution, community effects, and land-use shifts); and technical impacts (such as changes in facility condition, vulnerability and longevity, network mobility and accessibility, and facility and user safety and security). Methodologies for assessing such impacts generally depend on the types of impacts under investigation, the scope, and the project type and size; and a variety of disciplines typically are involved, including operations research, engineering, environmental science, and economics. It is important to view the evaluation of transportation projects and programs from a broad perspective, at both the project and network levels, that generally comprises overall system planning, project development, multiyear programming, budgeting, and financing. Furthermore, due cognizance should be taken of emerging or continuing trends in the transportation sector, as such trends often necessitate review of the traditional portfolio of impact types and scopes. In this chapter, we discuss the various phases involved in a typical transportation development process, and the importance of evaluation particularly at project development and programming phases.

1.1 OVERALL TRANSPORTATION PROGRAM DEVELOPMENT

In its most complex form, the development of a transportation program may involve an entire network of various facility types spanning multiple modes. In its simplest form, it may comprise a single project at a specified location. Regardless of its scope, the entire sequence of transportation development generally comprises the phases of network-level planning, development of individual projects, programming, budgeting, and financing (Figure 1.1). This sequence may have variations, depending on the existing practices of the implementing country, state, or agency.

1.1.1 Network-Level Planning

Network-level planning involves an estimation of travel demand for a general network-wide system on the basis of past trends and major shifts in the socioeconomic environment. In the United States, the transportation planning process comprises metropolitan and state-level planning, each of which is required to have short- and long-term transportation improvement programs (TIP). Various aspects of network-level systems planning include environmental inventories as well as inputs from the management systems for pavements, bridges, public transportation, intermodal facilities, safety, and congestion. These management systems help identify the candidate projects for improvements in facility condition, safety enhancement, and congestion mitigation. Transportation plans include long-range capital (e.g., new construction, added lanes) plans and a set of strategies for preservation and effective operations of all facilities on the network. A transportation plan is typically accompanied by a financial plan that not only involves the cash flows associated with needed physical improvements but also validates the feasibility of the transportation plan. Certain large MPOs are also required to develop a strategy for long-range congestion mitigation

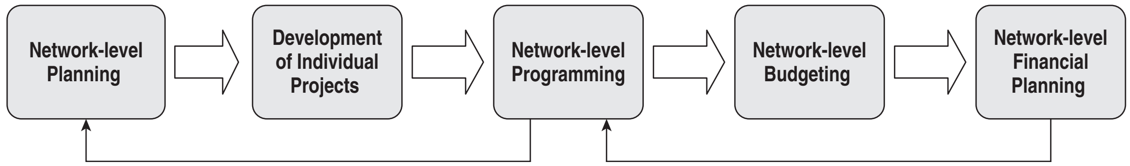

Figure 1.1 Phases of overall transportation development process.

and air quality management. Network-level systems planning is a continuous process that consists of:

- Inventory of current transportation facilities and use (travel)
- Analysis and forecast of population, employment, land use, travel data, and facility needs
- Establishing and evaluating alternatives for future facility physical components or policies

The evaluation step of network-level planning includes an assessment of conformity of the developed plan with other existing transportation improvement plans of the agency. At this phase, the major players are the federal, state, and regional agencies, as well as local governments and citizen groups. Special-interest groups also become involved through townhall meetings, public hearings, and other forums. Network-level planning yields a collection of selected projects that takes due cognizance of network-level needs. Relevant issues to be considered include the expected impacts of the network-level plan on existing land-use patterns, cooperation between various agencies, and a clear definition of the need for the proposed system. Legislation that needs to be considered at this step is related to issues such as air quality and energy conservation.

1.1.2 Project Development

This process is applied to each candidate project identified in the network, identification being through the long-range plan or through the various management systems. For each candidate, project development involves design, construction, management, operation, and postimplementation evaluation. At certain agencies, project development includes, as a first step, a project-level plan that is essentially a review of an existing overall transportation system plan for a region or network that includes the project corridor or area. In Section 1.2, we discuss the transportation project development phase in the context of an overall transportation program development process.

1.1.3 Programming

Programming involves the formulation of a schedule that specifies what activity to carry out and when. This is typically accomplished using tools such as ranking, prioritization, and optimization; the goal typically is to select the project types, locations, and timings such that some network-level utility is maximized within a given budget. Such utility, in the context of safety management, for example, could be a systemwide reduction in travel fatal crashes per dollar of safety investment. In the context of congestion management, the utility could be a systemwide reduction in travel delay per dollar of congestion mitigation investment; and in the context of bridge or pavement management, the utility could be a systemwide increase in facility condition, security, or longevity per dollar of facility preservation investment.

1.1.4 Budgeting

Although budgeting and programming are intertwined, programming yields a mix of projects to be undertaken during a given period, typically one to four years. Thus, setting the investment needs and budgeting involves a reconciliation of what work is needed and what resources will be available.

1.1.5 Financial Planning

An increasingly important aspect of transportation program development is financial planning. A financial plan or program is a specification of cash flows into (and in some cases, out of) a transportation facility over its entire period of implementation and operation, or part thereof. This step follows logically from the development of a program budget.

1.2 THE PROCESS OF TRANSPORTATION PROJECT DEVELOPMENT

A transportation *project development process* (PDP) can be defined as the sequence of activities related to the planning, design, construction, management, operation, and evaluation of a single transportation facility (Mickelson, 1998). PDP is a project-level endeavor that takes its input from an overall network-level transportation plan.

The process for developing transportation projects varies from agency to agency, due to differences in

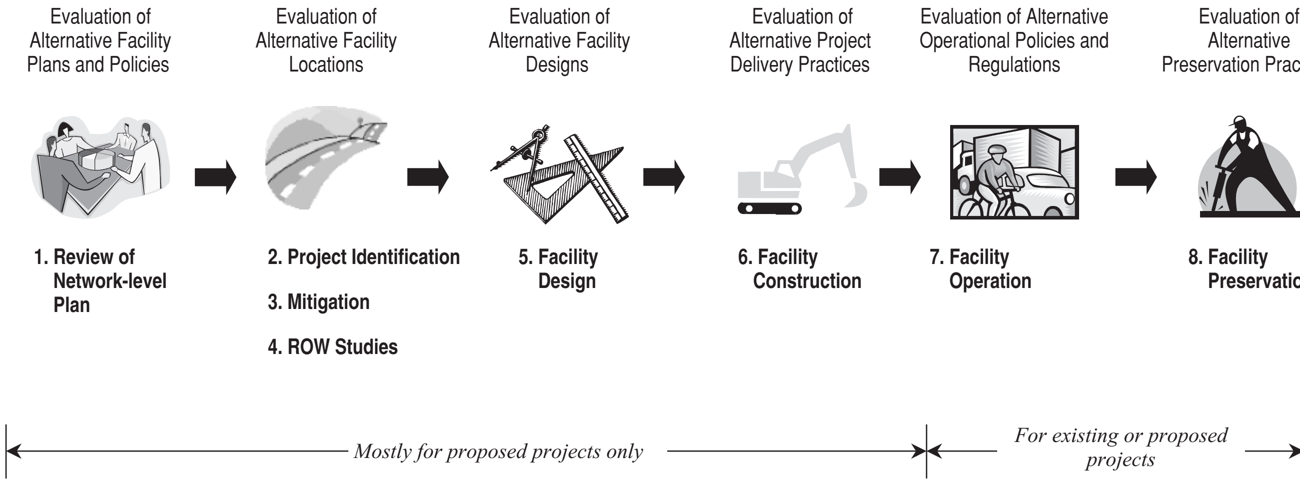

Figure 1.2 Steps for the project development process.

local requirements and conditions. The project development process is complex and resource intensive because it involves consideration of sensitive social, economic, environmental, cultural, and public policy issues. However, the overall PDP effort can be greatly facilitated by adopting good practices. The PDP often involves all levels of government: national, state (or provincial), and local. As illustrated in Figure 1.2, a PDP comprises several steps: a review of the network-level plan, particularly how it relates to the project in question, location planning and site selection, engineering design, construction, operations, and preservation. The tools for transportation systems evaluation are applicable at each of the PDP steps which are discussed briefly below.

1.2.1 PDP Steps

(*a*) *Review of the Overall Network-Level Plan with Focus on the Project Area* Overall network-level planning can be considered implicitly as an initial step of the PDP and is a continuous process. Even when a project involves only a single mode, its planning must be carried out in a multimodal context. Multimodal transportation planning defines transportation demand and supply problems for an integrated network that comprises all available modes, selecting alternative actions to mitigate any problems identified, evaluating such actions on the basis of their costs and effectiveness, and selecting the action that best satisfies technical, economic, and environmental considerations and meets community goals.

(*b*) *Project Identification and Scoping* This phase involves an individual portion (corridor, link, or node) of a network-level plan, includes location planning, and typically takes three to five years, depending on the project complexity. In general, the following steps are involved:

1. Evaluation of existing modal facilities and further study of the need and purpose of the proposed improvement
2. Collection and analysis of social, economic, and environmental data
3. Definition of alternative project corridors, links, or nodes
4. Informal public meetings
5. Draft environmental impact report
6. Location public hearings
7. Final report and environmental impact statement approval
8. Location approval

The project identification step includes the most sensitive aspects of a PDP. The heightened emphasis on the social, economic, and environmental impacts necessitates a comprehensive and objective approach to the collection and analysis of data relating to such impacts. Federal laws and regulations that need to be considered at this step concern ecology, natural resource (i.e., land, water, energy, etc.) conservation, air pollution, historic facility preservation, archeological resources, civil rights, property relocation and acquisition, and other factors. As a result, the influence of special-interest groups such as the Sierra Club, the Environmental Defense Fund, and the Center for Law in the Public Interest could be most visible at the project development step. Although the involvement of special-interest groups typically leads to increased project development time and cost, particularly for controversial projects, it should nevertheless be carried out. Another federal requirement at this step is the major investment study (MIS) for the proposed project corridor or surrounding subarea, especially when the project has a high cost estimate or is expected to have significant adverse impacts. The United States Department of Transportation (USDOT) (1994) provides details on the various issues that should be addressed by an MIS. Coordination among various state and local agencies is critical at the project identification and scoping phase.

(*c*) *Mitigation* This involves refinement of the project development plans and is carried out after approval of the location design. Such refinement is often necessary to reduce adverse impacts that are identified through public involvement and other means.

(*d*) *Right-of-Way Issues* Activities at this stage include land surveys, development of right-of-way plans, acquisition, compensation, or relocation of affected property. The Uniform Relocation Assistance and Real Property Acquisition Policies Act (1970) establishes procedures that must be followed when there is a need to acquire property falling within the right-of-way of federal funded highway or transit projects. The legislation seeks to ensure equitable and fair compensation to affected persons.

(*e*) *Facility Design* (*Including Preparation of Contract Documents*) This step involves preparation of detailed construction plans and drawings, technical and general specifications, and a schedule of quantities. In many cases, the design step of (PDP) also includes an invitation to bid, bid evaluation and selection, and preparation of contract award documents. This step may take two to five years, depending on project type and size, and typically includes:

- *Engineering design*
  - Engineering design studies and review
  - Public hearings on design
  - Final design
  - Approval of final design
  - Development or refinement of detailed plans and specifications
  - Project cost estimation
- *Contract administration*
  - Preparation of contract documents and invitation to bid
  - Evaluation of submitted bids and selection of best bidder
  - Contract award

At this step, the federal laws that need to be considered concern ecology, resource conservation (e.g., land, water, energy), and air pollution. Other federal requirements that need to be considered at the design step relate to design standards, policies, and specifications. For highway projects for instance, the Federal Highway Administration has established design standards, policies, and specifications based on American Association of State Highway and Transportation Officials (AASHTO) work to address highway-related issues such as pavement and geometrics (AASHTO, 1993; 2004), asset management and preservation (AASHTO, 2003), and traffic monitoring (AASHTO, 1990), among others. At the design step, relevant areas for evaluation include alternatives on material type (such as asphalt vs. concrete) and identification of optimal facility preservation practices over the life of a facility. Life-cycle costing, which can help identify optimal designs, is now a standard feature during the evaluation of design alternatives. Also, the need to consider the tort consequences of transportation design and operations is deservedly gaining increased attention (Cooley, 1996). Evaluation concerns in contract administration include alternative contractual practices (such as warranties vs. traditional contracts).

(*f*) *Facility Construction* Sometimes referred to as *project implementation*, the actual construction of a project may take two to five years. Depending on the type of contract, the transportation agency shoulders varying degrees of supervisory and quality control responsibilities. An example of the evaluation of transportation construction alternatives can involve the estimation of the costs and benefits of total highway closure vis-à-vis partial closure during facility reconstruction (Nam et al., 1999).

(*g*) *Facility Operation* The use of a facility is associated with a significant number of impacts on the ecology, agency resources, noise, and air pollution, among others. Evaluation of alternative operational policies can be used to identify best practices that would yield minimal cost and maximum benefits in terms of environmental degradation, mobility, safety, accessibility, and agency resources. Examples include studies that have evaluated the overall impacts of stimuli such as changes in rail operating policies, post-9/11 changes in air and transit security measures, changes in highway speed limits, implementation of truck-only highway lanes, and so on.

(*h*) *Facility Preservation* After a project is constructed, it needs continuous rehabilitation and maintenance. Life-cycle cost analysis may be used to determine the most cost-effective schedule of rehabilitation and preventive maintenance treatments over the project's remaining life (Colucci-Rios and Sinha, 1985; Markow and Balta, 1985; Murakami and Turnquist, 1985; Tsunokawa and Schofer, 1994; Li and Madanat, 2002; Lamptey, 2004), or to determine the optimal funding levels to be set aside for preventive maintenance activities within periods of rehabilitation (Labi and Sinha, 2005). Also, it may be required to identify, at a given time, the most cost-effective practices, including treatment type (such as microsurfacing vs. thin asphaltic overlay), material type (such as bitumen vs. crumb rubber for crack sealing), work source (such as contractual vs. in-house), or work procedure.

1.2.2 Federal Legislation That Affects Transportation Decision Making

Figure 1.3 presents a time line of the historical developments in federal legislation related to transportation planning and programming. In what constituted the first formal recognition of the need to consider the consequences of transportation development and public input in transportation decisions, the Federal Highway Act of 1962 established the continuous, comprehensive, and cooperative (3C) planning process for metropolitan areas.

Prior to the 1960s, probably the only federal legislative actions that affected PDPs (informal at the time) were the Rivers and Harbor Act of 1899 and the Fish and Wildlife Coordination Act of 1934. The 1960s were characterized by increased concern for the environmental impacts of human activity. In that decade, the PDP became formalized and the Land and Water Conservation Act and Wilderness Act were passed. The Historic Preservation Act in 1966 mandated that transportation agencies evaluate the impacts of their decisions on historic resources, publicly owned recreational facilities, wildlife refuges, and sites of historic importance. In 1969, the National Environmental Policy Act (NEPA) was passed and has since had a profound impact on transportation decision making. NEPA established a national environmental policy geared at promoting environmentally sound and sustainable transportation decisions. The type and scale of environmental studies required for each project depend on the certainty and expected degree of impact. For projects expected to have a significant impact, an environmental impact statement (EIS) is required. Categorical exclusion (CE) reports are prepared for projects that do not have any significant impact on the human and natural environment. Environmental assessment (EA) and finding of no significant impact (FONSI) reports or statements are prepared for projects where the scale of environmental impact is uncertain. If an EA suggests that there could be a significant impact, an EIS is prepared. Otherwise, a FONSI is prepared as a separate document.

In the 1970s, important legislation that affected the PDP included the Clean Air Act of 1970, the Endangered Species Act of 1973, and the Resource Conservation and Recovery Act of 1976. Also, in the wake of the 1973 oil crisis, energy conservation became a major criterion in the evaluation of transportation decisions. The 1970 Uniform Relocation Assistance and Real Property Acquisition Policies Act made available a set of procedures for compensation to owners of properties physically affected by transportation projects and required that for any new transportation facility in a metropolitan area, several alternatives involving TSM strategies be developed.

PDP-related legislation in the following decade seemed to focus primarily on funding issues but contained clauses that reinforced the importance of evaluating

Up to 1969	1970s	1980s	After 1990
Rivers and Harbors Act, 1899 Fish and Wildlife Coordination Act Federal-Aid Highway Act of 1950 Federal Aid Highway Act of 1956 Federal Aid Highway Act of 1962 Urban Mass Transportation Act National Historic Preservation Act National Environmental Policy Act Land and Water Conservation Act Wilderness Act Civil Rights Act	Uniform Relocation Assistance and Real Property Acquisition Policies Act Environmental Quality Improvement Act Clean Air Act Federal Water Pollution Control Act/Clean Water Act Resource Conservation and Recovery Act Wild and Scenic River Act Marine Protection Research and Sanctuaries Act Coastal Zone Management Act Endangered Species Act Archeological Resources Protection Act	Coastal Barrier Resources Act Comprehensive Environmental Response, Compensation and Liability Act Farmland Protection Policy Act Safe Drinking Water Act Surface Transportation and Uniform Relocation Assistance Act of 1987	Intermodal Surface Transportation Efficiency Act Americans with Disabilities Act National Highway Systems Act Transportation Equity Act of the 21st Century Safe, Accountable, Flexible, Efficient Transportation Equity Act – A Legacy for Users

Figure 1.3 Historical developments in federal legislation related to the transportation project development process.

the environmental impact of transportation decisions. Furthermore, the 1980s legislation appeared to give much importance to accessibility criteria, as a dominant share of the funding went to complete metropolitan connections to the interstate highway system.

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 had a significant impact on transportation decision making. It provided a foundation for subsequent establishment of the national highway system (NHS) and spawned several programs that emphasized aesthetics, mobility, and air quality impacts, such as the Scenic Byways Program and the Congestion Mitigation and Air Quality Program. Also, ISTEA brought about changes in the processes of planning, programming, coordination, and public involvement. It mandated the inclusion of management system outputs (this requirement was subsequently removed but is nevertheless being pursued by individual states) and made the entire PDP process more flexible and open to innovation (Mickelson, 1998). From the perspective of accessibility impacts, the NHS Act of 1995 helped to enhance linkages between intermodal facilities. Other legislation in the 1990s, such as the Americans with Disabilities Act, focused on the socioeconomic impacts of transportation projects or renewed the emphasis on water and air quality impacts.

The Transportation Efficiency Act of the 21st Century (TEA-21), passed in 2001, required state highway agencies to streamline the environmental clearance process in order to expedite project development. A key difference of TEA-21 from its predecessors is its consolidation of 16 previous planning factors into seven broad imperatives for inclusion in the planning process:

1. Support the economic vitality of the metropolitan area, especially by enabling global competitiveness, productivity, and efficiency
2. Increase the safety and security of the transportation system for motorized and nonmotorized users
3. Increase the accessibility and mobility options available to people and for freight
4. Protect and enhance the environment, promote energy conservation, and improve the quality of life
5. Enhance the integration and connectivity of the transportation system, across and between modes, for people and freight
6. Promote efficient system management and operation
7. Emphasize the preservation of the existing transportation system

The Safe, Accountable, Flexible, Efficient Transportation Equity Act—A Legacy for Users (SAFETEA-LU) of 2005 includes provisions for environmental stewardship and incorporates changes aimed at improving and streamlining the environmental clearance process for highway transit and multimodal transportation projects. Also included is an appropriate mechanism for integrating air quality and transportation planning requirements to facilitate the transportation project development process. In addition, SAFETEA-LU establishes highway safety improvement as a core program tied to strategic safety planning and performance. Fundamental in SAFETEA-LU are provisions aimed at reducing congestion, which will in turn save time and fuel, decrease vehicle emissions, lower transportation costs, allow more predictable and consistent travel times, and provide safer highways.

1.3 IMPACTS OF TRANSPORTATION SYSTEM STIMULI

1.3.1 Types of Transportation Stimuli

Synonymous with the words *change* and *intervention*, a *stimulus* may be defined as "an agent that directly influences the operation of a system or part thereof" and may be due to deliberate physical or policy intervention by an agency or to the external environment (Figure 1.4). External stimuli may be natural or human-made. Natural stimuli include severe weather events and earthquakes; human-made stimuli include facility overloads, interventions (facility repair by the owner or agency), and disruptions (terrorist attacks). Also, in the context of transportation decision making, stimuli may be categorized as *physical stimuli* (change in the physical structure) and *regulatory stimuli* (institutional policy or regulation of transportation infrastructure use). An example of a change in physical structure is the construction of a new road or the

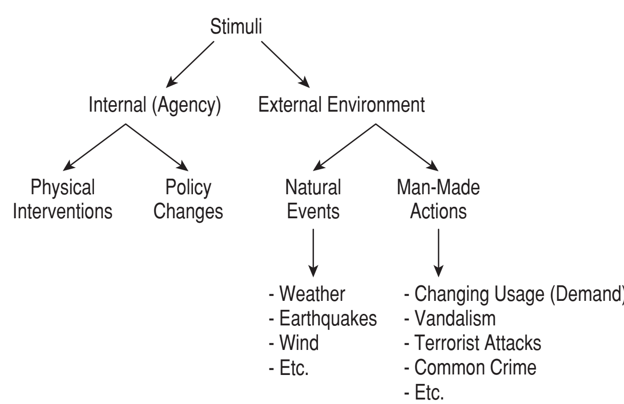

Figure 1.4 Classification of transportation stimuli.

addition of new lanes. Examples of institutional policy and regulation are speed limit and seat belt laws, respectively.

1.3.2 Impact Categories and Types

Identification of the various types and levels of impacts arising from a stimulus is a key aspect of transportation system evaluation and decision making. Given the multiplicity of stakeholders in transportation decision making, it is vital that all possible impact types be duly considered. Therefore, the various categories and types of impacts expected to occur in response to transportation system changes need to be identified prior to detailed analyses of the impacts. For example, the construction of a new transit line may affect (1) travelers (by decreasing their travel time), (2) the transit agency (by introducing a need for the agency to maintain the system after it has been constructed), (3) persons living near the transit line (by creating a noise pollution source), and (4) travelers on the network (by offering them new travel choices, and possibly changing their origin–destination patterns). In Table 1.1 and the sections that follow, we present briefly various categories and types of impacts of transportation system stimuli.

Table 1.1 Impact Categories and Types

Categories of Impact	Impact Types
"Technical"	Facility condition
	Travel time
	Vehicle operating cost
	Accessibility, mobility, and congestion
	Safety
	Intermodal movement efficiency
	Land-use patterns (including urbanization)
	Risk and vulnerability
Environmental	Air quality
	Water resources
	Noise
	Wetlands and ecology
	Aesthetics
Economic efficiency	Initial costs
	Life-cycle costs and benefits
	Benefit–cost ratio
	Net present value
Economic development	Employment
	Number of business establishments
	Gross domestic product
	Regional economy
	International trade
Legal	Tort liability exposure
Sociocultural	Quality of life

(*a*) *Technical Impacts* These impacts typically constitute the primary motive for undertaking improvements in a transportation system. The secondary (but no less important) impacts are the consequences or side effects of the stimulus. Technical impacts are described below.

Facility Condition: An improvement in the condition of a facility leads to a host of impacts, such as increased service life, reduction in vehicle operating costs, and decreased vulnerability to natural or human-made threats. There are established standards of facility characteristics and conditions that must be met, failing which a facility owner may suffer increased operational or safety liability risks.

Vehicle Operating Costs: In the course of using transportation facilities, vehicles consume fuel, lubricants, and other fluids; "soft" replacements such as wiper blades and tires; "hard" replacements such as alternators and batteries; and experience general vehicle depreciation due to accumulated weather and usage effects. VOCs are categorized as *running costs* (whose values are typically a function of vehicle speed) and *nonrunning costs* (whose values are largely independent of speed). In a network-level estimation of VOCs, it is important to recognize that networks having only new and small vehicles (on one extreme) would incur far lower average vehicle operating costs than would a network having only old and large trucks (on the other extreme). As such, the changing composition of the network-level vehicle fleets, as well as the relationship between running cost and age (for each vehicle class), are important (Heggie, 1972). The changing fleet composition is best tracked using cohort analysis (Mannering and Sinha, 1980).

Travel-Time Impacts: For a given project, the travel-time impact is the product of the reduction in travel time (in vehicle-hours) and the value of travel time per unit vehicle and per unit hour. If vehicle occupancies are known, the analysis can be done in terms of persons rather than vehicles.

Accessibility, Mobility, and Congestion: For already developed transportation networks, a desired impact of system improvements [e.g., lane additions, high-occupancy-vehicle (HOV) and bus rapid transit (BRT) facilities, intelligent transportation system (ITS) implementation, ramp metering, signal timing revisions] may be the mitigation of traffic congestion. On the other hand, in rural areas of developing countries, system improvement may be expected to provide accessibility to markets, health centers, agricultural extension facilities, and so on. In both cases, system improvements can lead to enhanced mobility of people, goods, and services.

Safety: Increased transportation system safety is typically due to diverse safety enhancement efforts including physical changes to a system and institutional changes such as educating the facility users and enforcing the operating laws and regulations. Safety enhancement may be due to direct implementation of such changes to address safety concerns (e.g., guardrail construction) or may be a secondary benefit of a larger project scope (e.g., pavement resurfacing, which enhances safety by improving skid resistance in addition to its primary objective of increasing pavement strength and service life).

Intermodalism: Physical or institutional changes in a transportation system can have profound effects on the efficiency or effectiveness of the overall intermodal transportation network in a region. For example, provision of additional links for a mode, or imposing or relaxing restrictions on the types and quantities of loads, can profoundly change the overall economics of freight delivery.

Land-Use Patterns: It is well known that changes in a transportation system cause shifts in land-use patterns, and vice versa. For example, highway construction and transit line extensions have been linked to changes in the extent and distribution of residential, commercial, and industrial developments.

Risk and Vulnerability: Recent world events have led to increased awareness of the need to assess the risk and vulnerability of existing transportation facilities or changes thereto. Thus, there are increasing calls to evaluate the impacts of system improvement (or deterioration) based not only on traditional impact criteria but also on the vulnerability of the facility to failure in the event of human-made or natural disasters.

(*b*) *Environmental Impacts*
Air Quality: Transportation-related legislation passed over the past three decades has consistently emphasized the need to consider air quality as a criterion in the evaluation of transportation systems.

Water Resources: Construction and operations of a transportation system can cause a significant reduction in both the quantity and quality of water resources, and it is often necessary to evaluate the extent of this impact prior and subsequent to project implementation. Construction or expansion of airport runway and highway pavements and other surface transportation facilities lead to reduction in the permeable land cover, reduced percolation of surface water, and consequent reduced recharge of underground aquifers. Surface runoff from such facilities often results in increased soil erosion, flooding, and degraded water quality.

Noise: The noise associated with transportation system construction and operation has been linked to health problems, especially in urban areas, and often merits analysis at the stages of preimplementation (i.e., the planning stage) and postimplementation evaluation and monitoring.

Ecology: The construction and operation of transportation facilities may lead to the destruction of flora and fauna and their habitat, such as wetlands. For a comprehensive evaluation of ecological impacts, a basic knowledge of ecological science, at a minimum, is needed.

Aesthetics: Transportation projects typically have a profound visual impact on the surrounding built or natural environment. Such impacts may be in the form of a good or bad blend with the surrounding environment, or obscuring an aesthetically pleasant natural or human-made feature.

(*c*) *Project Economic Efficiency Impacts*
Initial Cost: The cost of designing, constructing, preserving, and operating a transportation facility is an important "impact" of the facility. Of these, the construction cost is typically dominant, particularly for a new project. The definition of construction and preservation costs can be expanded to include the cost of associated activities, such as administrative work, work-zone traffic control, work-zone impacts to facility users (such as safety and delay), and diversions.

Life-Cycle Costs and Benefits: The life-cycle approach involves the use of economic analysis methods to account for different cost and benefit streams over time. The life-cycle approach makes it possible to consider the fact that an alternative with high initial cost may have a lower overall life-cycle cost. TEA-21 required the consideration of LCCA procedures in the evaluation of NHS projects (FHWA, 1998).

(*d*) *Economic Development Impacts* Economic development benefits of transportation projects are increasingly being recognized as a criterion for consideration in the evaluation of such projects. The impacts of transportation facilities in a regional economy may be viewed by examining their specific roles at each stage of the economic production process.

(*e*) *Legal Impacts* The operation of transportation facilities is associated with certain risk of harm to operators, users, and nonusers. With the removal of sovereign immunity in most states, agencies are now generally liable to lawsuits arising from death, injury, or property damage resulting from negligent design, construction, or maintenance of their transportation facilities. The growing problem of transportation tort liability costs is considered even more critical at the present time, due to increasing demand and higher user expectations vis-à-vis severe resource constraints. It is therefore useful to evaluate the impact of a change in a transportation system (project or policy) on the exposure of an agency to possible tort.

1.3.3 Dimensions of the Evaluation

It is important to identify the dimensions of the evaluation, as doing so would help guide the scope of the study and to identify the appropriate performance measures to be considered in the evaluation. The categories of the dimensions are presented in Table 1.2. The possible levels of each dimension are also shown.

(*a*) *Entities Affected* In carrying out project evaluation for purposes of decision making, it is essential to consider not only the types of impacts but also the various entities that are affected, as discussed below.

Users: User impacts include the ways in which persons using a transportation system (vehicle operators and passengers) are directly affected by a change in the system. User impacts typically include vehicle operating costs, and travel time, and safety.

Table 1.2 Evaluation Scopes of Impacts

Dimension (Scope)	Levels
Entities affected	Users Nonusers (Community) Agency Facility Operator Government
Geographical scope of impacts	Project Corridor Regional National and global
Temporal scope of impacts	Short term Medium term Long term

Nonusers (Community): Consideration of the effect of transportation systems on nonusers is necessary to ensure equity of system benefits and costs to the society at large. These impacts often include noise and air pollution, other environmental degradation, dislocation of farms, homes, and businesses, land-use shifts, and social and cultural impacts.

Facility Operator: Operators of transportation systems, such as shippers, truckers, highway agencies, and air, rail, water, and land carriers, may be affected by physical changes (e.g., improvements) and institutional changes (e.g., deregulation, speed limits) in a transportation system. This typically occurs through increased or decreased resources for operations (and in the case of rail operators, for facility preservation).

Agency: The impacts on a transportation agency are typically long term in nature and are related to the costs of subsequent agency activities. For example, system improvements may lead to lower costs of maintenance and tort liability in the long run.

Government: These impacts concern the change in the nature or level of the functioning of the city, county, state, or national government due to a change in a transportation system. For example, a new type of infrastructure, policy, or regulation for the system may lead to the establishment of a new position, office, or department to implement or monitor implementation of the change.

(*b*) *Geographical Scope* A well-designed study area is critical in transportation evaluation studies because the outcome of the analysis may very well be influenced by the geographical scope of the impacts. As shown in Figure 1.5, spatial scopes for the analysis may range from point or segmentwide (local), to facility- or corridorwide, to areawide (city, county, district, state, etc.) As the geographical scope of an evaluation widens, the impact of the transportation project not only diminishes but also becomes more difficult to measure, due to the extenuating effects of other factors. Specific geographical scopes are typically associated with specific impact types and affected entities. For example, in the context of air pollution, carbon monoxide concentration is a local problem, whereas hydrocarbons are a regional problem, and the emission of greenhouse gases is a global problem. Also, each geographical impact may be short, medium, or long term, in duration but wider geographical scopes are typically more associated with longer terms, as impacts often take time to spread or be felt over a wider area.

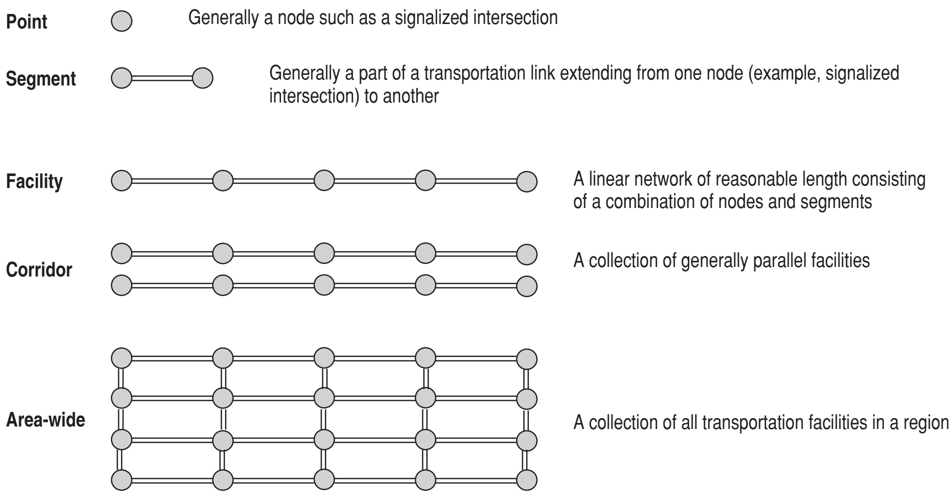

Figure 1.5 Spatial scopes of transportation systems evaluation.

Table 1.3 Suggested Relationships between Project Impact Categories and Dimensions

Impact Category	Temporal Scope of the Evaluation	Parties That Are Directly Concerned or Affected[a]			
		Users	Nonusers (Community)	Transportation Agency or Operator	Governmental
Technical (system preservation and operational effectiveness)	Short term	P	—	P	—
	Medium term	P	—	P	—
	Long term	P	—	P	—
Environmental	Short term	—	P, C	—	C, R
	Medium term	—	C, R	—	C, R
	Long term	—	C, R	—	C, R
Economic efficiency	Short term	P	—	P	—
	Medium term	P	—	P	—
	Long term	P	—	P	—
Economic development	Short term	—	—	—	C
	Medium term	—	C, R, N	—	C, R
	Long term	—	C, R, N	—	C, R, N
Safety and security	Short term	P	P, C	P, C	C
	Medium term	P	P, C	P, C	C, R
	Long term	P	P, C	P, C	C, R
Quality of life and sociocultural	Short term	—	P	—	—
	Medium term	—	P, C	—	—
	Long term	—	P, C, R	—	—

[a]P, project; C, corridor; R, regional; N, national or global.

(*c*) *Temporal Scope* A transportation system stimulus may have impacts that last only a relatively short time (e.g., dust pollution during facility construction) or may endure for many decades after implementation (e.g., economic development). Obviously, the temporal scope of the evaluation will depend on the type of impact under investigation and is also sometimes influenced by (or related to) the geographical scope of the evaluation and the entity affected. Temporal distribution of impacts can also be classified by the occurrence in relation to the time of the stimulus: during-implementation impacts vs. postimplementation impacts. For example, construction dust and topsoil disturbance constitute during-implementation impacts, whereas traffic noise during highway operation is a postimplementation impact. For the purpose of grouping impacts from a temporal perspective, the categories used are short, medium, or long term.

Table 1.3 presents the relationships among the various impact categories, temporal scopes of evaluation, and parties most affected by (or concerned with) the impact.

1.4 OTHER WAYS OF CATEGORIZING TRANSPORTATION SYSTEM IMPACTS

Depending on the viewpoint of the decision maker, there are several alternative or additional ways of categorizing the impacts of transportation stimuli (Manheim, 1979; Meyer and Miller, 2001) as discussed below.

(*a*) *Direct vs. Indirect Impacts* Direct benefits and costs are those related directly to the goals and objectives of the transportation stimulus and affect the road users and agency directly, whereas indirect impacts are generally by-products of the action and are experienced by society as a whole. For example, a major objective of speed-limit increases may be to enhance mobility (a direct impact), but may result in indirect impacts such as increased fuel use or increased frequency or severity of crashes.

(*b*) *Tangible vs. Intangible Impacts* Unlike intangible benefits and costs, tangible benefits and costs can be measured in monetary terms. Examples of tangible impacts are construction cost and increase in business sales due to an improved economy. Examples of intangible impacts are increased security (due, for example, to transit video surveillance) or the aesthetic appeal of a rehabilitated urban highway. The intangibility of certain impacts precludes an evaluation of all impacts on the basis of a single criterion such as economic efficiency. Therefore, in evaluating a system that produces both tangible and intangible impacts, the techniques of scaling the multiple criteria are useful. An alternative way is to monetize intangible performance measures using the concept of willingness to pay: for example, how much people would pay to see a specific improvement in the aesthetic appeal of a bridge in their community, and then use economic efficiency to assess and evaluate all impacts.

(*c*) *Real vs. Pecuniary Impacts* In assessing the impacts of transportation systems, it is important to distinguish between real costs or benefits [i.e., some utility that is completely lost to (or gained from) the world] and pecuniary costs or benefits (i.e., some utility that is related only to the movement of money around the economy). Real costs represent a subtraction from community welfare. An example is the cost of fatal crashes on the streets of a city. Pecuniary costs are costs borne by people or communities that are exactly matched by pecuniary benefits received elsewhere, so that although there is a redistribution of welfare, there is no change in total community welfare. The same definitions apply in the case of real and pecuniary benefits. An example is the increase in business relocations to a city due to improved transportation infrastructure. This would be at the expense of competing cities (located in the region) from which the businesses are expected to relocate; thus, there is no net welfare gain for the region. Failure to distinguish between real and pecuniary costs can lead to double counting of costs. It has been recommended that strictly pecuniary effects could be excluded from the evaluation. However, such effects could be included in the evaluation if the analyst seeks to investigate the redistributional impacts of the transportation system among population subgroups or among cities in a region.

(*d*) *Internal vs. External Impacts* For jurisdictional and administrative reasons, it may be worthwhile to consider whether system impacts are internal or external to the study area or analysis period defined at the initial stages of the evaluation procedure. Often, the benefits or costs of transportation system actions are felt beyond the study region or analysis period. For example, enhancement in air quality due to transportation improvements in a region may benefit another region located downwind. Also, the economic impacts of transportation system improvement may start to be realized only after the analysis period has expired.

(*e*) *Cumulative vs. Incremental Impacts* Cumulative costs or benefits are the overall costs and benefits from a preidentified initial time frame and include the impacts of the transportation stimuli. On the other hand, incremental costs and benefits are those impacts associated only with the transportation stimuli and are determined as the total impact after application of the stimuli less the the existing costs and benefits before application.

(*f*) *Other Categorizations* Heggie (1972) grouped transportation impacts from the perspectives of consumption of scarce resources, creation of additional consumption, and generation of non-monetary costs and benefits. Also, Manheim (1979) categorized transportation system impacts in two different ways: the party affected and the resource type consumed in constructing, preserving, and operating a transportation system.

Changes in a transportation system may result in desired outcomes with regard to some impact types and undesired outcomes with regard to others. For example, a new road in a town may yield improved travel time and accessibility but may have adverse impacts on pedestrian safety or the ecology. Stakeholders often have conflicting perceptions of the benefits of a transportation system change. As such, it is important to develop a methodology that incorporates all the various impacts, including social and cultural issues, to arrive at a single, balanced, impartial, and final decision. Unfortunately, in real practice, final decisions are sometimes made without regard to (or giving only minimal consideration to) the foregoing impacts.

In some countries or regions where transportation projects are sponsored by multilateral lending agencies, it may be required to measure the impacts, mostly in terms of economic benefits in which case economic efficiency impacts assume a dominant role in the evaluation process. In such cases, impact types such as vehicle operating costs, initial (construction) and preservation costs, and increased farm productivity are often given the highest priority in the evaluation process.

1.5 ROLE OF EVALUATION IN PDP AND BASIC ELEMENTS OF EVALUATION

1.5.1 Role of Evaluation in PDP

As seen in Figure 1.1, each step of the transportation project development process requires evaluation of alternative actions so that the best decision can be made to address the requirements of that step. The most visible (and probably the best known) traditional step that involves explicit evaluation of alternatives is the network-level or systems planning step, where projects are identified. The next common steps are those for site selection and facility design. With regard to impact type, the most common evaluation criterion that has traditionally been used for all steps is economic efficiency. Depending on the scale of a project, other criteria including environmental, economic development, and socioculture are also considered. In recent times, there are increasing calls to include system effectiveness and equity evaluation criteria such as system vulnerability and social justice. Evaluation of public projects therefore needs to give due cognizance to such concerns.

At any step of the PDP, any evaluation process should seek not only to identify the most optimal course of action, but also to investigate what-if scenarios because transportation systems are often characterized by significant risk and uncertainty. The sensitivity analysis should be for various levels of factors, such as system use (e.g., traffic volumes) and economic climate (e.g., interest rates), and should help reveal trade-offs between competing objectives. Given the importance of public participation in the decision-making process and the multiplicity of stakeholders, another important role of evaluation is consensus building. Performance measures for decision making are typically derived from conflicting interests and considerations. Evaluation can therefore generate an impartial solution that yields the highest "benefits" while incurring the least possible "cost" to all parties affected.

1.5.2 Reasons for Evaluation

Evaluation studies are typically needed for at least one of the following reasons (USDOT, 1994; Forkenbrock and Weisbrod, 2001)

1. *Assessment of proposed investments.* For decision-support purposes, an agency may seek to determine the impacts of several alternative project attributes (such as operating policies, designs, or locations). Methods used to determine these impacts range from questionnaire surveys to comprehensive analytical or simulation models. The output of such studies is typically a prediction of the outcomes expected relative to base-case scenarios.

2. *Special transportation development programs.* In some cases, the evaluation seeks to measure the effectiveness of a specific stimulus on a specific aspect of the transportation system, such as the impact of seat belt use on teen fatalities.

3. *Fulfillment of regulatory mandate.* Impact assessments are often required to ensure compliance with government regulations and policies.

4. *Postimplementation evaluation.* It is useful to assess the actual impacts that are measured after project implementation and to evaluate such findings vis-à-vis the levels predicted at the pre-implementation phase as well as base-year levels. Unfortunately, few agencies typically invest time and resources in such efforts.

5. *Public education.* In controversial project cases or for the purposes of public relations, a transportation agency may carry out the evaluation with the objective of increasing general public awareness of the expected benefits to the citizenry.

1.5.3 Measures of a Project's Worth

The choice of any particular evaluation parameter depends on the decision maker, the type of problem, and the available alternative actions that can be undertaken. In the course of evaluation, the relative and absolute assessment of the worth of a particular course of action is debated in relation to the existing situation or other alternatives. Two questions are raised:

1. How should worth be measured?
2. What unit of measure should be used?

The worth of a project differs for different stakeholders. For a given project, therefore, there are several (sometimes conflicting) measures of worth that often have different units. Some measures may not be easily quantifiable on a numerical scale. The challenge here is to bring to a common and commensurate scale the various aspects of worth and identifying the trade-off relationships that exist between them. For example, a proposed transit line may enhance accessibility but may involve destruction of some natural habitats. The question then would be how much ecological damage can be tolerated to gain a certain level of accessibility.

In public project decision making, it is sought to select the *best possible* alternative—one that can be considered a good (rather than optimal) choice, which means that it may not be possible to arrive at a true optimal solution because all conflicting interests may not be fully satisfied. However, the achieved solution can be a consensus solution that represents a good balance of all possible concerns known at the time of decision making.

After all possible courses of action have been screened for their appropriateness, adequacy, and feasibility for implementation, the resulting feasible courses of action are defined as *alternatives*. The alternatives are evaluated on the basis of the three E's or 3E triangle: efficiency, effectiveness, and equity (Figure 1.6). These may be considered the *overall goals* of evaluation.

1. *Efficiency:* indicates the relative monetary value of the return from a project with respect to the investment required. By evaluating efficiency, the analyst seeks to ascertain if the transportation project is yielding its money's worth. Therefore, efficiency involves economic analysis and accompanying concepts of life-cycle agency and user costing. However, the range of performance measures to be considered is much wider than that implied by efficiency considerations alone, as it includes nonmonetary or nonquantifiable performance measures.

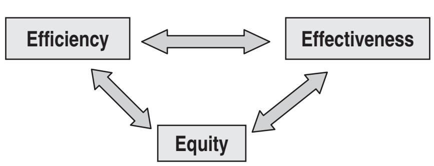

Figure 1.6 Basis of evaluation: the 3E triangle of overall goals.

2. *Effectiveness:* represents the degree to which an alternative is expected to accomplish a given set of tasks: in other words, just how well it attains the specified objectives. A clear understanding of the goals and objectives of the project is important to analyze its effectiveness. Effectiveness can include both monetary and nonmonetary or nonquantifiable benefits and costs, such as social well-being and aesthetic appeal.
3. *Equity:* can be measured in terms of both social and geographical equity in the distribution of both costs and benefits related to an alternative. Although equity can be incorporated within the effectiveness consideration, it may also be evaluated separately. Equity issues include whether low-income or minority populations bear a disproportionate share of the adverse impacts or whether they receive a proportionate share of the benefits of a transportation system change. Federal legislation such as the Civil Rights Act of 1964 and the Americans with Disabilities Act as well as the environmental justice requirements have led to the increased importance of equity considerations.

1.6 PROCEDURE FOR TRANSPORTATION SYSTEM EVALUATION

Most transportation agencies have established procedures that they follow in evaluating alternative policies or physical improvements to their assets. At some agencies, such procedures are not documented and thus vary from one decision maker to another. Formally documented evaluation procedures enable rational, consistent, and defensible decision making. Figure 1.7 presents the general steps that could be used to carry out the evaluation of alternative transportation system actions.

Step 1: Identify the Evaluation Subject The subject of evaluation depends on which step of the transportation project development process is involved. At the project identification step, an action can be new construction or modification of an existing asset. If the step under investigation is construction, the subject of evaluation could be an innovative system of construction delivery. Also, if the investigation pertains to the operations step, the evaluation subject could be a change in service attributes or operations policy, such as changes in the operation of a BRT system or a change in truck weight restrictions.

Step 2: Identify the Concerns of the Decision Makers and Other Stakeholders The next step is to identify stakeholders or affected parties, which could include the

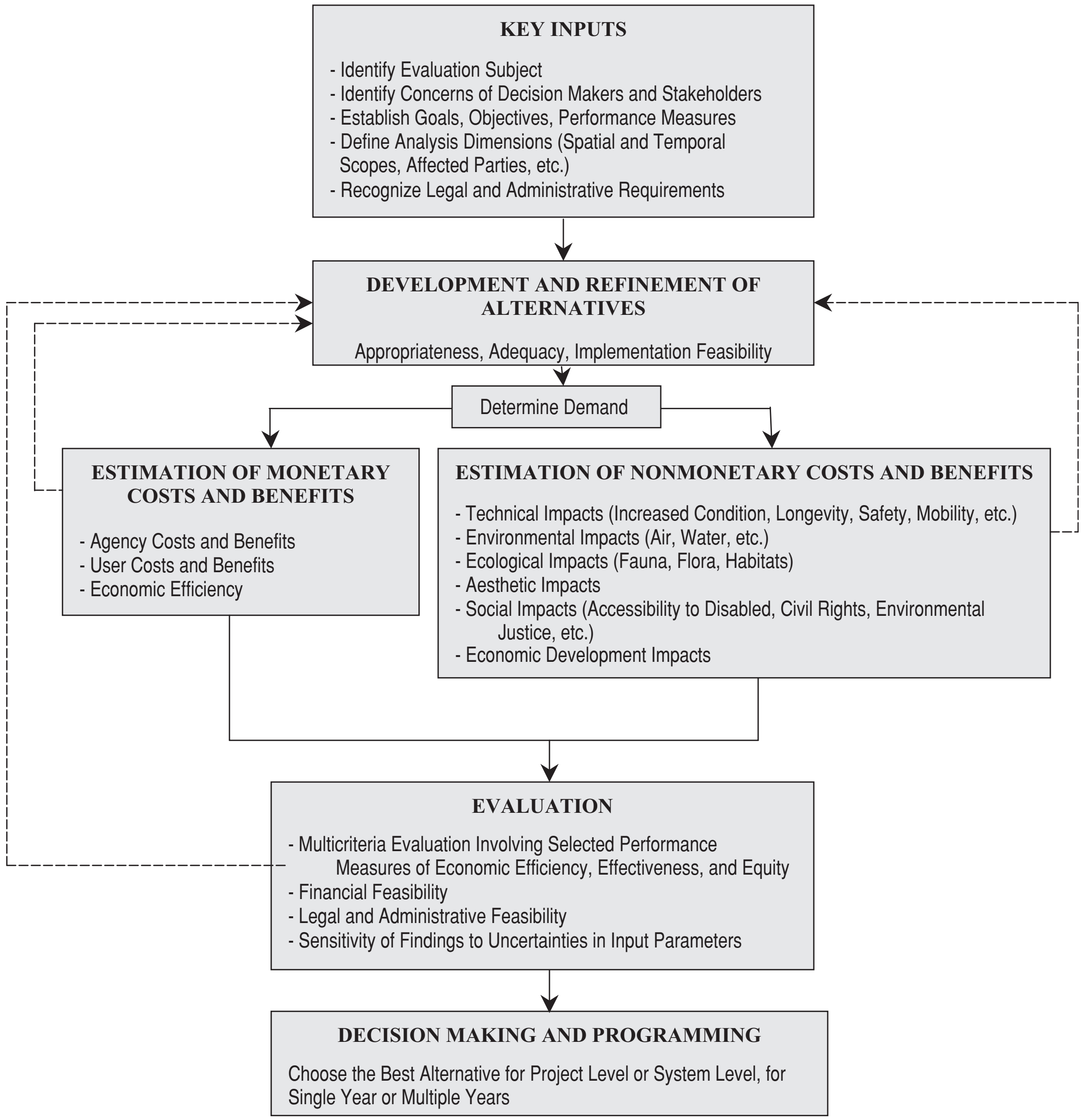

Figure 1.7 Procedural framework for transportation systems evaluation.

transportation agency that is responsible for the upkeep of the facility; the users of the facility, who reap direct benefits; and nonusers or the society as a whole. This step of the evaluation is important because it serves as a prelude to the development of the appropriate performance measures and dimensions of the evaluation (temporal and spatial scopes, etc.).

Strong local opposition can severely impede the possibility or progress of a transportation project or policy implementation. As such, early public involvement in the PDP is vital. Public involvement helps to identify stakeholders, affected parties, and interest groups (and their concerns); helps to identify the impacts that may have been overlooked by the planners; and also helps to determine the information needed to measure and mitigate the impacts expected. For major capital improvements, the involvement of the public is particularly necessary because such projects tend to have severe adverse impacts on the community and the environment. Before soliciting the input of the public, the decision makers need to decide on the timing, type, and level of public participation, to maximize the effectiveness of that effort.

Public participation can yield favorable results when the transportation agency interacts with the public in a way that demonstrates sincerity that the input from the public is valued and would be given due consideration. Public participation can also be used as a didactic instrument: to educate the public about favorable but not-so-obvious impacts of the proposed development. Public participation also affords the decision maker knowledge of public perceptions regarding the trade-offs among the various performance measures, including mobility and accessibility, air quality, and the economy. In soliciting public participation, the agency should remind the public that the best solution may not satisfy all interest groups and that a healthy compromise may be needed. The elements of effective public involvement include (NHI, 1995):

- Offering each interest group, a level of involvement and a type of interaction consistent with its requirements. Levels of interaction should range from Web site comments to detailed work sessions with the appropriate staff.
- Establishment of a proactive rather than a reactive program to inform the public and interest groups through the use of town hall meetings, print media, the Internet, and other mechanisms.
- Soliciting advice from representatives of citizens' associations and interest groups.

Step 3: Identify the Goals and Objectives of Transportation Improvement After the concerns of decision makers and other stakeholders have been identified, the objectives and goals of the evaluation process should be established to form the basis for the development of performance measures (measures of effectiveness). Goals are set to cover not only agency objectives, but also the perspectives of users, nonusers, and the government. The goals of the affected community provide an indication of the relative importance of various nonuser impacts and how the locality might react to such impacts. The most common community goals are mobility, safety, accessibility, and security. Other impacts of interest to the community are more long term in nature: environmental improvements, economic development impacts, downtown revitalization, and arresting urban sprawl. The early definition of goals helps not only in reaching an early consensus and compromise among conflicting interests, but also in identifying specific issues about the consensus reached. At this stage of the evaluation process, any documented material on regional or metropolitan goals and objectives should be collected and reviewed for consideration. Such efforts should include solicitation of information and perspectives from all stakeholders.

Step 4: Establish the Performance Measures for Assessing Objectives After identifying the goals and objectives for the proposed transportation stimuli, the performance measures or measures of effectiveness (MOEs) for each impact type can then be established. Examples of MOEs for multiple criteria that may be associated with a transportation action include the number of fatal crashes reduced (safety impacts), the number of jobs created (economic development impacts), the extent of natural habitat area damaged (ecological impacts), and the benefit–cost ratio (economic efficiency impacts).

Step 5: Establish the Dimensions for Analysis (Evaluation Scopes) The analyst should establish the boundaries of regions affected in the analysis: project, corridor, subarea, systemwide, regional, national, or even international. For any given impact type and temporal scope, different spatial scopes may have different approaches to the evaluation as well as different MOEs. The importance of certain impact types may differ from one spatial scope to another and even across temporal scopes.

Step 6: Recognize the Legal and Administrative Requirements Legal and administrative requirements typically encountered in a PDP include local ordinances, state statutes, and federal program requirements concerning the environment, safety, equity, and access. As discussed in Section 1.2.2, several laws and regulations have been passed over the last few decades in a bid to ensure efficiency in the decision-making process; to protect the environment, ecology, historical treasures, scenic beauty and so on; and to ensure equity. Also, the process of transportation system investment involves a multiplicity of administrative issues that need to be addressed. As such, the evolution of a transportation system stimulus from the conceptual stage through implementation involves a sequence that consists of formal notifications and requests; submission of engineering, economic, environmental, and other studies; approvals of requests and studies; and other administrative processes.

Identification and documentation of requisite legal and administrative processes is important because it helps the decision maker to define the various duties to be carried out by the transportation agency and the expected duties of other parties responsible for approving, reviewing, or commenting on the actions of the agency. Also, legal requirements need to be identified because they affect the establishment of performance measures and constraints and therefore have a great potential to influence the narrowing down of possible actions to selected alternatives and may even influence the choice of the best alternative.

Step 7: Identify Possible Courses of Action and Develop Feasible Alternatives All possible courses of action should be identified and should then be screened for their appropriateness, adequacy, and feasibility for implementation. The resulting feasible actions are defined as *alternatives*. Criteria that may be used to screen the possible courses of action are as follows:

- *Appropriateness*. Does the course of action address the specific goals or objectives sought by the decision maker? Does the alternative respond directly to other secondary considerations, such as community goals and needs?
- *Adequacy* (*of each alternative*). Does the course of action address the intended goals and objectives adequately? In other words, is the performance offered by the alternative within the standards for the performance measures?
- *Implementation feasibility*. Is it physically feasible to implement the alternative? Is there enough right-of-way? Is there sufficient technological know-how? Is the cost of implementing the alternative within the means of the agency?

On the basis of the above criteria step 7 should be carried out to ensure due responsiveness to existing goals and needs, generation of a suitable number of alternatives, and a transparent sequence of development the alternatives.

(a) *Responsiveness of Alternatives to Local Goals and Needs* For a corridor project that goes through several communities, the local goals and needs in each community should be considered along with corridorwide objectives. Traditionally, alternatives have been developed by considering single physical facilities and operating strategies. At the current time, however, multimodal approaches are increasingly being used in the development of alternatives. As such, any alternative is not considered as an independent entity but as a part of a larger network of multimodal facilities. Such an approach encourages consideration of a possible mix of modes, physical facilities (e.g., access policies and location), and operating strategies.

(b) *Optimal Range of Alternatives* How many alternatives should be established? The least number of alternatives is two: One is to carry out a proposed activity, and the other is to do nothing. Inclusion of the do-nothing or "no-build" alternative in the list of alternatives is required by NEPA, while at least one alternative involving transportation system management is required by major investment studies (MIS) procedures. The number of alternatives should be large enough to enable identification of trade-offs across the various performance goals and objectives. Alternatives that involve transportation demand management and pricing are not formally required by legislation but offer a low-cost benchmark and should be considered as much as possible (NHI, 1995). A fall-back alternative should be provided where feasibility of the "best" alternative becomes questionable for any reason. The number of alternatives should not be too many but rather, should be manageable.

(c) *Open and Documented Development of Alternatives* The development of alternatives typically involves three steps:

1. *Conceptual development:* where details are sketchy but enough is known to state the intention to carry out the transportation development
2. *Detailed development:* where enough detail is developed to support analyses
3. *Final development:* involves a systematic process of evaluating and modifying the detailed alternatives (decisions are documented at this stage)

The need for inclusion and transparency in the development of alternatives cannot be overemphasized. Each of the steps mentioned above should be carried out collaboratively with the parties affected, with stakeholders, and with interest groups, and the results of each step should be open to full review and participation by the general public. Each alternative will need to be defined by its associated levels of performance measures. Performance measures may include general location, operating policies, institutional setting, and financial strategy.

Developed alternatives may differ by transportation mode, location (in terms of siting, routing, or alignment), facility or service type, area served by facility or service, effectiveness expected from the alternative stimulus (i.e., change in the performance associated with the stimulus), overall operating policies, institutional setting, and financial strategy. In a few cases, alternatives may also differ by analysis periods, a situation that should be avoided, especially where it is difficult to annualize effectively the impacts of the various alternatives.

No method exists that would, at all times, assure identification of all alternatives because the conception of alternatives is a product of endeavor that is only too human. As such, group thinking and brainstorming involving persons from diverse backgrounds and disciplines are helpful. In developing alternatives it should be realized that some alternatives are physical whereas others are policy-oriented, and some involve little capital outlay whereas others involve a large investment. Some alternatives pertain to transportation supply, whereas others pertain to transportation demand. Also, some alternatives primarily involve the physical highway facility, whereas others primarily involve the vehicle operator (driver), the vehicle, or the driving environment. Some alternatives involve little or no cost to the agency but a high cost to society or road users, whereas others may involve high cost to the agency and little or no cost to the users and or nonusers. It is important to consider all feasible alternatives, and a thorough discussion of the merits and demerits of each alternative would help justify the choice of the best alternative.

Step 8: Estimate the Agency and User Costs After alternatives have been developed, their costs should be estimated. Initial costs are still used by most agencies to make implementation decisions. However, the costs could be estimated over the life cycle of the facility (or service life of the stimulus under investigation) and therefore economic analysis principles should be used. Only those costs that differ by alternative should be used. Agency costs include construction costs, preservation (rehabilitation and maintenance) costs, and operating costs. User costs comprise work-zone costs (such as queuing delay) and costs associated with normal facility operation (such as vehicle operating costs). In Chapters 3 and 4, we discuss how agency and user costs can be developed for purposes of systems evaluation.

Step 9: Estimate Other Benefits and Costs The nonmonetary impacts due to each alternative should then be estimated. Impact types to be considered should be consistent with the established performance measures, objectives, and goals, as discussed in Section 1.3 and Chapter 2. Such impacts, whose estimations are required by law, include air quality, water resources, historic preservation, and others. Chapters 3 to 17 provide detailed procedures for the estimation of such impacts.

Step 10: Compare the Alternatives The evaluation of alternatives is simply an assessment of their respective costs, benefits, and cost-effectiveness used to make a selection of the best alternative. All performance measures (measures of effectiveness) may be successive hierarchical categories of system objectives, system goals, and overall system goals (economic efficiency, effectiveness, and equity). Furthermore, each alternative should be evaluated on the basis of its financial, legal, and administrative feasibility. Finally, economic and technical inputs (such as interest rates and the costs and effectiveness of interventions) are not constant over time, but rather, are subject to marked variations in response to foreseen and unforeseen conditions The evaluation process therefore should include a sensitivity analysis (what-if scenarios) for deterministic problems and a probabilistic analysis that incorporates the probability distributions of various input parameters, whereby an alternative that may seem optimal for a current or given set of conditions might be found to be far from optimal under a different (but not unlikely) set of conditions.

Another important consideration in evaluation is the role of system demand. There are several temporal physical and operational attributes of transportation systems that influence (and may be affected by) a proposed change to the system, such as facility condition, use, and so on. Usage forecasts are seen as particularly important because they have a profound influence on performance measures such as economic efficiency impacts, air quality, and energy consumption. It is therefore important that the evaluation process be accompanied by reliable predictions of travel demand changes in response to the transportation system stimulus. Again, as an input parameter, future demand is not known with certainty and could be subjected to some probabilistic analysis.

Faced with the costs and benefits (expressed in terms of the performance measures) that are associated with each of several alternatives, on what basis should a decision maker choose the best alternative? In other words, what *comparison criteria* should be used? Obviously, the choice of criterion or criteria for evaluation depends on the nature of the performance measures that are being considered. In helping a decision maker compare that which is sacrificed (cost) to that which is gained (benefit or effectiveness), an evaluation compares the input costs to the outcomes, whether or not such outcomes are priced. The outcomes of each strategy could be a reduction in subsequent facility preservation or operating costs, community benefits, economic or financial returns, public satisfaction, or progress toward stated objectives. From an economist's viewpoint, an evaluation could be carried out in three ways:

- The maximum benefits for a given level of investment (the maximum benefit approach)
- The least cost for effective treatment of problems (least cost approach)
- The maximum cost-effectiveness (a function that maximizes benefits and minimizes costs)

(a) *Benefits-Only Comparison Criteria* This approach is often used for evaluation of capital investment projects that typically involve a single large investment that is associated with significant elements of uncertainty and where the alternatives have equal costs. Furthermore, this approach is appropriate for such projects, where it is difficult to identify cost related performance measures or to provide a scale for such measures, due in part to the complex nature of such projects and their relatively long duration and spillover effects.

(b) *Costs-Only Comparison Criteria* In cases where benefits are expected to be similar across alternatives or where it is difficult to measures the benefits, the evaluation criteria are comprised of costs only. For many years, this has been the practice at many agencies, where decision makers compared alternatives solely on the basis of initial or life-cycle agency costs.

(c) *Comparison Criteria Involving Both Costs and Benefits* To arrive at a fair comparison of alternatives, both benefits and costs should be considered. If all the performance measures chosen can be expressed adequately in monetary terms, economic efficiency criteria such as benefit–cost ratio or net present value can be used. An alternative is deemed superior if its cost-effectiveness value exceeds that of other alternatives. If the performance measures consist of monetary and nonmonetary measures, an approach is to carry out multicriteria decision making where both monetary and nonmonetary criteria are expressed weighted, scaled, and amalgamated to derive a single objective function. The alternative action that yields the most favorable value of the objective function is deemed the best option.

1.6.1 Good Practices in Evaluation

A multitude of literature provides indications of good practices that could be followed in the evaluation of alternative transportation systems for the purpose of decision making, and include the following:

1. *Focus on the problem at hand.* The types of impacts (performance measures) to be considered and the dimensions of the impacts (temporal, geographical scope, and entities affected) should be pertinent to the problem under investigation.
2. *Relationship between the consequences of the alternatives and the established goals and objectives.* It should be possible to relate the performance levels associated with the alternatives to minimum levels of performance measures.
3. *Comprehensive list of appropriate criteria.* There is a need to consider a wide range of performance criteria (impact types) so that all stakeholders (decision makers, interest groups, affected parties, etc.) are duly represented. The desired characteristics of criteria used for decision making should be adequate to indicate the degree to which the overall set of goals is met. The list should be operational (must be useful and meaningful to understand the implications of the alternatives and to make the problem more tractable), nonredundant (should be defined to avoid double counting of consequences), and minimal (the number of criteria should not be so large as to obfuscate the evaluation and decision process).
4. *Clear definition of evaluation criterion or objective function.* Due to the multiplicity of stakeholders and the diversity of their interests, it is important to incorporate all key performance measures so that the evaluation results may be acceptable to all major parties concerned. Also, because there may be differences in the units of performance measures, they should be brought to dimensionless and commensurate values before they are incorporated into the objective function.
5. *Clear definition of constraints.* The performance measures that are used to build the objective function also individually present constraints within which the decision must be made. Such constraints arise largely from legal or administrative requirements and technical considerations and are often due to the influence of the stakeholders. For example, it may be required that an increase in emissions due to the system improvement should not exceed a certain maximum, or that the average condition of a physical facility or network of facilities should exceed some minimum.
6. *Ability to carry out trade-offs between performance measures.* For example, how much vulnerability can be reduced by a given budget, or how much would it cost to ensure a given level of risk?
7. *Ability to carry out sensitivity analysis with respect to key evaluation input variables.* The sensitivity of findings to uncertainties and value-based assumptions, and the adequacies of alternatives and impacts involved, will need to be considered.
8. *Clear presentation of evaluation process and results.* In decision making for public projects, several performance criteria involve subjective judgment, such as quality of life and convenience. As such, evaluation documents tend to contain lengthy and detailed statements of the influence of each impact type on each alternative, requiring decision makers to read and digest a large amount of information. The documented result of a comprehensive evaluation should therefore be presented in a very pleasing and easy-to-read manner. Key findings should be highlighted, and the reader should be able to navigate through the evaluation report with as much ease as possible.

SUMMARY

Traditionally, the evaluation of transportation systems has aimed at analyzing the economic efficiency of alternative proposed engineering plans and/or designs by comparing the monetary benefits and costs. Where the analysis involves cash flow over time, the economic principles of discounting and compounding are used to convert cash streams into time-independent values. This approach makes it possible to include only those evaluation criteria that could be expressed in monetary terms. Thus, vital nonmonetary criteria such as environmental impacts, economic development impacts, and sociocultural impacts are excluded in engineering economic analysis. At agencies, where there is no requirement to consider non-monetary criteria, this traditional practice continues at the present time. The evaluation of transportation systems, however, is currently evolving from the traditional approach and is increasingly being adapted to include nonmonetary criteria. In this chapter, we presented a framework for comprehensive evaluation of transportation alternatives and outlined key inputs to evaluation, important relationships between evaluation and other planning activities, and the basic components of evaluation itself. As shown, the estimation of impacts depends on a clear definition of the characteristics of modal alternatives and the local context in terms of the goals, the concerns of stakeholders, and the legal and other administrative requirements. Public involvement is desirable in all phases, particularly when developing key inputs, designing and refining alternatives, and evaluation. Decision making involves choices about the combinations of alternatives to pursue, including anticipated levels of performance measures, collateral mitigation measures, funding, and other relevant issues.

EXERCISES

1.1. Identify the various types of impacts of transportation system changes, and give one example of each.

1.2. Describe the role of evaluation in the transportation development process.

1.3. What are the elements of the 3E triangle, and what do they represent?

1.4. List some of the common measures of effectiveness for assessing community objectives of transportation projects.

1.5. List the phases of a typical evaluation work plan.

1.6. What are the basic principles for developing transportation alternatives?

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