# Technical Report Documentation Page

**1. REPORT No.**
RTA-65S524-1

**2. GOVERNMENT ACCESSION No.**

**3. RECIPIENT'S CATALOG No.**

**4. TITLE AND SUBTITLE**
New Technology Research: Costs and Benefits

**5. REPORT DATE**
June, 1993

**6. PERFORMING ORGANIZATION**

**7. AUTHOR(S)**
Linda R. Cohen and Gordon J. Fielding

**8. PERFORMING ORGANIZATION REPORT No.**

**9. PERFORMING ORGANIZATION NAME AND ADDRESS**
School of Social Sciences
University of California, Irvine
Irvine, CA 92717

**10. WORK UNIT No.**

**11. CONTRACT OR GRANT No.**
RTA-65S5524

**12. SPONSORING AGENCY NAME AND ADDRESS**
California Department of Transportation
Division of New Technology,
Materials and Research

**13. TYPE OF REPORT & PERIOD COVERED**
Final Report February, 1992- June, 1993

**14. SPONSORING AGENCY CODE**

**15. SUPPLEMENTARY NOTES**

**16. ABSTRACT**
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Every proposal must be evaluated to determine if the research will make a positive contribution to economic growth. Cost-benefit analysis (CBA) is a technique which examines the merits of competing proposals. The Net Present Value (NPV) method for CBA is recommended. Only proposals with a positive NPV should be funded, and given limited resources, proposals with a greater NPV should receive a higher priority.

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**17. KEYWORDS**
Benefits of R&D, Cost-Benefit Analysis, Goals Application Matrix, Net Present Value, Technology Assessment

**18. No. OF PAGES:**
167

**19. DRI WEBSITE LINK**
http://www.dot.ca.gov/hq/research/researchreports/1989-1996/93-21.pdf

**20. FILE NAME**
93-21.pdf

Report No. Caltrans: RTA-655524

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Linda R. Cohen
Gordon J. Fielding

School o
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**FINAL REPORT**


**PREPARED FOR**
California Department of Transportation
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Sacramento, CA 95819-012

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*Notice*

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Technical Report Documentation Page

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| RTA-65S524-1 | | |

| | |
|---|---|
| 4. Title and Subtitle<br>New Technology Research: Costs and Benefits | 5. Report Date<br>June, 1993<br>6. Performing Organization Code |
| 7. Author(s)<br>Linda R. Cohen and Gordon J. Fielding | 8. Performing Organization Report No. |
| 9. Performing Organization Name and Address<br>School of Social Sciences<br>University of California, Irvine<br>Irvine, CA 92717 | 10. Work Unit No. (TRAIS)<br>11. Contract or Grant No.<br>RTA-65S5524 |
| 12. Sponsoring Agency Name and Address<br>California Department of Transportation<br>Division of New Technology, Materials and Research<br>Sacramento, CA 95891-012 | 13. Type of Report and Period Covered<br>Final Report<br>February, 1992- June, 1993<br>14. Sponsoring Agency Code |

15. Supplementary Notes

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| 17. Key Words | 18. Distribution Statement |
|---|---|
| Benefits of R&D, Cost-Benefit Analysis, Goals Application Matrix, Net Present Value, Technology Assessment | Available to the public from<br>Department of Transportation<br>New Technology, Materials and Research<br>P.O. Box 19128<br>Sacramento, CA 95891-0128 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | | |

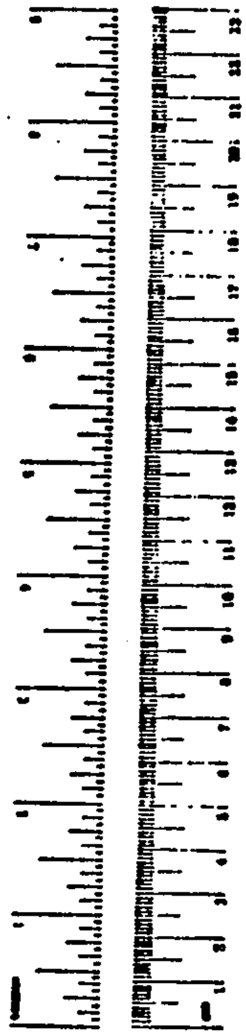
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

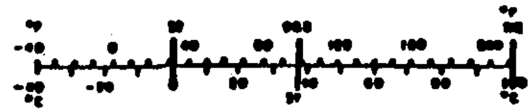
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | **LENGTH** | | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | **AREA** | | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | **MASS (weight)** | | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | **VOLUME** | | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | **TEMPERATURE (exact)** | | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | **LENGTH** | | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | **AREA** | | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | **MASS (weight)** | | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | **VOLUME** | | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | **TEMPERATURE (exact)** | | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



ACKNOWLEDGMENTS

Procedures for the evaluation of transportation projects are well established, and we have benefitted from the critical review provided by David Lewis, Primer on Transportation, Productivity and Economic Development, Washington, D.C.: Transportation Research Board, 1991. By contrast, little guidance was available on methods to evaluate transportation research proposals. We have adapted cost-benefit analysis for this purpose and made recommendations on how it might be extended and improved.

In keeping with purposes of university research and training, we have required a high degree of student involvement in the research. Karen Griffin gathered the information used for the case studies on Automated Traffic Surveillance in Los Angeles and High Speed Ground Transportation. Karen also coordinated production of the Final Report. Brent Kerr assembled the information on Alternative Fuels for Transit Vehicles. And James Nolan assembled the information on cost-benefit analysis.

We would also like to acknowledge the assistance received from the School of Social Sciences; especially the help of Betty Simmes, Cheryl Larrson, and Tricia Joerger.

Encouragement and cooperation from the California Department of Transportation (Caltrans) has influenced the content and direction of the research. George C. Smith, Contract Monitor, and Kazem Attaran, Technical Monitor, provided constructive suggestions and have assisted us in obtaining reports from previous research contracts.

Linda R. Cohen
G.J.(Pete) Fielding

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# EXECUTIVE SUMMARY

Every year the state receives hundreds of proposals to study California's transportation system and its challenges. Proposals are received internally from Caltrans and externally from universities and private consultants.

The Caltrans budget for research and development in 1991-92 was $17.7 million: $7.8 million for general research while advanced technology projects received $9.9 million. Of the total, $6.6 million was reimbursed by federal agencies.

The Legislature has questioned whether these studies are worthwhile, and the 1991-92 Budget Act contained Supplemental Report Language requiring that:

> "The Department of Transportation shall report to the Legislature, prior to budget hearings in 1992, on potential costs and benefits of non-IVHS research opportunities and how these activities might be incorporated into the NTDP program."

"NTDP" is the Department's New Technology Development Program which includes IVHS and non-IVHS research. "IVHS" is the acronym for Intelligent Vehicle Highway Systems.

The Department's report to the Legislature in 1992 indicated that new approaches were needed to predict the benefits and costs of research. The University of California, Irvine contracted to investigate alternative approaches. This report summarizes our conclusions and recommends a methodology for analyzing research.

A cost-benefit approach is recommended that appraises the contribution of each proposal to economic development and other transportation goals. An economic orientation is inherent in the recommendation as is the premise that research is vital to economic growth.

Research and Economic Prosperity

Research is the driving force behind this state's, and our nations's, productivity. It is through research that public agencies and firms acquire the knowledge that enables them to utilize capital investments efficiently.

Advances in knowledge were the single largest contributor to economic growth between 1929 and 1969. Investment in capital alone is insufficient; investment in research and development is required to demonstrate how labor should use additional capital to improve productivity.

Investment in transportation facilities can trigger productivity increases. By decreasing assembly and distribution costs, the areal scope of competition is enlarged. Management is challenged to improve research technologies for producing goods and services. Productivity increases result in real economic benefits.

The causal relationship between transportation, research, and productivity growth is vigorously debated by economists. The consensus is that there is a positive relationship. However, the effect is not as large as some advocates of transportation investment have suggested.

Transportation Research in California

California must continue to fund research in order to ensure development of new products and improved management. Only through such investments will California regain its preeminence in the nation's economy.

The rationale for the state's intervention is based upon two features of research: first, successful research contributes information beneficial to the entire economy, not only the investor, and second, there is always uncertainty about the commercial prospects of a research proposal, so without state assistance, there will be underinvestment in research.

The California Legislature has demonstrated great foresight in funding transportation research and development. For example, the Petroleum Violation Account was used to develop computer-assisted controls for traffic signals. This allowed traffic to flow with fewer stops and resulted in substantial energy savings. The Transportation Planning and Development Account has been used to analyze the seismic safety of bridges, as well as to demonstrate the effectiveness of intercity rail. And the Transportation Development Act has funded numerous management studies that have improved the performance of public transit agencies.

Grants to public agencies and the competitive solicitation of proposals are the usual manner for initiating research. However, the state should consider other options like prizes for successful innovations or market guarantees to encourage technological improvements in fields such as automobile emission systems and electronic license plates.

Research which addresses problems that uniquely or disproportionately affect California deserves emphasis. The size and diversity of the state, however, requires that a broad portfolio of research be considered in terms of real cost and benefits.

## Cost-Benefit Analysis

Although research and development are vital to productivity in California, this does not mean that every proposal deserves funding. Quite the contrary, every proposal must be carefully evaluated to determine if the research will make a positive contribution to economic growth.

Cost-benefit analysis (CBA) is a technique that examines the merits of competing proposals. The criterion is the maximizing of monetary return (benefits) for a given amount of money invested (costs). Quantifiable estimates are preferred, but qualitative can be used to assist the ranking of proposals. CBA can also assist decision makers in choosing between proposals when total cost exceeds funding.

Although widely used in transportation, CBA is seldom employed correctly. Special care is required in order to avoid errors such as the failure to define a base case as a datum against which future improvements can be measured or to discount benefits. It has been estimated that fewer than one in five cost-benefit studies conducted in transportation are adequate.

The Net Present Value (NPV) method for CBA is recommended. NPV discounts both costs and benefits to present-day values. The discount rate must be decided in advance and applied uniformly so as to reduce future benefits to the equivalent of previous and continuing costs.

Only proposals with a positive NPV should be funded. And those with a greater NPV should receive a higher priority if there is insufficient money to fund all proposals.

Using NPV to create a fair and consistent appraisal of research proposals requires an agency to consider the following:

- o Appropriate goals for the research and how these relate to other goals sought by the agency.
- o Selection of an appropriate base case which includes the best available current practice rather than accepting the status quo as the basis for calculating benefits.
- o Duration of appraisal because the payoff from research is normally some years in the future.
- o Choosing a discount rate suitable for public investment when the probability of success is low.
- o Inclusion of all costs associated with proposal development, administration, and conduct of research. Costs in the form of negative benefits are normally deducted from benefits when they occur.
- o Appraisal of benefits to include direct savings as well as indirect effects on the economy achieved through the restructuring of activities.
- o Use of sensitivity analysis to test the influence of changing assumptions about discount rates and prices upon the ranking of proposals.

Appraising Benefits

Research presents special difficulties when estimating benefits. First, benefits are seldom captured by the research sponsor as the effects of technological change spread throughout the economy. And second, the market value of research may not be apparent for many years.

Forecasting techniques are required to estimate the magnitude of future benefits in transportation, but the value people place on the same benefit will vary. For example:

- o Value of time saved will vary by income of the traveler and the trip purpose. Work trips are valued more highly than recreational trips.
- o Estimates for the value of lives saved through improved safety or reduced pollutions vary from $1.5 to $9.0 million per life.
- o Environmental benefits and costs are difficult to appraise in terms of their value to individual citizens.

The wide discrepancy between high and low values placed upon transportation variables makes the forecasting of benefits difficult and controversial. The NPV method accommodates this by requiring that, first, the same values be used when appraising each alternative, and second, the results be tested for their sensitivity to changes in critical values.

The NPV method provides a consistent appraisal of alternative research proposals designed to achieve the same or similar goals. The values assigned are for comparative purposes only; they **should not** be used in predicting future revenue streams. Revenue analysis requires financial forecasting techniques that adjust demand for changes in price and quality of service.

Case studies

To illustrate the use of NPV when evaluating research proposals, two recently completed studies are analyzed as well as a statement concerning intended research. The purpose is to demonstrate how both evaluation of proposals and conduct of the research might be improved when NPV is used.

Research results from three modes were chosen, each with different goals:

1. Highway: automatic traffic surveillance and control in Los Angeles to reduce congestion.
2. Transit: alternative fuels for transit vehicles in Southern California to reduce hazardous emissions.
3. Rail: high-speed, intercity service using the proposed Anaheim to Los Vegas route as an example of how a research proposal should be evaluated in advance of funding.

All three studies produce helpful results. Our purpose is not to criticize the research. Rather it is to use the research to illustrate how NPV can be helpful.

Research for the development of the automatic traffic surveillance and the control system in central Los Angeles was conducted in advance of the solicitation of proposals to install the system. However, this information was not used effectively in the request for proposals. The estimated cost was $12.15 million to achieve benefits that were described as the reduction in stops and delays in the range of 13 to 17 percent. However, it is impossible to evaluate the proposed benefits because neither a base case is described, nor are the associated improvements in traffic management adequately explained.

Despite the deficiencies in the way proposals were solicited, the project has been beneficial. In a subsequent evaluation study, the City of Los Angeles indicates that annualized benefits exceed costs by a ratio of almost 10 to 1. This study discounts costs but not benefits. But when the same 8 percent rate of discount is applied to benefits the ratio is still 6 to 1. Discounting both costs and benefits reveals an annualized benefit of $4.5 million. By expressing the net present value, rather than a ratio, the magnitude of the project's contribution to economic efficiency is made apparent.

Research designed to evaluate alternative fuels has been conducted separately by the Orange County Transportation Authority and the Southern California Rapid Transit District. Each project assumes that an alternative to the diesel bus must be implemented prior to 2007. The goal is to discover the most cost-effective, alternative fuel.

Results from those two studies could have been more useful to transit agencies if both had used the diesel bus equipped with a particulate trap as their base case. By using emissions from a standard bus as the base case, comparative emission reduction from alternative fuels is exaggerated.

Implementation of high-speed rail service between metropolitan areas in California has been proposed. The goal is to reduce travel time. The case study demonstrates how CBA might be used to appraise the probable results from this research.

## CONCLUSION

The objective for this research has been to develop a methodology by which Caltrans may evaluate research and develop a portfolio of proposals for consideration by the Legislature. Increasing productivity has been emphasized as the priority goal because research should be appraised in terms of its contribution to economic efficiency.

The NPV methodology is advocated because it provides a consistent way to evaluate alternative proposals in terms of current dollars. Proposals can be ranked in terms of the magnitude of benefits, or they can be placed in an array viii representing their contribution to other goals and various modes. This latter use of NPV will facilitate the selection of a portfolio of research proposals.

Agencies utilizing NPV will be able to rank alternative proposals in terms of economic efficiency as well as other desired goals. This will assist decision makers to arrive at informed and economically justifiable decisions. And this is what economic analysis is all about-- the allocation of scarce resources to their best possible use.

# CHAPTER 1

# TRANSPORTATION, PRODUCTIVITY, AND ECONOMIC PROSPERITY

Transportation has been a major influence on economic development in California. Construction of ports, railroads, roads, airports, pipelines, and transit systems has provided employment and allowed industries to compete nationally and internationally. These benefits became apparent during the 1970s and 1980s as the state capitalized upon investments initiated during the 1960s. Between 1975 and 1985 annual output (gross state product) grew at an annual rate of 4.1 percent while the U.S. economy was growing by only 2.9 percent a year. California surged ahead to unprecedented success, becoming the sixth largest economy in the world.

All this has now changed. The transportation infrastructure network is virtually complete; an increase of only 4 percent in lane miles is contemplated for the state highway system during the 1990s. The industrial complex of defense, aerospace, and electronics is being displaced by employment in services, commerce, entertainment, and tourism industries for which transport of freight is less important. Los Angeles County, for example, led the nation in manufacturing-related employment in 1985 with 900,000 manufacturing workers, but the county is now losing manufacturing plants to both neighboring states and foreign countries. These changes are starkly reflected in the gross state product which declined by 5 percent in 1991.

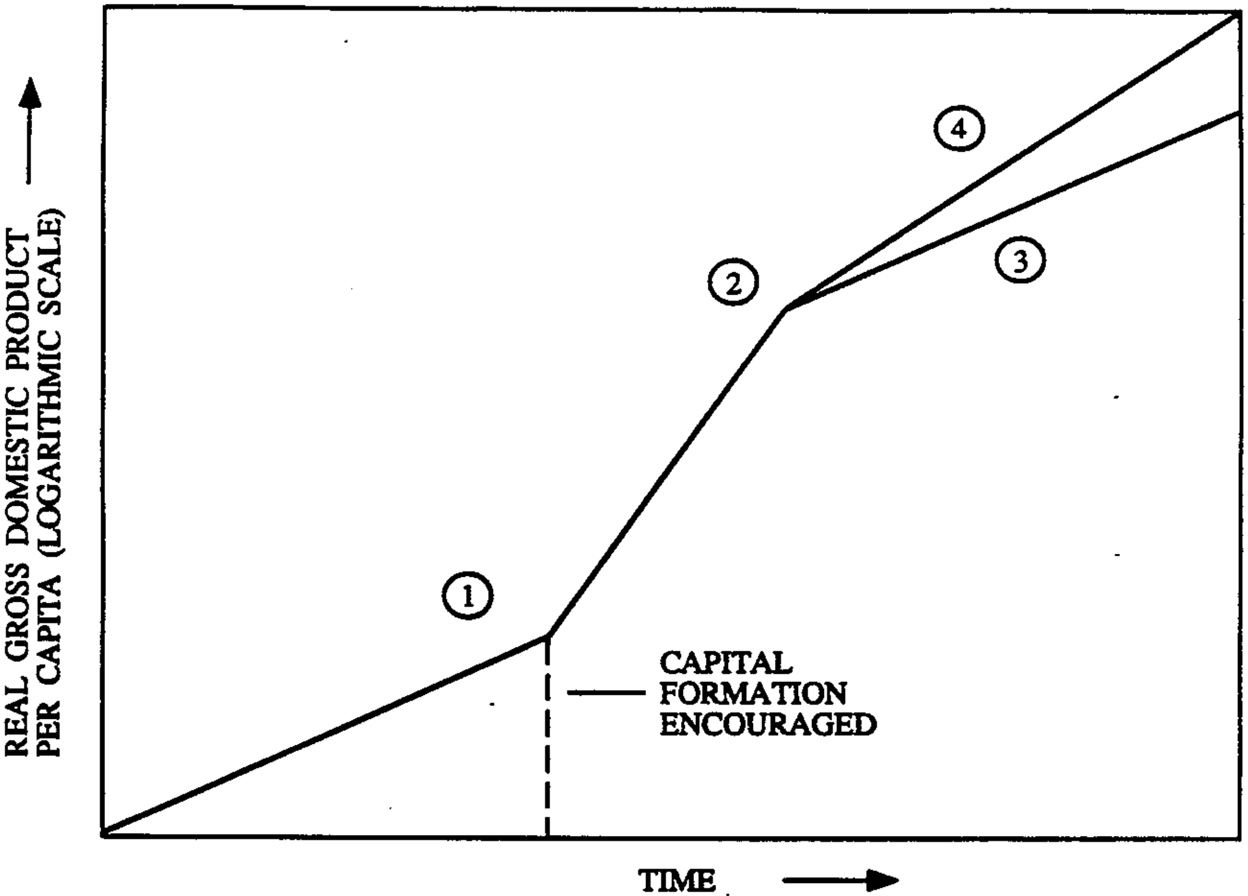
Transportation remains important, but its role in the economy has shifted. For many years, expansion of the states transportation network dominated economic activity, but now maintenance requires the greater proportion of expenditure. And in the future, California will have to seek productivity improvements through more efficient use of existing infrastructure, rather than relying on network expansion.

This chapter analyzes the contribution of transportation to productivity and economic prosperity. The previous importance of capital investment in infrastructure is acknowledged, but emphasis is placed on the current need to improve productivity growth through more efficient use of existing facilities. The thesis is developed in three sections: the first explains the role of capital investment, the second outlines the crucial role of research, and the third discusses the impacts of transportation on a service-oriented economy.

## CAPITAL INVESTMENT AND ECONOMIC GROWTH

Achieving higher growth rates requires increased public and private capital investment. Ralph Landau (1988) illustrates the crucial effect of capital formation on the economy (Box 1.1). As long as the rate of capital formation is constant (Curve 1), labor force improvements and adoption of new technology take place at a constant rate. However, when capital formation is encouraged by economic policy, the rate of change accelerates (Curve 2). The economy does not return to the former rate of growth (Curve 3) afterwards, but continues to increase as research develops new technologies and operating practices to utilize the new equipment and facilities (Curve 4).

Landau makes disturbing comparisons between the meager increase in capital per worker in the U.S. since 1964 and a growth rate of less than one percent per annum in labor productivity. West Germany and France have had capital investment rates roughly twice those of the U.S. and have enjoyed about twice the growth in labor productivity. The results for Japan are even more startling. Between 1964 and 1984




Box 1.1: **RATE OF ECONOMIC GROWTH** is constant (1) as long as capital formation (the construction of new factories and production equipment), labor-force improvements (the training of workers) and technological change (the development of new inventions take place at a constant rate. When capital formation is encouraged by changes in a nation's economic policy, the growth rate increases (2), since the nation acquires a greater capacity to supply goods and services. If there are no interactions among the rate of capital formation, the quality of the labor force and the pace of technological change, the economy returns to its original rate of growth in the long term (3). But if increasing the rate of captial formation accelerates the rate of labor-force improvements and stimulates technological innovation, there may be a longer-term increase in the rate of growth (4). (After Landau, 1988, p. 47).

the average annual growth rate of gross capital per worker was 8.8 percent with the result that productivity increased by 4.6 percent annually.

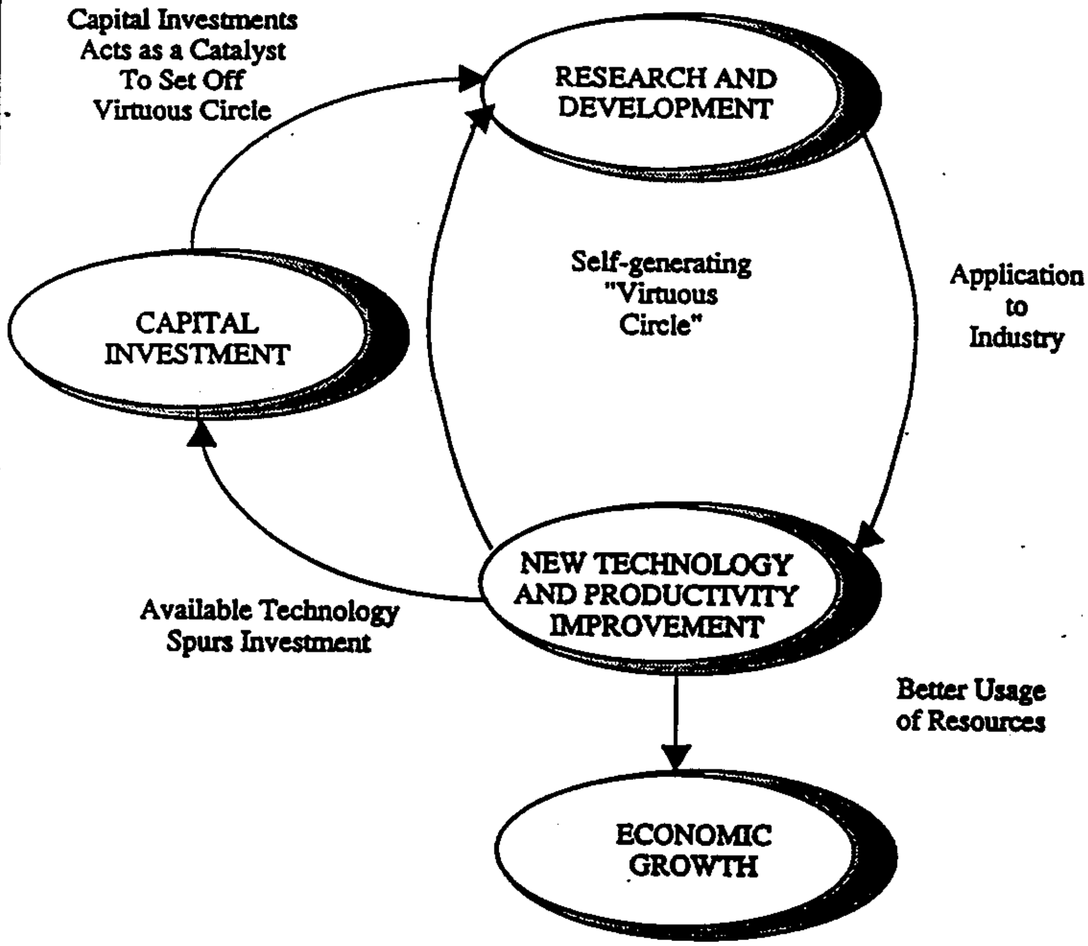
A similar pattern of capital disinvestment is apparent in U.S. transportation. Between 1970 and 1989 capital investment in all forms of transportation declined from $62.00 to $52.00 per capita. Net investment also declined.

Failure to invest in transportation creates a loss in productivity through the additional travel time required as the result of congested or poorly maintained facilities. Employees waste time commuting, and the cost of assembling and distributing goods and services increases. And it may have an even wider, negative influence because investment in transportation triggers a cycle that stimulates private as well as public investment throughout the economy.

Productivity and prosperity

Governmental investment in transportation is based upon public good and externality principles. Unless there is congestion, everyone enjoys similar benefits from using transportation facilities, and increased accessibility reduces costs or raises the quality of goods and services throughout the economy. The state provides airports, highways, and ports, and taxes all users for the benefits they enjoy. Achieving these benefits, however, requires a partnership between government and private business; public agencies provide the facilities and private firms invest in aircraft, trucks, automobiles, and ships that utilize these facilities. Public improvements spur private investments that far exceed public investments.

The rate of both public and private capital investment influences productivity. Together they positively affect output through scale economies: manufacturing




SOURCE: David Lewis, Daniel Hara and Joseph Revis, The Role of Public Infrastructure in the 21st Century, Special Report 220, Transportation Research Board (National Research Council), 1988.

Fig. 1.1 The "virtuous circle": economic growth through capital investment.

the development and maintenance of transportation infrastructure, offers one of the most effective catalysts for productivity growth. Innovations from research spur better use of resources; implementation occurs through new facilities and superior operating modes that can improve productivity and contribute to economic growth. And the investment of additional capital prompts the cycle of new research and improved technology. However, Lewis, et al., caution that not all transportation investments are beneficial. They counsel decision makers to undertake research which evaluates the net benefit of proposals before investing capital.

Lasting benefits from transportation are achieved through increased productivity. Travel time reductions may benefit commuters, and special services may satisfy the travel needs of individual groups, but the sustaining benefits are those which boost productivity by reducing costs or raising the quality of goods and services.

## IMPACTS OF TRANSPORTATION

Improvements in transportation can be analyzed in terms of **efficiency and social, environmental, and economic impacts** (Fig. 1.2). **Efficiency** identifies benefits achieved through reduced cost and travel time. **Social and environmental** impacts include improved mobility and safety, and environmental consequences. **Economic** benefits are those associated with changes in personal, regional, and sectorial income. These categories are not mutually exclusive as improvements in efficiency are required to attain economic benefits.

Efficiency benefits are the easiest to identify and measure because they can be equated with travel time savings. Social, environmental, and economic impacts are

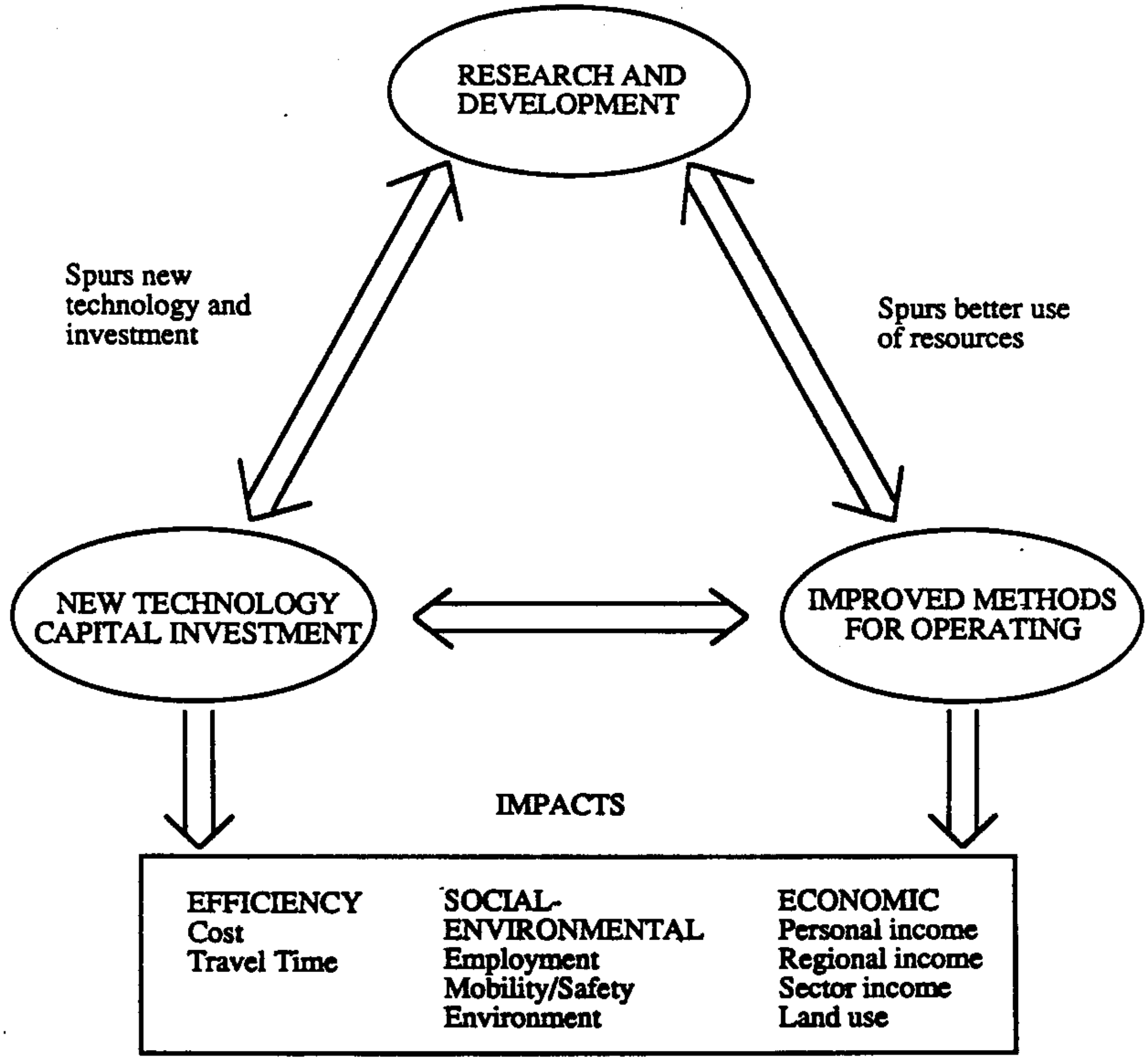



**Figure 1.2: The productivity triangle: research and development spur development of new methods for operating transportation as well as new technology and capital investment. New technology demands new operating methods and vice versa so that a triangle of continuing improvement and new research develops. The resulting increased output per employee stimulates economic growth.**

more difficult to quantify. Also, the impacts are frequently obscured by controversy between interest groups when local life-styles are adversely affected by proposed regional improvements. Additional research into life-style impacts (what the economist refers to as welfare impacts) is required, and new methodologies incorporating risk need to be considered. For example, how should the risk of using diesel or more expensive electric locomotives be evaluated when analyzing the benefits associated with commuter rail in Southern California? Is the reduction in air pollution worth delaying implementation of commuter rail service, or could the savings be more effectively invested in air pollution reduction elsewhere in the region? Additional research into transportation impacts is required to identify benefits and costs and to express them as economic variables.

Economic impacts

Overall benefits of transportation improvement are frequently obscured. They are normally expressed as the number of jobs created or the number of purchases from other sectors, whereas it is through increased productivity that real economic benefits are achieved. In addition, the influence of transportation upon personal and regional income and land use is usually omitted because of the time and cost required for this analysis.

Promotional literature associated with transportation improvements boasts about the number of jobs that will be created. If this logic is followed, workers would be unemployed at the conclusion of construction. A counter argument goes as follows: if the taxes had not been collected to pay for the improvement, individuals would have spent their money and created private demands for additional employment. Only in regions of chronic unemployment can a genuine case be made for transportation investment creating jobs (Lewis, 1992). The classic misuse of this argument is apparent in California where metropolitan counties increase sales taxes to improve freeways and rail transit. The case for increasing the sales tax is normally accompanied by claims about the employment benefits. However, the number of jobs are not adjusted downward due to the private employment that might have occurred had the money not been taxed away by local government.

The American Public Transit Association (1983 and 1984) used similar, although more sophisticated, analyses to demonstrate the economic benefits derived from transit capital and operating spending. Employment impacts were estimated based upon each $100 million of expenditures in 1979 (Table 1.2). Operating expenditures were shown to create 20 to 30 percent more employment than capital projects. The sophisticated, input-output model developed by the U.S. Department of Commerce was used to estimate the sum of direct, indirect and induced impacts of transit capital and operating expenditures as business revenues in 38 sectors of the economy. One dollar spent on transit was estimated to create a $4.29 increase in household income and a $3.07 increase in business sales. However, neither publication gives more than brief mention to the influence of transit on the overall economy. For instance, metropolitan areas rely on public transit to transport employees and patrons. As is apparent during a transit work stoppage, most central cities cannot function without the congestion relief provided by buses and trains. But this contribution to productivity and economic growth is overlooked in the aforementioned publications.

A more thorough assessment of overall benefits is made by examining the productivity increases derived from transportation investment. Elimination of congestion reduces travel time and translates into real improvements in

Table 1.2: Employment Impacts per $100 Million Expenditure in 1989

| Expenditure | Transit Capital Rail Starts | Transit Capital Rail Modernization | Transit Capital Bus Facilities | Operating Expend. |
|---|---|---|---|---|
| New Construction | 934.86 | 258.94 | 464.26 | 0 |
| Mainten./Repairs | 15.22 | 1085.55 | 18.79 | 11.49 |
| Motor Vehicles | 93.16 | 241.60 | 605.81 | 77.30 |
| Wholesale Trade | 115.20 | 140.35 | 260.76 | 23.00 |
| Business Services | 1124.76 | 405.29 | 232.82 | 236.32 |
| Transportation | 131.09 | 91.43 | 119.73 | 3165.55 |
| Insurance | 17.97 | 20.16 | 16.36 | 154.70 |
| Other | 947.25 | 969.70 | 1430.40 | 394.65 |
| Total | 3379.60 | 3213.02 | 3148.93 | 4063.01 |

Source: American Public Transit Association (1983) productivity, allowing firms to reduce costs. Improved productivity stimulates the economy and encourage the hiring of additional employees. For example, a supermarket chain owning stores and warehouses in Southern California will benefit from highway improvements through reduced travel time for trucks. Even larger benefits could be achieved, however, if reduced and more predictable travel times allowed the company to restructure warehousing to fewer locations. Larger and more efficient warehouses would reduce cost and increase productivity. These benefits have been described by Quarmby (1989) for the Sainsbury supermarket chain and adapted as a case study by Lewis (1992) (Box 1.2).

The influence of transportation on manufacturing can also be illustrated graphically (Fig. 1.3). The cost of shipping output increases with distance so that the factory maximized profit with output A. If transportation is improved, not only is profit per unit at A increased, but also the market area is enlarged; the quantity/price curve moves to the right. The new maximum profit output is at B. Additional capital and labor must be invested to achieve output B. And in this way the initial investment in transportation multiplies its influence throughout the economy. Competing factories, observing the increased profit, may also invest capital and labor in anticipation of increasing the size of their market share. Price might decrease as a result of competition, allowing more consumers to enjoy the output at or below the original price.

National productivity

There is also a relationship between national productivity and investment in public infrastructure including transportation. The decline in productivity has been widely identified as one of the most urgent dilemmas facing the nation. Total

BOX 1.2

## CASE STUDY

### Accounting for Industrial Productivity Benefits Associated with Major Network Improvements

Sainsbury's, Britains largest supermarket chain, considered the impact of a road network improvement on food distribution. The road improvements are seen to have two impacts. One is to reduce the driving time required for trips. The second, as a result of the faster driving time, is to permit the firm to make a major structural change in logistics, namely to reduce the number of its depots from 6 to 5. The closure of depots requires an increase in the number of miles travelled of 9.5%, but the additional cost is outweighed by the savings from closing a depot. Savings in closing the depot come from reduced inventory holdings and economies of scale in handling increased volumes of goods with one less depot.

The firm looked at the measurement of benefits in two ways. Case A, counts only the savings in driving time and associated costs, assuming that the structure of the firm's operations remains the same. Case B, considers the additional impact from the reduction in the number of depots.

*Savings from Improvements in Road Network*

| | Per case handled |
|---|---|
| | British Pence (p) |
| *Case A* | |
| - Transport savings without restructuring | 1.3 |
| *Case B* | |
| - With Restructuring | 1.6 |
| Marginal volume benefit | 0.5 |
| Stock saving | 2.1 |
| | 0.5 |
| *Less* extra transport cost | 1.6 |
| Total | 0.3 over |
| - *Extra benefit* over transport savings | 1.3p = 23% |

The analysis indicates that true benefits to the firm, including the benefits of restructuring, are 23 percent higher than those captured by conventional Benefit-Cost practice which would measure only the direct benefits from faster travel time.

Formal theoretical extensions of the traditional Benefit-Cost framework developed for the Primer confirm the validity of the Sainsbury's analysis, (see Technical Report). Other tests conducted in the Technical Report indicate that failure to account for productivity impacts can understate the true economic of major improvements by more than 100 percent.

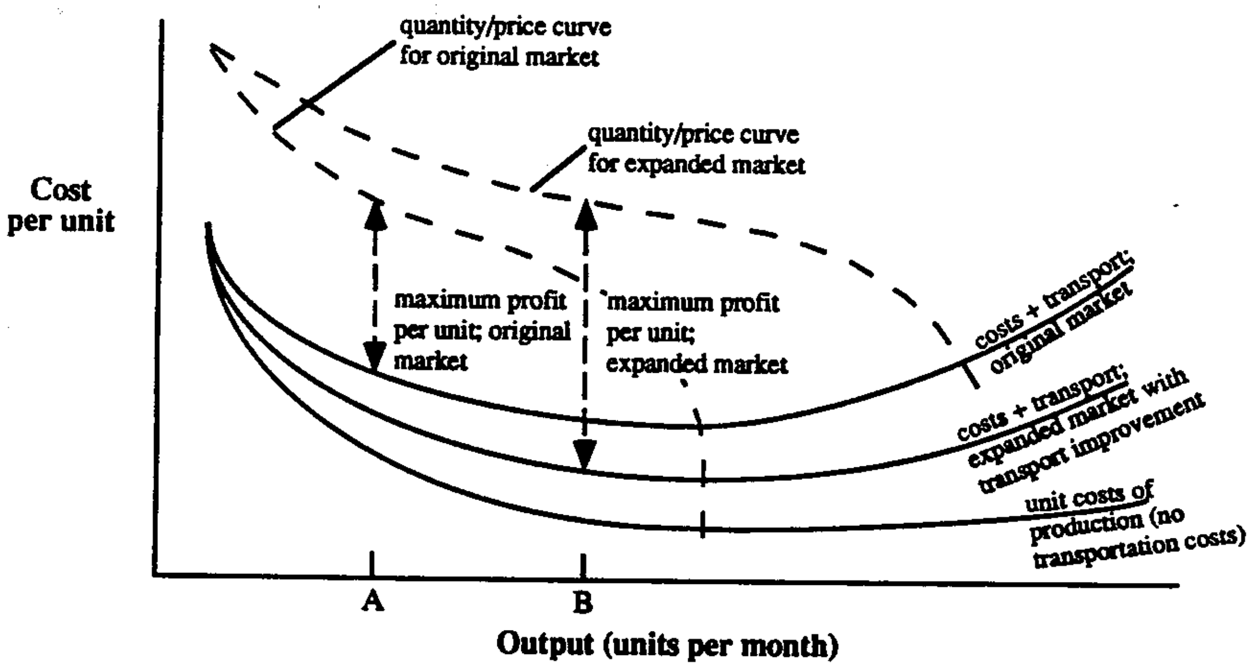



**Fig. 1.3: Influence of reduced transportation cost on demand and output for manufacturing.**

factor productivity in the private, non-farm, business sector declined from an annual average rate of 2.0 percent between 1950-70 to 0.8 percent between 1971-85 (Aschauer, 1989). Recent numbers are somewhat better, but still well below the achievements of the 1950s and 1960s. Although economists have concluded that a variety of factors have contributed to the slowdown, Alice Munnel (1990,4) writing in the New England Economic Review makes a case for the notion that "the stock of public infrastructure as well as the stock of private capital may be the key to explaining changes in output from the private sector." She concludes that the slowdown in the 1970s and 1980s was associated with decreased public investment in streets, highways, mass transit, airports, and water systems (Fig 1.4).

Other economists have disagreed with the significance that Aschauer and Munnel have placed on the role of public investments, especially those in transportation. McGuire (1992) reviews the opposing arguments and explains that the influence is difficult to isolate because four transformations are taking place concurrently:

- changes in production process
- changes in the structure of the industrial sector
- shifts in the location of various economic activities, and
- the increasing importance of the service sector

Failure to account for these transformations helps to explain differences in the results. McGuire concludes, however, "a consensus that public capital has a weak positive effect on private economic activity is emerging among the researchers involved." As the majority of studies indicate that investment in transportation has a small positive, although weak, effect on overall productivity, this may help to explain the decline in productivity growth. Transportation investment did not

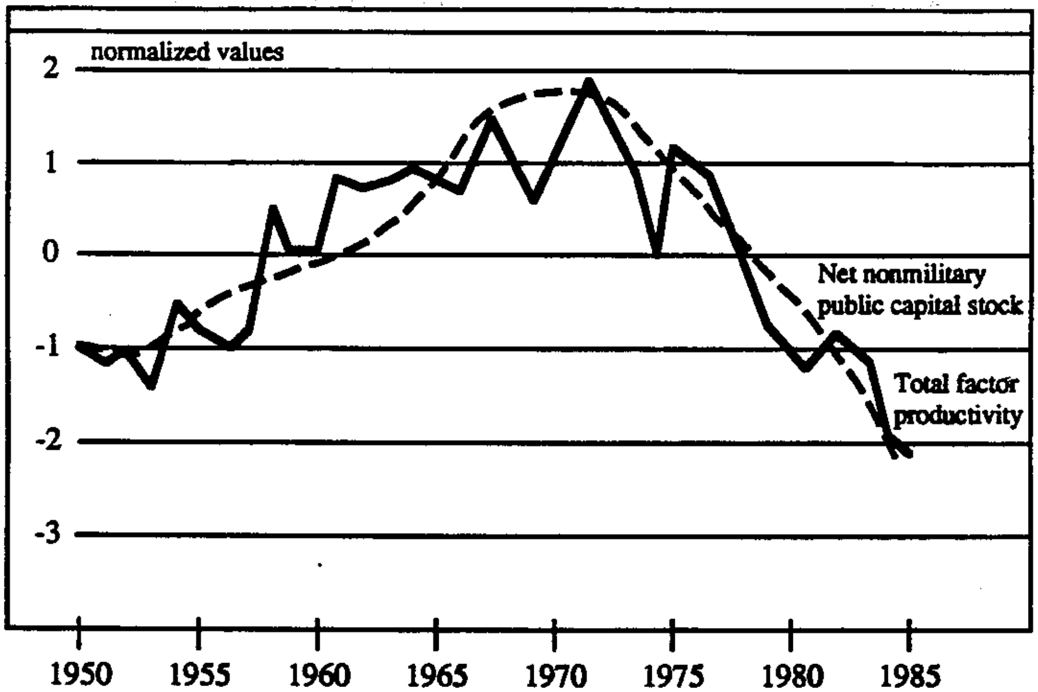



Fig. 1.4: Net nonmilitary public capital (adjusted for the effects of time) and total factor productivity (adjusted for the effects of time, private input, and capacity utilization; annual data 1949-85; sample size = 37. (After Aschauer, 1989, p. 196.)

keep pace with depreciation between 1970 and 1989, causing the net stock of transportation infrastructure to decline.

International comparison

Comparison between developed and developing nations illustrates the crucial role of infrastructure in economic development. In countries where transport facilities are poor and service unreliable, development is concentrated in major cities. Throughout most of the rest of such a country, a subsistence economy predominates with few opportunities for economic specialization because of the lack of adequate transportation competition.

Mexico suffers as a result of inadequate infrastructure. There are 27,600 kilometers of road per million population and the once proud rail system has insufficient equipment to cope with expanding demand. Most of the 20,000 kilometer national railroad is without electric signals, cannot carry the 120-ton load of a modern hopper car, and is woefully short of engines and rolling stock. More than one-fifth of the 84 million population dwells in Mexico City where 36 percent of the gross national product is produced. There are substantial diseconomies created by this level of concentration, but this does not discourage migrants because insufficient employment is available elsewhere. Attempts to develop other regions have not fared well because of inadequate infrastructure. The exceptions are based upon local resources in mining, agriculture, or tourism. Malquiladoras cluster in border states, not only because labor is available from migrants, but also because proximity to the U.S. provides access to superior highway and rail systems. Economic activity is concentrated in the largest city because inadequate infrastructure prevents rival cities and their industries from achieving economies of scale in production. And without infrastructure improvements, Mexico will not obtain full economic advantage from the proposed North American Free Trade Agreement.

## CONCLUSION

Development of transportation infrastructure has played a crucial role in the economic development of California. Without railroads, interstate highways, and airports, California would have remained a high-cost, marginal area for both supply and demand reasons. Prior to 1910, manufactured goods had to be imported from Europe and the Northeast, and wages had to be high to compensate for the high cost of living. Improved access to national and international markets and raw materials allowed industries to specialize; to become more productive, to compete internationally, and to import those goods produced more efficiently elsewhere.

Although transportation facilities have assisted California, real growth in personal income has resulted from improved productivity when capital invested in public and private facilities has increased labor output in agricultural, manufacturing, tourism, and service industries so that they could compete nationally and internationally. Capital investment plays a crucial role; it triggers a "virtuous circle" by stimulating the introduction of new technology and improved operating methods.

Investment in transportation alone is not sufficient. Faster growth requires more investment in machinery, equipment, education, and training in order to take advantage of the transportation improvements. The challenge is to determine which investment, and in what sequence, will be most beneficial.

When the planned transportation network is virtually complete, as it is in California, improvements come primarily from innovations in design and operation. In this respect, R&D is crucial because it prepares managers for new ideas and encourages the testing of potentially valuable techniques. Not all innovations are viable; each needs to be evaluated, first for consistency with agency goals, and second to assess proposed benefits against anticipated costs.

# CHAPTER 2

# TRANSPORTATION RESEARCH IN CALIFORNIA

The economic case for public sponsorship of research and development (R&D) is generally accepted in the United States. The federal government directly spends over $70 billion in R&D annually and pursues a variety of other policies, from tax credits to antitrust exemptions, to promote private investment in research and technology development. The Caltrans budget for research in 1991-1992 was $17.7 million; $7.8 million was made available for general research while advanced technology projects received $9.9 million. Of the total, $6.6 million came from federal agencies. Caltrans also provided state funding to local agencies and the University of California to match federal grants for transportation R&D.

The case for state policies to promote R&D has received little attention. The purpose of this chapter is to explore the arguments for a pro-active government role in R&D and to give guidance on where and how the state government might concentrate research activities in transportation. Our recommendations follow from integrating three aspects of the problem, which are addressed in turn. First, we consider the different categories of activities that comprise research. Second, we discuss different reasons why the public sector should support research. Third, we identify several strategies that are available to a state agency for the support of research. The chapter concludes with a set of guidelines for prioritizing state-supported research.

## THE CHARACTER OF R&D

Research is usually characterized as basic, applied or development. The critical distinction relates to how close research activities are to a non-researchapplication. The defining characteristics of **basic research** are that it is undertaken without any particular commercial product or process as a goal, and that its results may be applied to a wide variety of problems. Due to its potentially broad applicability, basic research is sometimes referred to as generic. **Applied work** undertakes to use and extend basic research for a particular purpose, but is still pre-commercial. At this stage a number of alternative strategies might be considered for development; in part, the purpose of applied research is to narrow down the options before undertaking expensive development activities. Typically, **development activities**, which are intended to bring a product or process to market, are far more expensive than either basic or applied research, for it is at this stage that prototypes and demonstration facilities need to be built.

Most projects fit only loosely into this classification. Development projects often run into snags that require applied (or worse, fundamental) research. Indeed, this is a major source of cost overruns in pilot programs that involve sophisticated new technology. Basic science is often motivated by applied problems, even if the application appears remote. Moreover, in some high tech fields, notably, biotechnology, even basic research results can have near-term commercial value, and most major research universities have active patent offices.

Nevertheless, because of several critical differences, these categories are useful in the formulation of government policies. The first difference is the nature and extent of uncertainty. Basic research results are typically very and difficult to predict, and many alternative lines of inquiry may be appropriate for pursuit. Applied research is characterized by uncertainty as well although researchers usually have a better idea of which paths are most promising and where the paths lead than for basic research. A second difference is cost: basic research projects are generally far less costly than either applied or development work,development costs overwhelm the other categories. The third difference is that the time horizon varies. Basic research cannot be expected to pay off until years in the future; applied and development programs usually have shorter time horizons. Because of these differences, the nature of problems in the private conduct of R&D varies for basic, applied, and development activities, and hence the rationale and appropriate strategies for government intervention vary as well.

## PRIVATE MARKET FAILURES: THE CASE FOR PUBLIC SUPPORT OF R&D

Economists justify government support for research on market failure arguments. The argument is that firms are not sufficiently rewarded for undertaking research activities because their profits may be substantially less than the social value of innovations. This argument rests on two attributes of research: first, a successful project results in information about new products or processes, and second, substantial uncertainty exists about the commercial prospects of a research enterprise.

Information, once it becomes public, can be used freely by people other than its discoverers. Sometimes just the knowledge that a product is feasible gives an advantage to potential competitors. The first characteristic of research implies that an innovation can be copied at much less expense than the original research or development work, so that competing firms can reap profits from the invention at a lower cost than the original innovator. This is known as the "appropriability problem"; researchers may be unable to appropriate the full returns from an invention. Indeed, it may be in everyone's interest to be a copier rather than an innovator. As a result, research will receive less attention than it should, and in some cases it might not be performed at all.

The second attribute, uncertainty, is more subtle. The problem is not just that uncertainty over profits exist, but that risks to individual investors may be much greater than for society as a whole. When private risk exceeds social risk, firms underinvest in research activities.

Use of public resources to subsidize research is a common response to these market failures. However, while lack of appropriability and uncertainty are characteristics common to all research activities, they are particularly problematic in some areas. A closer examination of market failure arguments can yield more useful policy recommendations.

<u>Appropriability</u>

Economists define appropriability as the degree that a firm can profit from its own research innovations. Two issues determine the extent to which innovators profit from an invention: the nature of the innovation and the structure of the industry. When research yields a specific product, an efficient battery, i.e., the innovating firm may be able to patent the product. In this case, the firm can choose to exclusively market its invention for some years and fully recoup its development expenses, or it may choose to license the technology to other companies for a fee which similarly covers research and development costs. Alternatively, if the research results in more fundamental knowledge, i.e., about chemical properties of compounds that can be used in the construction of batteries, then patenting is not only more problematic, but also socially inefficient. The first problem arises when knowledge of chemical properties is generally available. Under these circumstances, its use is difficult to trace and charge for. In addition, the knowledge itself may not produce the battery. Further development work, perhaps by researchers with different fields of expertise from the original innovators, may be necessary to produce a commercial device. In this case, if the knowledge is kept secret so as to protect its value, society suffers because commercial opportunities are not exploited. Thus, full and free dissemination is in the social interest. In general, the more basic the research, the further away it is from commercial application, the less effective or desirable is the patent policy, and the greater the need for direct public subsidies to encourage research.

Industry structure relates to this issue as follows. Firms fail to fully capitalize on inventions when competitors succeed in using it without paying for their share of the research costs. When firms compete for customers, i.e., the industry is subject to product market competition, a new process that reduces product cost will cause the product's price to drop. In other words, none of the firms benefit; rather, customers are the prime beneficiaries of the research. Alternatively, if firms do not face product market competition, they can recoup at least some of the development costs. Thus, it is important to distinguish between products sold in competitive and noncompetitive industries. Regulated utilities are an example of noncompetitive industry. Electric utilities base their retail prices on decisions made by public utility commissions rather than competitive market forces. Thus, the state has an alternative strategy for funding research in regulated sectors. It can allow prices to remain at levels that are higher than costs after the innovation is commercialized, or it can raise prices to support research. This latter strategy has been proposed to amortize the cost of developing electric vehicles for California (L.A. Times, 1-8-93). Similarly, the state can encourage toll road authorities to conduct research by establishing a policy that allows them to recoup research costs in higher (regulated) tolls or a higher return on equity. Lack of appropriability need not present as great a hurdle to the conduct of R&D in regulated industries.

Unless the firm is a monopolist, and few industries exist in the United States that can be described as sole sellers, then lack of product market competition does not fully resolve the problem of research benefits being gained by firms which did not fund the research. Without patent protection, benefits are still captured by all firms, not just the innovating company. The potential innovator will still underinvest in research, and hence the public sector still has a role in funding research activities. This issue, which is usually described as "spillover", has been receiving increased attention at the federal level as the world economy has become increasingly integrated. In brief, federal subsidies have spillover benefits not just to domestic firms, but to foreign firms as well. While the case is clear for subsidizing a domestic industry, it is more controversial at the international level.

Clearly, the problem is even more applicable at the state level, for innovations subsidized by the California government will benefit firms and consumers in other states. Note that the reverse process can also apply: the state may be able to receive spillover benefits from research performed by other states or by firms subsidized by other state governments. The extent of spillovers, however, is related to the nature of the problem that research is addressing. Some transportation problems are relatively unique, or perhaps particularly pressing within California. In this case, waiting for results from projects outside the state is likely to be a futile strategy. However, the conclusion does not immediately follow that such projects be prioritized for state support. If the problem is fairly local, spillovers outside the state will be smaller and local benefits more closely aligned to total benefits. In other words, less of a market failure results from lack of appropriability. Justification for state support then depends on the number of potential competitors in the industry and the market structure of the industry.

For research problems that are not unique to California, it is tempting to fall into the same market failure trap at the government level as at the firm level: to wait for other states to fund research and then take advantage of the results. A closer examination of the research process suggests that the argument is flawed in practice.

Studies of technological innovations conclude that in order to innovate, a firm must have considerable technological expertise. It must be able to recognize the potential value of a new product or process, and usually it must modify an innovation to produce a product with commercial value. Practically, the implication is that innovating firms need to maintain at least a base level of research: they need to employ scientists or engineers who are aware of innovations produced elsewhere, who can recognize the potential applications, and who are able to modify them to fit into the capabilities of the parent firm. Copying a technology is not a free activity; much of the successful industrial policies of developing countries have been devoted to precisely this activity. Copying requires time, effort, and money. Thus, while California need not, and should not, attempt to independently pursue all lines of research, if it is to make use of technological advances elsewhere, it must pursue an active research and development program of its own.

This process is known as technology diffusion. A relevant example is in the diffusion of dial-a-ride (DAR) technology in California. DAR buses were first introduced to California by the Orange County Transit District (OCTD) in 1972 (Fielding and Shilling, 1974). The District had a small, professionally-trained staff. They had both training and expertise to recognize the benefits of DAR buses, yet were not burdened by operating responsibilities. The innovation had been developed and tested by UMTA and the State of New Jersey in Haddonfield; OCTD used their knowledge to replicate the innovation in La Habra, California, and after the service potential was demonstrated, expanded DAR throughout Orange County. Other communities recognized the appeal and the innovation spread throughout California.

Furthermore, successful research is associated with a high level of serendipity. It is not possible to predict in advance what strategies are likely to pay off. This is especially the case with important inventions, and the history of technical advance is replete with examples of inventions arising from unlikely sources. Very few research projects genuinely duplicate other efforts, and the more lines of research that are investigated, then the more likely is success. Thus, even if research in a field is conducted in other states, pursuing additional projects here raises the probability of success.

The importance of these factors varies with the nature of the research project. The further a project is from a commercial application, or the more basic or generic the activity, the greater the justification for investigating the problem even if other research groups are looking at it as well. The more sophisticated the technology, in a scientific sense, the more important it is to have local expertise. Thus, as a general guideline, state support for research is most critical for leading edge applications or for basic science activities. However, as the DAR story demonstrates, the spillover value of expertise can be substantial even at the demonstration end of the research process.

Uncertainty

Uncertainty permeates R&D programs because the likelihood or extent of the technological success is difficult to anticipate. In addition, the actual application of research (the product area) may be imperfectly known at the research stage. If the ultimate product is unknown beforehand, it follows that the size of the market for the application, and whether it will exist at all, is subject to uncertainty. Finally, uncertainty exists about who will profit from the research results. Thus, research is not only risky, but it is likely to be far riskier than other investment activities that firms undertake.

Uncertainty over basic research activities can be mitigated by simultaneously pursuing multiple strategies. Just as the risk of stock return variations can be reduced by investing in a portfolio of companies, so is the risk of research lowered by sponsoring multiple projects. As a result, research is less risky to society, which benefits from average success rates from all projects, than to firms who rely on a smaller set of projects.

Research on alternative fuels illustrates the desirability of undertaking basic research on multiple sources. Diesel, propane, methanol, natural gas, and electricity each have their advocates. Their relative energy efficiency is known, but we do not know what pollutants result from combustion, how these gases interact in the atmosphere, or what the spillover effects will be on other industries if demand is increased in transportation. Basic research on alternative fuels is required, but advocates have no incentive to conduct this research. It is too risky unless sponsored by governmental agencies. And until the basic research is complete, applied research on the costs and benefits of different fuels will be inadequate.

Empirical studies have found that in the United States bigger firms do not on average invest more in risky research projects than do small firms. The explanations for this phenomenon have centered on bureaucratic hypotheses. Management structures in large firms appear to impose effective risk avoidance on the activities of their research groups. Thus we cannot conclude that uncertainty poses more of a disincentive to research investment in small firms than large firms: both may need help from the public sector in overcoming an uncertainty-based market failure.

The conjunction of uncertainty with the potential for research benefits to be gained by firms which did not pay for them yields a further market failure in the private provision of research. When the results of research are unknown, there is a possibility that they will yield a product that will be of value to someone else. In the worst case (for a firm), the results might profit a competitor who because of the appropriability problem, will not need to compensate the innovator. Society, the sum total of all firms, has nevertheless benefitted, but not the innovating company. Thus, uncertainty can create a potential discrepancy between private and social returns, and provides yet another rationale for public subsidies for research.

Thusfar, this section has suggested that uncertainty in research means that government should concentrate resources in subsidizing basic research activities.

Here the discrepancy between private and public returns are likely to be greatest, and we concur with the bulk of analysis that concludes that a direct subsidization role for government is likely to be most beneficial in the field of basic research. However,
uncertainty exists in applications as well, relating primarily to the potential loss of a large sum of money. Consequently, the government can also play an important role in encouraging development, although it may be different from standard funding of R&D. A different public strategy designed specifically to address problems in financing risky development may be appropriate.

Government goods

By government goods we mean any product whose use is determined, or significantly affected, by the public sector. Most infrastructure, including roads, is included in the category as well as other goods and services provided by government: schools, libraries, universities, police and fire departments and so on. In addition, the government is a major consumer of some products, and can account for an important part of the market for products like communications equipment or office machinery. Third, the government regulates the use of some products to such a degree that government policies are critical to determining their commercial value. For example, the use of air pollution and noise abatement equipment is contingent on government regulatory policies.

It is important to distinguish government goods from other products in assessing R&D policy for two reasons. First, because the public sector is instrumental in the use and, hence, commercial value of these goods, a range of policy options for encouraging R&D through market-pull policies is available to government that is not feasible for other products. We discuss these strategies below. Second, the market failure problems discussed above can be exacerbated for government goods so that ameliorating policies may be especially important.

Uncertainty is compounded for private companies who might be interested in improving the technology of government goods. Public decisions reflect nonprofit oriented goals; in addition, they depend on constraints not present in the private market. Purchasing decisions can reflect political imperatives: maintaining employment in a certain area, for example, or "buy American" requirements. Regulatory requirements that might be critical for establishing a market for products can shift for reasons unrelated to the actions of suppliers. For example, strict environmental requirements are sometimes relaxed during economic downturns or might be modified in response to lobbying efforts by politically powerful interest groups. Furthermore, personnel shifts, either administrative or legislative, are frequently accompanied by changes in policies. Different administrations may place different priorities on conflicting public goals: for example, the desire to spur economic growth versus avoiding environmental harm caused by development. All of these factors raise uncertainty for firms so that they become reluctant to invest in research.

Underinvestment in research for government goods arises because government cannot commit to a set of policies over time. Market failure is likely to be most severe when the time horizon of the research project is long, for in this case the resulting innovations are likely to be available only after the government, and with it policies, has changed. In addition, policies are most likely to change when they are relatively controversial to begin with. Thus, in designing strategies to promote research for government goods, it is important to consider the relationship of the product to potential changes in policies, and to attempt to tailor strategies to take into account, or, ideally, to directly address the commitment problems in the public sector.

This section has identified a number of different market failures that can give rise to underinvestment in research. These include the inability to appropriate results, excess risk arising from product uncertainty, market uncertainty, capital requirements, and public policy changes. Their importance varies for different types of research, thus establishing a case for varying the extent of public subsidies for research enterprises and for pursuing different strategies to promote different research activities. We turn next to an overview of promotional strategies available to a government agency.

## PUBLIC STRATEGIES TO PROMOTE R&D

Strategies to promote research fall into two main categories: those designed to lower the cost of research, and those intended to increase the value of innovations. The latter are usually called "market-pull" or demand strategies, while the former attempt to increase the supply of research directly. We consider here four alternatives: on the supply side, direct funding of research and conducting research in-house; on the demand side, establishing prizes for innovations and creating market guarantees.

### Direct funding of research activities

Grants and contracts to firms and individuals form the main alternative by which government promotes research. The chief advantages of the strategy are: first, it is relatively easy to institute; second, it enables state goals to be addressed with some precision; and third, it allows the government to retain control over the quantity of expenditures devoted to a project. In addition, many federal cost-sharing programs are exclusively for research grants and contracts so the state can take advantage of federal programs only if it institutes this method of encouraging R&D. The strategy has two main disadvantages for the promotion of research. Most importantly, it puts the government in the position of "picking winners": specifically, the agency needs to assess which research strategies are likely to yield the biggest payoffs. In consequence, this places a substantial informational burden on the state to evaluate proposals. In a new field such as automatic vehicle control systems, few firms have track records to support proposals and new firms may be mistakenly overlooked. Also, the strategy requires a significant level of state monitoring. Research effort can be very difficult to assess; for example, it may involve determining whether firms are assigning their best scientists to the project and whether they are devoting adequate support activities.

Direct subsidies for research can take several different forms. The federal government gives a tax credit to firms for expenditures devoted to R&D. This policy avoids both picking winners and monitoring; alternatively, it does not allow the government to single out those areas that are more prone to underinvestment. A potential modification of this policy would be to give tax credits for all firms that invest in particular technologies. Another related strategy is to subsidize loans to firms, either through a direct interest subsidy (for example, the Japanese government funds the Japan Development Bank, which gives low-interest loans to targeted industries) or through a loan guarantee program. The Federal Synthetic Fuel Corporation guaranteed loans to selected companies that built energy demonstration programs in the early 1980s; an expanded version of this policy is currently under debate.

The previous discussion gives some guidance about the appropriateness of different means of directly subsidizing R&D. Tax credits are of use only to companies that pay taxes and are thus not an option for subsidizing research by nonprofit firms. In order to generate additional results in basic science, it is probably necessary to rely on traditional grant policies. When the market failure in the provision of research is directly linked to capital availability -- specifically, large-scale development programs -- then programs that address liquidity constraints directly are appropriate.

In-house research

Another possibility is for the government agency to conduct research in house. For example, the Division of New Technology, Materials and Research provides in-house research and testing of materials and structures for Caltrans. In addition to avoiding monitoring problems associated with contracting out research, the strategy provides an important spillover benefit for the agency. Specifically, it provides the agency with a cadre of scientists who can evaluate outside proposals and inform the agency about research opportunities. More than 300 engineers, specialists, technicians, and support personnel are assigned to the Division. Research contracts with both state university systems and several private research institutions are managed by the Division to examine and develop innovative approaches to transportation.

A similar rationale is used by major firms who conduct basic research. A number of large U.S. firms have world class science laboratories. The corporate role of the laboratories is not just the pursuit of science -- although they have produced important discoveries that the labs' parent firms commercialized, including high temperature superconductors (IBM) and semiconducting material (ATT). The companies claim further that the expense of their laboratories is justified because the quality of scientific advice that they get from employees on a range of topics would not be available if they didn't provide the scientists with opportunities to conduct research as well as review and evaluate research done elsewhere.

Conducting research in-house is subject to several pitfalls. Civil service rules, and indeed, normal employment practices, make it difficult to either cut back or change employment in a short period of time. The former might be desirable in times of budget shortfalls, while the latter possibility might be desirable when research priorities change. Research contracting gives an agency a level of flexibility that is difficult to duplicate when activities are concentrated within the agency. An additional problem is that the agency's employees are likely to be proponents for the use of innovations developed within the agency, as opposed to technological alternatives developed elsewhere. Thus, it is probably more appropriate for an agency to undertake activities that overlap only minimally with technologies investigated in the private sector.

Prizes for innovation

Another alternative to funding research is to give some kind of financial award to successful innovators in particular technology areas. In order for this strategy to establish incentives to conduct research, the prize needs to be announced in advance. For example, the Department of Defense holds design competitions for weapons systems that require technological advances. Firms conduct research (a fraction of which is typically paid for by DOD) and then submit the results of the research. The "best" system wins a procurement contract, which is usually extremely lucrative.

A second form of prize that government can give to firms is through standard setting. A current example is the high definition television (HDTV) "standards competition" that the Federal Communication Commission (FCC) has undertaken. The FCC has announced that it will establish a standard for HDTV, probably within the next year, which will support the best design from among several proposals that are being submitted by competing television firms. The standard will yield considerable wealth to the firm or firms that will hold relevant patents, and is thus a form of prize for research activities.

Prizes have been shown to be very effective devices for inducing private firms to expand their research activities. For example, estimates of the incentive effect of DOD design competitions conclude that each dollar of procurement induces firms to spend at least an additional five cents on research. Selection of private consortia to construct and operate the four toll road projects authorized by AB 680 is an example of the prize strategy. Caltrans initiated the process by inviting firms to submit qualifications; 10 firms were accepted and invited to propose specific projects. Eight proposals were submitted. Although each proposal had cost private companies $1 million or more to prepare, only four were awarded franchises.

The prize strategy avoids many of the problems identified with direct research awards in that the government need not choose a research strategy, nor need it evaluate the qualifications of potential researchers. However, it too suffers from limitations. First, the strategy is most successful when a number of different firms can compete for the prize. For example, the defense results are very sensitive to the extent of competition. When procurement contracts are awarded on a noncompetitive basis (e.g., sole-sourced), they yield no measurable incentive for firms to conduct research in advance of the contract. Second, the government needs to be able to specify the particular product or application in advance. Thus, it is not a feasible strategy for the conduct of basic research. Third, the commitment to provide the prize needs to be firm. If a technology forcing regulation is modified in subsequent years, firms that invested in the desired technology would be left in the cold. Indeed, firms would probably discount the potential profits to reflect their assessment of the strength of the political commitment. For these reasons, commitments become attenuated over time in the political sector; as a result, the policy is probably most effective for innovations that require relatively little lead-time.

Market guarantees

The government can guarantee a market for categories of innovations, although not for specific firms, through several mechanisms. One is technology-forcing regulations. Such regulations, which are successful in such areas as automobile emission systems, establish a future date by which products must conform to new technological standards. Another option is government procurement; this strategy yields efforts in research when firms have reason to believe that their product will be adopted by the government. It is most effective when the government sets a policy in advance of adopting products that incorporate new technology. Both mechanisms could be used to develop Automatic Vehicle Indicators (AVI - electronic licence plates) for California.

As with prizes for innovation, the policy avoids problems with direct research funding in that government need not identify which firms are likely to be most successful in advance. The strategy is clearly only available to goods which the government regulates or purchases in significant quantities. Since the policies need to be credibly committed to in advance (a problem with the public sector) the use of this strategy is further limited to cases where the government can make a commitment to either follow through on purchases or not modify standards and regulations. We identify above two situations where commitments may be most credible: when they are relatively short-term, and when they are fairly noncontroversial. However this is unlikely to be an effective strategy for promoting basic research whose applications are both uncertain and only likely to be available far in the future. Market guarantees are an attractive alternative to encouraging research in areas that are likely to pay off soon (development work, in particular) and whose importance is agreed to by consensus.

## CONCLUSION

This chapter highlights general guidelines for establishing an R&D policy. Underinvestment in R&D occurs for different reasons and these underlie our recommendations for strategies to encourage research. Because of the uncertainty in the conduct of basic research, direct grants are probably the only mechanism that can correct for underinvestment. Caltrans has two basic choices: contracting out for research or performing it in-house. As it is important to have some in-house capability, it is recommended that Caltrans identify a subset of basic research projects to undertake itself. Not only will this produce solutions, but it will also provide general expertise in transportation research so that Caltrans can evaluate work done elsewhere.

When contracting for research, Calrans should have clearly defined objectives. Proposals should be requested using a format requiring submissions that explain costs and benefits in reference to the best current practice. Not only will this assist Caltrans to select the most beneficial proposal, but also to assess the merit of competing research within a portfolio of research agendas. Incentives are also available for the private provision of R&D.

Prizes, when possible, are an effective means of encouraging both speculative and more certain development work. Development of technical standards for technologies like AVI, vehicle emissions, and fuel efficiency could have beneficial results. A form of direct funding that is appropriate for development projects is the establishment of a loan-guarantee or loan-subsidy program. Improvements in freight handling may respond to this latter incentive.

Although prizes and market guarantees are effective strategies for encouraging research, subsequent chapters will focus upon direct funding and in-house strategies. Concern over the effectiveness of these two approaches resulted in the legislative requirement that this report on research be initiated. However, the Legislature and Caltrans should always seek incentives that will engage private firms in the provision of R&D, as this may produce procedures and/or products which have commercial applications.

Among research problems, a case can be made for emphasizing projects that address problems which uniquely (or disproportionately) affect California. Our discussion, however, underscores the need to maintain a broad research portfolio that allows individual proposals to be evaluated in terms of their real costs and benefits to both transportation and the economy.

# CHAPTER 3

# COST-BENEFIT ANALYSIS

For a state to remain competitive in an expanding global economy, research and development must be an integral part of the commitment to economic growth. In this respect, transportation research serves a twofold role: it is a way in which agencies may look into their own future to set their strategic course, and it is a way to improve the efficiency of operating systems.

The current financial climate, however, imposes strict constraints upon the allocation of funds for research. California can no longer invest money in research without clear objectives and knowledge of probable outcomes; therefore, techniques like cost-benefit analysis (CBA) are required to examine the merits of, and guide the choice between, competing proposals. Although widely used in transportation, CBA is seldom employed correctly, and special care is required in order to avoid errors. The following requirements are essential:

- Uniformity in assessments across proposals must be preserved. Cost-benefit analysis relies upon the art of arranging uniform assessment of alternatives that may sacrifice information available for only some alternatives.
- Goals must be defined in operational terms together with the rate of return that is expected from transportation investments.
- A base case using the best available practice must be defined so that there is a datum against which future improvements can be measured rather than the "do nothing" case.

- Timing of costs and benefits must be estimated and values discounted to current dollars.
- And results should be tested for sensitivity to changes in critical assumptions, such as the rate of discount.

Cost-benefit analysis creates a ranking among competing alternatives. The criterion used is that of maximizing monetary return (benefits) for a given amount of money invested (costs). Quantifiable estimates are preferred, but qualitative estimates can be used and the ranking can be integrated with other criteria to create a system based upon different goals. For example, Gosling and Jackson (1986) describe the methodology used by the Wisconsin Department of Transportation to allocate funding among projects. The methodology consists of an equal weighting between cost-benefit analysis and the goal of political acceptance.

The purpose of CBA is to provide a consistent ranking of alternatives so as to facilitate decision making. Several forms of CBA are available differing in the way in which costs and benefits are expressed. Benefit-cost ratio, the ratio of benefits to cost, is the most popular. However, this chapter will recommend the Net Present Value method; it emphasizes the discounting of costs and benefits to current values that are frequently omitted in benefit-cost ratios.

Net present value (NPV) is the present-day value of the benefits minus the present-day value of the costs for each proposal. The discount rate must be decided in advance and applied uniformly so as to reduce future benefits to the equivalent of present costs. For example, the benefits of this research, conducted in 1992, will be captured through more effective and less costly research in future years. However, it will require an average stream of $9295 in savings each year over 15 years for the state to recover the $80,000 cost in 1992, assuming a 10 percent discount rate. Any excess will provide a positive NPV and an economic benefit for the state. Only proposals with a positive NPV should be initiated, and those with a greater NPV should receive a higher priority if there is insufficient funding for all proposals.

This chapter begins with the history of CBA, and follows with a description of the most commonly used forms of CBA illustrated by examples, diagrams, and a critique of the current use of CBA in transportation. Special attention will focus on CBA applied to the appraisal of a research agenda. Currently, the choice of a proper discount rate is the issue causing the most difficulty and controversy, and a section is devoted to this topic. This chapter also recommends that sensitivity analysis be performed to see how strongly the chosen discount rate affects the result.

## COST-BENEFIT ANALYSIS AS A METHODOLOGY

The theoretical justification for cost-benefit analysis comes from the idea of Pareto improvement in welfare economics (Trumbull, 1991). The Pareto notion asserts that a change is beneficial for society if it makes some persons better off without making others any worse off. When benefits exceed costs in a cost-benefit evaluation, we assume that the outcome is beneficial to society as a whole.

The strength of CBA as a tool of project evaluation is realized when the decision making unit can organize the set of underlying assumptions and data collection in cost-benefit studies so that consistency is maintained across all studies. Consistency allows comparisons of projects within the framework.

An additional value of using CBA is that it can emulate market processes by directing limited resources into the most highly valued social purposes. For instance, a correct CBA takes into account external effects of a project, such as pollution, by imputing a dollar value for any such costs or benefits. This allows decision makers to view each project with the rest of society in mind, not only those persons who benefit directly from its implementation. Cost-benefit analysis attempts to make policy choices rationally, to increase the efficiency of state intervention by transforming impacts into economic variables.

A brief history of cost-benefit analysis

The methodological underpinnings of cost-benefit analysis originated in the 19th century with the work of the "Ecole Polytechnique" (engineering school) and its appraisal of public works projects in France. Dupuit (1844) is perhaps the best known author of such studies, but Navier (1832) conducted the first appraisals explicitly considering costs and benefits. Both expanded upon simple efficiency notions, creating a format very similar to modern cost-benefit analysis. Dupuit's work is noteworthy because he also incorporated microeconomic theory into his studies.

Button and Pearman (1983) trace the modern era of cost-benefit analysis back to the turn of the century and the River and Harbor Act of 1902. Although there was substantial pre-World War II interest in cost-benefit analysis, there were no consistent guidelines for the technique in the United States until the publication in 1957 of a Federal River Basin Committee report which suggested a procedure for cost-benefit studies.

Early uses of CBA in transportation projects included studies of the Victoria Underground (subway) and the M1 motorway in England. Button and Pearman stress that transportation planning has been one of the few fields where cost-benefit work is frequently completed prior to actual investment.

During the 1970s and 1980s, an improved appreciation for the limitations of CBA developed in addition to new ways for the planner to account for items and ideas that had been neglected or omitted from previous studies. The creation of computerized methodologies such as the Productivity Estimation Computer Model (Lewis, 1991) in the United States and COBA (Cost Benefit Analysis) in England allowed greater standardization of project evaluation and improved comparisons among competing sets of similar projects. Evaluations for projects funded by the United States Department of Transportation during this time were required to include an assessment of alternative projects, including the "no build" alternative, using CBA. The requirements prompted several attempts to modify and extend aspects of the existing theory (Rubenstein, et al., 1980) but the basic methodology remains unchanged.

Cost-benefit analysis is a well established and efficient way for an agency to evaluate the allocation of scarce resources among alternative proposals. The history of CBA illustrates not only its applicability to all types of projects, but also the need for such a decision-aiding tool.

## TYPOLOGY FOR COST-BENEFIT ANALYSIS

Cost-benefit analysis comes in a number of forms which differ in the way in which either costs or benefits are expressed. Although each method has its merit, **net present value** is recommended.

Cost-effectiveness analysis

In cost-effectiveness analysis there exists a unique goal and different ways to achieve this objective. The problem is to identify alternative courses of action and to calculate their costs. Costs of alternatives are then ranked from lowest to highest. This method is used when a set of alternatives to be ranked yields the same benefits; e.g., when a tangible goal is set by a government or agency and is competed for by alternative proposals. Bids to construct an interchange would be an example. Achievement of the goal is the sole benefit, and costs are the basis for comparison. A nonpecuniary example would be the analysis of different methods to reduce highway fatalities; the benefit is stated as a goal and the cost of alternative strategies is analyzed.

Cost-effectiveness takes into account only part of the available information. By ranking alternatives in terms of cost alone, the disintegrate is assuming that one of the alternatives must be chosen. However, it is possible that none of the alternative projects achieve benefits that exceed their real cost, and the economy would be better off with no action. For example, the proposed interchange may cause more direct and indirect costs than benefits for the adjoining community and travelers. When enhanced productivity and economic growth are desired, it is essential that all costs and benefits be considered.

Benefit-cost ratio

A more complete measure of welfare is the benefit-cost ratio. This is the ratio of discounted benefits to discounted costs. The measure is constructed so that projects with higher benefits than costs will have larger benefit-cost ratios. The algebraic formula is:

$$\textbf{Benefit Cost Ratio} = \Sigma[B_t/(1+r)^t] \,/\Sigma[C_t/(1+r)^t]$$

where B is benefits, C is costs, and r is the discount rate (or the rate at which money could be invested elsewhere in the economy) and t is the number of time periods involved, usually the projected lifetime of the particular project. A project is considered beneficial to society if the ratio is greater than one.

Discounting corrects for the different value assigned to having equivalent amounts of money now or in the future; i.e., a dollar next year being worth less than a dollar now. To bring costs and benefits to a common reference point (the present) we divide by one plus the discount rate for each time period. Caltrans uses the "pooled money investment" return as their current discount rate.

In a benefit-cost ratio analysis, substantial variation in the results can occur as the result of choosing different discount rates. Therefore, this form of CBA is difficult to use in transportation projects because both the costs and the benefits involve long time periods. Furthermore, discounting procedures are a frequent cause of error.

<u>Net present value</u>

The preferred method for expressing the relationship between costs and benefits is net present value. This criterion is similar to the benefit-cost ratio, but it expresses the result in current dollars rather than a ratio. The formula is written as:

$$NPV = \Sigma(B_t - C_t)/(1+r)^t$$

The larger this value, the more a project improves welfare. Expression of the result in current dollars is a real advantage for decision making, and most of the information required to calculate NPV is available from the same data used to calculate cost-effectiveness and cost-benefit studies (Box 3.1). Lewis (1991) illustrates the superiority of NPV by recalculating the results from an UMTA sponsored study that appraised four transit alternatives in reference to the goal of lowering "cost per new transit rider." The results are instructive: whereas the cost effectiveness study appraisal favors the light rail option, NPV shows that no alternative yields a positive benefit over the base case that entailed using the existing infrastructure more effectively. Lewis cautions, however, that the results would change if different discount rates were used, or if a longer project life was assumed.

These cautions are appropriate; NPV, like other methods of CBA, is a technique for appraising similar proposals. It should not be used to predict the financial outcome of a proposal or project.

## CASE STUDY

### Net Present Value versus Cost-Effectiveness Analysis as a Basis for Transit Investment Decisions

Many transit authorities, as well as the federal government, use cost-effectiveness tests to help guide investment decisions. Tests such as cost per new-rider in help is the search for investments that maximize the number of travellers attracted to transit for each dollar spent on facilities and services. Such tests do not, however, indicate which alternatives offer the highest net economic returns nor whether the economic benefits of transit projects, such as time savings and environmental gains, outweigh their costs and thus contribute to productivity and economic growth.

Tests conducted in preparing the Primer confirm that cost-effectiveness and net present value tests can yield very different economic signals to decision makers. The Case Study reported in the Table below indicates that, for the city in question, the cost-effectiveness test favors a light rail option whereas the net present value criterion indicates that an express bus approach is likely to yield a higher net economic benefit.

The Table also indicates a risk that none of the options considered are likely to yield benefits in excess of costs (all net present values being negative). This information would be unavailable with only cost-effectiveness information.

Like any forecast, however, net present values should be viewed in the context of sensitivity and risk analysis. Express Bus Option Two, for example, produces an NPV near zero, indicating a broadly satisfactory rate of return. As well, a longer assumed life for each of the options shows that the Light Rail Two alternative is likely to yield a positive Net Present Value. The Express Bus Option Two, however, remains the most economically attractive from an economic perspective.

**Economic Benefits of Alternative Transit Improvements in a Selected Urban Area, by Alternative Decision Criteria**

| Alternative | Cost-Effectiveness (Cost Per New Rider) | Net Present Value (Millions) |
|---|---|---|
| Transportation System Management | $ 3.71 | -$ 5.60 |
| Express Bus Option One | $18.18 | -$16.40 |
| Express Bus Option Two | $ 3.12 | -$ 0.30 |
| Light Rail Option One | $ 5.86 | -$46.90 |
| Light Rail Option Two | $ 2.87 | -$ 8.60 |

Box 3.1. Source Lewis (1991), pp 47.

Internal rate of return

Another useful method of analysis is the internal rate of return, the interest or discount rate at which the net present value of the project is zero. The formula is:

$$\textbf{find r such that } \Sigma\ (B_t - C_t)/(1+r)^t = 0$$

The higher the internal rate of return, the faster benefits will be able to cover the costs. Therefore the alternative with the highest rank is placed first. The advantage to the internal rate method is that it reveals what kind of return can be expected for given costs and benefits. It makes an ideal starting point for project evaluation. Alternatives that cannot achieve a rate of return comparable to those that exist in the bond or securities market can be eliminated.

There are situations, however, where the internal rate of return can yield more than a single rate for a project. This happens when net benefits (benefits minus costs) are both positive and negative over an entire investment stream (Fig 3.1). If the net benefit curve crosses the interest axis (x-axis) more than once, i.e., if the curve is quadratic, then this apparent contradiction occurs.

Advantages of NPV

Although these four methods, cost-effectiveness, benefit-cost ratio, NPV, and internal rate of return are frequently used in transportation, this does not imply that they yield the same information. Both cost-effectiveness and benefit-cost ratio neglect the magnitude of the benefit component. This omission can be

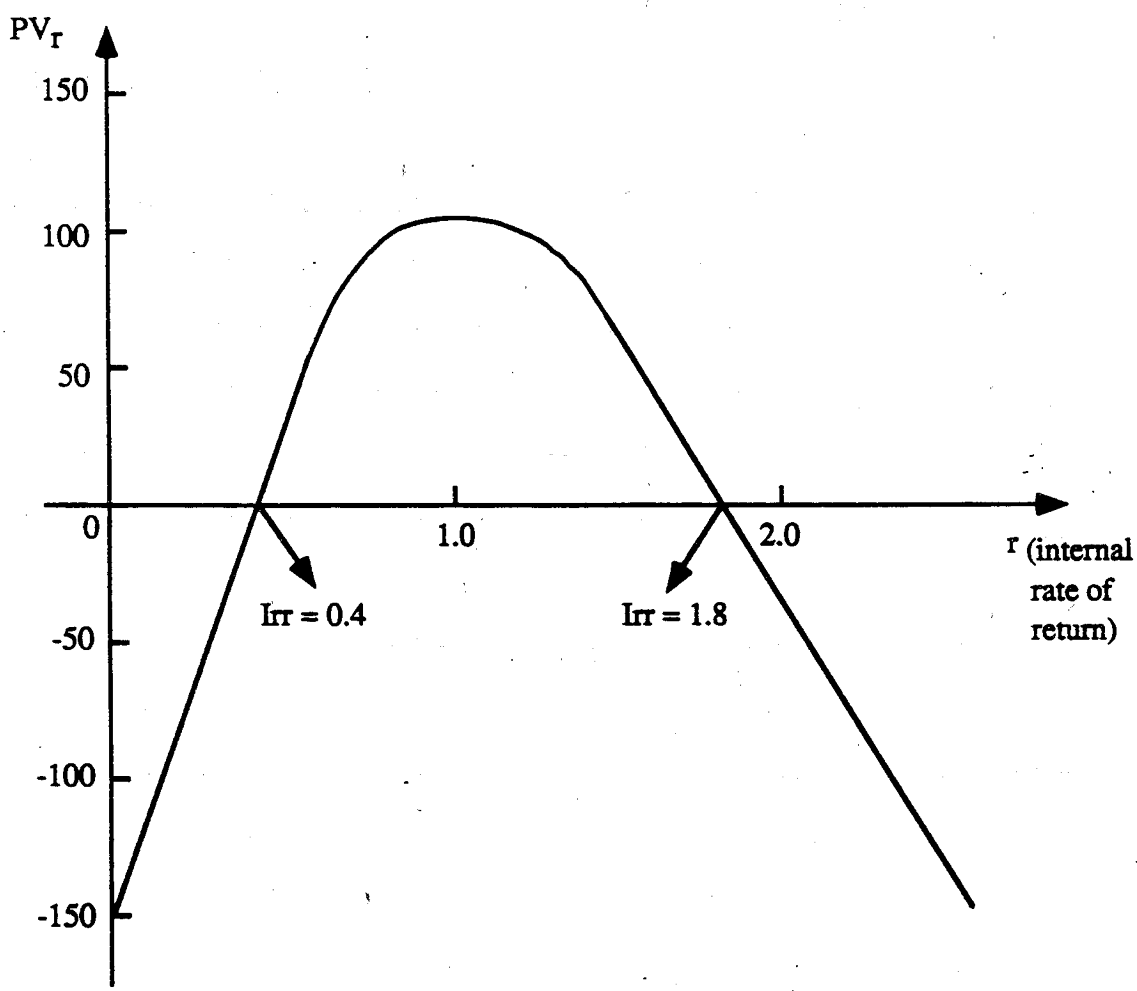



Fig. 3.1: A Net Present Value stream yielding two internal rates of return.
Source: Mishan (1998) pp. 242

confusing as the following example illustrates. Assume that there are two proposals:

Proposal 1) \$5 in benefits: \$1 in costs.

Proposal 2) \$1200 in benefits : \$1000 in costs.

By the benefit-cost ratio criterion, Project 1 is preferable. For every dollar in cost, the small project generates \$5 of benefits. But Project 2, which has a benefit-cost ratio of 1.2, yields \$200 in net benefits (benefits minus costs), a substantial improvement on the \$4 in net benefits generated by Project 1.

Using the NPV criterion, Proposal 2 is preferred. From a societal perspective, \$200 in net benefits is superior to \$4. NPV takes into account the size differentials between projects and removes biases towards smaller projects. Only when projects have similar benefits and costs do the two methods yield similar information.

A value judgment is made when recommending NPV as the preferred method for CBA. The judgment is that society prefers more to less, even at a certain cost in "efficiency", as measured by maximum benefits per unit cost (this is what the benefit-cost ratio indicates). This is not an extreme judgment, however, when there is no guarantee that a project with a high benefit-cost ratio at lower levels of costs and benefits will maintain the ratio over its entire potential net benefit stream. The likelihood of diminishing returns make it prudent for the decision maker to utilize NPV when making investment decisions between competing proposals.

The use of CBA gives the analyst an important tool to introduce additional information into the choice of which projects to fund. Of the methods available, NPV is the most helpful when appraising research proposals.

## COST-BENEFIT ANALYSIS FOR RESEARCH

Cost-benefit analysis is not a flawless tool for evaluating research proposals. The following is a discussion of some of the most common CBA and research proposals concern, including: 1) base case specification, 2) incorporation of indirect impacts ("general equilibrium"), and 3) distributional concerns.

### The base case

Perhaps the most important issue facing the disintegrate in choosing among research proposals, is the selection of the base case, a scenario wherein no new project is chosen. This does not mean the comparison is made to a situation where the agency does nothing. On the contrary, the base case scenario should include predicted improvements in current managerial practice and physical infrastructure. For example, the base case for the transit comparison illustrated in Box 3.1 assumed a traffic management system that would facilitate the use of streets by transit. Comparison of the capital intensive alternatives was based upon the improvements over the best, current managerial practice. Without designation of a base case, which happens frequently, assessment of benefits is exaggerated.

The feasibility study completed for the Space Shuttle illustrates some of the problems involved with the choice of a base case (Banks, Chapter 7 in Cohen and Noll, 1991). The initial cost-benefit analysis commissioned by NASA for the Shuttle was done only after Congress had rejected NASA's master plan for lunar colonization and an eventual trip to Mars.

The cost-benefit study done by Mathematica in 1971 came to a conclusion in favor of the shuttle as a net benefit to society; a conclusion which rested strongly on the concurrent success of the so-called "space tug." Without this system in operation, according to Banks, the foundation for Mathematica's cost-benefit analysis is drastically altered. He attributes at least some of the well-known Shuttle cost overruns to the undeveloped space tug.

Another criticism levelled at NASA's cost-benefit analysis was their choice of base case. Instead of comparing the Shuttle to a natural progression of existing technology (in the possible form of advanced, expendable rocket boosters) a comparison was made only with existing types of boosters. This tends to weigh in favor of the new technology because of the uncertain and underestimated nature of costs, what Banks refers to as "planning tendencies towards optimism," in uncertain estimates. Banks implies NASA manipulated and used these so-called "unbiased" economic studies to obtain at least a part of its grand engineering plan, of which the Shuttle was an integral component.

Indirect impacts (General equilibrium)

General equilibrium impacts in transportation refer to benefits (or costs) which result as a consequence of increased ease of movement for both goods and people. These impacts include the technical changes in industry, which transportation improvements allow, that create improved productivity. General equilibrium impacts are seldom consistently accounted for in CBA. The examination of each research proposal should carefully consider the following effects:

1) Technological Travel time is a direct consequence of research, and is represented by either a societal benefit or a cost saving.

2) Returns to scale-- firms are made more efficient with increases in certain factor inputs (like transportation). Costs may decrease for certain ranges of output.

3) Prices-- improvements as a consequence of the above gains (less costly goods for both consumers and producers).

4) Project Complimentarity or Substitutability--efficiency gains due to positive interrelations amongst a set of different proposals.

Travel time savings are frequently used as a surrogate for general equilibrium benefits in transportation, but the efficiency gains that travel time savings encourage are normally omitted, resulting in the underestimate of benefits. Quarmby (1990) references case studies from the grocery industry indicating that productivity gains accruing to the industry as a result of travel time savings by commercial vehicles tend to be underestimated by some 30-50%. Omitted benefits are those achieved through economies of scale.

Collection of data is the primary pitfall for most analyses of indirect impacts. The necessary data is frequently either costly or impossible to collect, and value judgements have to be made as to what kind of data is sufficient to account for general equilibrium effects or what kind of proxy data will suffice. Rather than requiring that all indirect impacts be included, it is more important that alternative proposals incorporate the same effects. In other words, equality should be achieved.

Distribution and redistribution

Regional and demographic inequalities sometimes require analysts to clarify how costs and benefits will affect different population groups. Regional economic disparities and other forms of economic inequality are easily accounted for in the framework. The analyst can weigh the economic benefits going to those who are considered underprivileged or underrepresented more heavily than those who are not, thus favoring projects beneficial to them. In a regional context, decision makers may perceive certain disparities and desire proposals helping the affected area. An example would be if the state of California had a preference for projects which favor Northern California over Southern California because the infrastructure of the North is not as well developed as that of the South.

Decisionmakers do not have to commit to ranking proposals exclusively by a single economic or political criterion. The planner performs an evaluation accounting for governmental preferences through more weighting on those benefits which are perceived as desirable. When this is done, fairness of the criterion is invariably called into question. However, when a proposal from a competing region or economic sector generates more benefits (with similar costs) for society as a whole, even after adjusting for redistribution requirements, the proposal with the highest NPV should be chosen.

Difficulty in appraising research proposals

Research offers special difficulties with regards to estimating benefits. First, all of the benefits are seldom appropriated by the sponsor. Nicholson (1971) explains the situation as follows: "In putting together the picture of benefits likely to arise from research and development, careful attention must be paid to the incentives or disincentives that such benefits imply. The general economic and social benefits do not appear as a cash return to the investors." Among these benefits are the benefits of technological change itemized previously as indirect impacts.

Second, the market valuation for research may not be apparent for many years. In part, this is because the payoffs are normally some years in the future. Without some forecasting technique that can estimate demand for future research today, the error involved in guessing at these values may become large, and the actual future value of the final research product could be far removed from present estimates. Research coming out of nonmarket organizations (such as universities) may adversely experience this effect because current market prices may not be an accurate guide for evaluating present worth.

## CHOOSING A PROPER DISCOUNT RATE

Cost-benefit analysis requires that all elements of the calculation be in a common time frame. The way to do this is through discounting as illustrated in Box 3.2. This section examines some issues involved in discounting.

Changes in the discount rate can substantially affect ranking in cost-benefit studies. Studies of these changes are known as sensitivity analyses and illustrate to the disintegrate the significance of the chosen discount rate in CBA.

Discount rates should be in real terms; i.e., corrected for inflation. Furthermore, these rates ideally are adjusted for risk, where risk in this case refers to a project's correlation with the overall health of the economy. It would be simpler if a financial risk of this type could be avoided so as to take away any economic biases (such as economic growth or decline) which may occur over the entire duration length of a benefit and cost stream.

## Box 3.2

### Computing discounted values

Discount factor is : $\frac{1}{(1+r)^t}$

where r is the discount rate
t is the number of years (start with t=0)

Example: compute the present value of $5000 per year for five years (including the present year) at a 7% rate of discount. Here, x = $5000, the amount to be used for the calculation in each year.

$$NPV = \sum_{t=0}^{4} \frac{x}{(1+r)^t}$$

starting at t=0, counting up to four years gives 5 elements for summing, including the present year.

$$= 5000 + 5000/(1.07) + 5000/(1.07)^2 + 5000/(1.07)^3 + 5000/(1.07)^4$$

= $5000 + $4673 + $4367 + $4082 + $3814

= <u>$21936</u>

as opposed to NPV = $25000 without discounting (when r = 0).

### Sensitivity Analysis

Change the discount rate and see how the NPV changes.

Now, let r = 0.10 (a 10 percent rate of discount) for 5 years, including the present year.

$$NPV = \sum_{t=0}^{4} \frac{x}{(1+r)^t}$$

$$= 5000 + 5000/(1.10) + 5000/(1.10)^2 + 5000/(1.10)^3 + 5000/(1.10)^4$$

= $5000 + $4545 + $4132 + $3757 + $3415

= <u>$20849</u>

higher rates of discount lower the net present value, all other things being equal.

For federal agencies, Lind (1988) reports a ten percent real rate of discount as standard. Ten percent is approximately equal to the return on private capital in the economy. A case could be made for a reevaluation of this rationale for discounting, given the nature of international capital markets. An open economy has various implications on private investment returns, the most important of which is that the prevailing rate of return in the home country may not be the highest or best return to private investment. Thus, in a single country, interest rate is no longer applicable as an indicator of the appropriate discount rate. Lind advocates using not only an equilibrium world interest rate as the discount rate, but also the consumer borrowing rate at home to measure investment as well as consumption effects in CBA. Additionally, the internal rate of return ought to be calculated as a benchmark measure for the two other discount rates.

Hartman's (1988) paper describes discount practices in the Congressional Budget Office (CBO) and gives a different rationale for the choice of discount rate. The government is described as viewing its investment projects in terms of opportunity costs, or the cost of the next best (or possible) alternative. The CBO judges the proper rate of discount to be an adjusted time consumption preference rate. Hartman suggests that this can be approximated by government security yields.

An agency should be cautious in choosing the discount rate for project evaluation. The structure of financial markets implies that the national opportunity cost of capital (interest rate) may no longer be a useful guide for making decisions in a regional context. Some measure of time preference, like the consumer borrowing rate, should also be used to discount projects. Since these rates may vary widely, it is essential that the analyst perform sensitivity analysis on cost-benefit rankings.

Value of time

Among the benefits occurring as a result of transportation research investment, value of time saved for travelers is likely the most important. Although it is a large portion of the benefit stream, value of time saved can be troublesome to express as an exact dollar figure, and there has been a great deal of disagreement over how to measure the value of time saved.

The value of time saved is based upon the notion that people are willing to pay some amount to save time traveling. A good example of this is air transit demand versus land transit demand for long trips. People are willing to pay more for air transit because it is more convenient and faster for trips of long duration. Another example is a toll road; people are willing to pay for the ability to travel faster by using the less congested toll road.

Research and development proposals seek to discover or develop ways in which transportation can be improved including the reduction of travel time. And any change which gives people better and faster access to where they want to go is something of value. This valuation becomes a value of time saved; a benefit that must be accounted for in NPV calculations for transportation research.

The description above yields some insight as to how the analyst would quantify this value. Opportunity cost is an economic notion describing the cost of something as the value of the next best possible alternative use of the object or service in question. Since a substantial portion of travel time is associated with the earning of income for most individuals, it has been postulated that people value time saved from traveling at some percentage of their working wage. Time gained through a quicker commute is time that can be best spent being productive at work.

Empirical estimations of the percentage of the post-tax wage rate at which individuals value time saved in traveling vary from 50 to 227 percent (Viton, 1991). This variation is caused by several factors. The factors most often accounting for valuation differences between travelers are the income of the traveler (higher value of time lost for higher incomes) and the trip purpose (work and pleasure trips possess different values of time for most people). The best strategy for choosing a standard value of time saved in an NPV calculation is to examine empirical studies which possess similar characteristics, and then calculate a value of time appropriate for the type of traveler and their trip purpose. These possibilities notwithstanding, it is best to be conservative. Several comparative analyses should be conducted to see how sensitive total benefits are to the choice of this value.

Additional difficulties with the quantification of the value of time saved measure stem from the problem of standardizing peoples perception of time. Whereas a saving of one hour in travel time would be a substantial, measurable gain for an individual, a savings of five minutes by twelve people might not be important.

Can we conclude that many small savings in time are equivalent to one large saving? These are very subjective issues, and as of the present there is no consensus as to the correct answer.

A related proposition is the idea that the important benefit as perceived by travelers is not necessarily time saved but improved predictability of journey times. People may commit set portions of their time to actual travel, and any deviation from these allocations cause disbenefits. Another relevant item for transit studies is waiting time. People dislike waiting and value time lost in waiting at roughly the same level as the cost of travel time (Mayworm et al. 1980).

It is important for the agency to note these potential sources of weakness in the calculation of value of time saved, and to be conservative in estimating this type of benefit.

## SENSITIVITY ANALYSIS

Sensitivity analysis is a method used to check how project a system will be affected by changes in assumptions or variables such as the discount rate. Its main strength is the simplicity of implementation and interpretation. Modifying CBA in this manner allows the analyst to note how changes in discount rates affect the choice between risky and non-risky projects.

Preference for present consumption implies that research projects with their longer benefit time horizons are risky investments. Imposing standard capital-budgeting discount rates invariably biases against research. Sensitivity analysis, however, allows research projects to be compared to other types of projects using different discount rates to see whether they achieve a positive NPV or rate of return under different assumptions. As research projects with long-term horizons appear to be sound investments only when lower discount rates are used, shorter term, demonstration proposals, with high payoffs in the short-run, can be used in conjunction with them to constitute a risk-minimizing portfolio of research investments.

## CBA IN TRANSPORTATION

Despite the extensive use of CBA by transportation agencies, many studies are deficient; they fail to comply with the basic requirements for economic analysis. A recent Transportation Research Board report (Lewis, 1991) examines 35 case studies and describes only 6 as adequate. Failure to discount costs and benefits correctly or to use sensitivity analysis to accommodate risk and uncertainty were the most common omissions. Such errors are avoidable because most of the inadequate studies contained data that would have allowed the deficiencies to have been corrected.

Net present value (NPV) and internal rate of return (IRR) are the most suitable measures to use when appraising the contribution of research proposals to economic growth and transportation productivity. Net present value is the present-day value of the benefits minus the present-day value of costs. A NPV greater than zero indicates that the minimum rate of economic return will be achieved, and the proposal has positive economic benefits. The rate of return is the discount rate that will reduce NPV to zero. It provides a quick way to assess benefits as the rate of return should exceed the preestablished discount rate for transportation proposals.

Using NPV to create a fair and consistent CBA is a matter of trying to account for items and effects mentioned in this chapter:

- Goals for research should be preestablished together with the rate of return that decision makers expect from transportation investments.
- Base case. Most transportation research is applied; it seeks to make an incremental improvement in current practice. Definition of current practice should include use of the best available practice, otherwise the benefit from the research will be exaggerated.
- Costs. All costs should be included and not only those used to finance the research. Relevant costs would include any negative effects on the environment and employment.

- Benefits. All benefits should be identified. They should include direct savings as well as indirect impacts (general equilibrium effects) on the economy achieved through any restructuring that may result from the research.
- Discounting. All benefits and costs should be projected for the duration of the longest proposal under review. And they should be reduced to present-day values by applying the discount rate agreed to as a goal for transportation research.
- Sensitivity analysis should be conducted to assess the robustness of results. CBA involves assumptions about likely costs and benefits and probable discount rates. Results should be tested against the most likely range for the critical assumptions. At a minimum, the sensitivity of projected travel demand and cost inflation should be examined as this will expose any uncertainty that may be inherent in the proposals.

Recommendations for CBA studies in this report should be viewed as a new outlook on a familiar framework rather than a new methodology. The procedures are well known, although seldom followed. The standard procedure provides a basis for any agency wishing to implement efficient and fair research allocations within increasingly limited budgets.

## CONCLUSION

Several economic methods have been discussed which are commonly used in CBA for transportation. Among these, NPV is the most flexible and useful guide to project evaluation. The internal rate of return method is helpful for gauging the expected rates of return so that inefficient proposals can be eliminated from NPV analysis.

Use of NPV requires guidelines for effective implementation. Specifications of a proper base case, reasonable and justifiable discount rates, along with accounting for external effects such as environmental impacts, are an integral part of a proper analysis. Consistency across project evaluations with respect to these ideas is critical as well.

Agencies performing CBA to these specifications will make more informed and economically justifiable decisions. This is what economic analysis is all about--the allocation of scarce resources to their best possible use.

Further advances on CBA have been demonstrated in the literature. **Expected net present value** can be calculated by associating probabilities with the various net benefits each year to yield expected values of outcomes. And **maximization of societal utility** provides a technique to account for individual preference for the costs and benefits associated with alternatives. As these methods go beyond what agencies might use to assess research proposals, they are discussed in Appendix I. They are included for the benefit of an agency who seeks to automate NPV. Any computer program should be written to allow the possibility of future expansion as more experience is gained with use of advanced techniques.

# CHAPTER 4

# PROBLEMS WITH ESTIMATING HEALTH AND ENVIRONMENTAL BENEFITS

Cost-benefit analysis is a powerful tool for analyzing alternate proposals. As we have emphasized, its power lies in the ability to make relatively clear choices among options. In part, however, its value is in clarifying and isolating the issues that are not easily quantified, so that informed decisions can be made that are cognizant of the remaining uncertainties. In this section we wish to discuss some areas where analysis has been so controversial that they are best omitted as quantified costs and/or benefits.

## Quantifying the value of life

Among the most important characteristics of transportation programs are health effects. Valuing the benefits of health effects is also one of the most problematic aspects of cost-benefit analysis. The simplest approach is based on the economic contributions of individuals. This methodology in essence equates the social value of a life lost (or other health problems) with resulting productivity losses to the economy. Studies that use this approach estimate the "value" of life at around several hundred thousand dollars. For example, NHTSA has estimated the value of life at $344,000 (in 1989 prices) based on an analysis of productivity losses to the economy of traffic accidents.

While productivity measures of the value of life are relatively straightforward to calculate, most analysts argue that they are a poor measure. The measures do give an indication of social losses, but only in a narrow economic sense. Most importantly, they significantly underestimate the value of the life to individuals; i.e., what an individual might be willing to pay to save his or her own life. Thus, most studies of the value of life use instead a methodology that estimates the so-called "willingness to pay." Conceptually, these studies investigate individual willingness to pay for reductions in risk, rather than for saving their lives. An individual would presumably be willing to pay anything to spare his or her own life. The analyses thus attempt to determine what an individual would be willing to pay for (say, a ten percent reduction in risk) and then extrapolate to the value of a life by multiplying the resulting number by (in this example) ten. Most willingness-to-pay studies yield estimates between $1.5 million and $9 million per life (in 1989 price) (Small, 1992).

This methodology is called contingent valuation, because individuals are asked to give a valuation contingent on some hypothetical, risky situation. The methodology is controversial, and problems exist at several levels. First, estimates typically assume that lives are equally valued. While any divergence from this principle is bound to be arbitrary, as a society we do make decisions that implicitly assume otherwise: that the value, for example, of protecting children is greater than the value of protecting other groups. Second, studies of risk assessment reveal inconsistencies. A reduction in an already small risk is usually not valued as highly as an equal reduction in a high risk (e.g., from .3 to .2 versus from .9 to .8). Thus, the linear extrapolations made to calculate "value of life" from valuing risk reductions are inaccurate. Furthermore, people generally respond differently to surveys that posit situations which vary in the exposure rate. Reducing a small risk of a catastrophic event is typically considered more valuable than reducing a larger risk of an isolated event. The implication of these issues is that using a single number for a value of life, multiplying it by the expected lives saved in different research proposals, and including the result as benefits in each cost-benefit analysis, probably ignores important differences in the health effects of different proposals.

More fundamentally, the specific formulation of questions on contingent valuation surveys have been shown to significantly affect the valuations elicited. For example, most people assign systematically larger values to the assumption of a risk ("willingness to accept") than to a reduction in risk ("willingness to pay"), although the two situations are analytically equivalent. Moreover, survey responses tend to diverge from actual behavior (costly actions undertaken by individuals actually exposed to risks) when the hypothetical risk is esoteric. The divergence is not systematically biased in one direction: some low-probability events tend to be ignored altogether; others, like risks of major accidents at nuclear power plants, may be vastly overrated. Thus, we can conclude in general only that contingent valuation surveys are unreliable when respondents are asked to evaluate situations with which they have little or no experience.

Probably the most telling criticism of contingent valuation studies is related to the hypothetical nature of the surveys. People are asked to give values for situations they do not actually face. As discussed by Kemp and Maxwell (1992), most people are far more generous when expenditures are theoretical than when the money comes out of their own pocket. Furthermore, surveys rarely pose a context in which respondents are asked to allocate money that could be spent for alternate purposes. Essentially, the answers given to surveys presume that individuals do not face a budget constraint. Kemp and Maxwell find that when values are elicited in a broader context; i.e., when people are asked to allocate funds to reduce numerous categories of risk, and when respondents are placed in a situation where they believe that they might actually have to pay up, the value of responses typically plummet by a factor of thirty or more.

Quantifying environmental benefits

Quantifying environmental benefits, as with health effects, requires indirect methods. Some categories of environmental benefits can be measured using hedonic analyses; these estimates are reasonably accurate and could be included in cost-benefit analyses. Hedonic studies rely on a market comparison of measurable attributes; i.e., housing values, in multiple regions where some regions are subject to environmental problems and others are not. Properly controlling for other measurable sources of difference in cost, the remaining price differences are equated to the "value" of the environmental benefit. For example, housing prices near or far from a freeway can be analyzed, with the residual equated to the environmental costs of living close to a major road. This approach has been used successfully to estimate the cost of such environmental irritants as noise and air pollution. The estimates are far from precise. For example, no consensus has formed in the economics profession about when the remaining unexplained variance reflects only the environmental differences of interest. However, with a sufficient degree of skepticism on the part of the analyst, the estimates are useful in comparing different projects.

Hedonic studies cannot be performed for all relevant environmental benefits. Not all environmental benefits are reflected in market values. For example, the value of saving endangered species and wetlands or of enhancing the attractiveness of parks are nowhere included in market assessments. Hedonic studies are of limited use in assessing the value of unique environmental attributes. For these situations analysts usually turn to contingent valuation surveys. As a result, the problems discussed above become paramount in obtaining values that are even reasonably accurate.

We believe that the problems with contingent valuations seriously undermine any attempt to put a specific dollar value on lives saved or on some environmental benefits. The level of uncertainty about these estimates is so high that summing such values with other benefits which can be estimated with a reasonable degree of confidence does a disservice to the latter.

## CONCLUSION

The considerations discussed above suggest that a judicious use of cost-benefit studies must necessarily be incomplete: we cannot rely on a single "cost" and "benefit" that summarizes all the information about a proposal. Rather, some program attributes are probably best left out of the cost-benefit study. Health effects, lives saved, and some types of environmental benefits should be considered in conjunction with, but separate from, the quantified benefits and costs.

We recommend that proposals be ranked on a series of dimensions. The net present value should be calculated for costs and benefits that can be reliably represented by monetary values. But when the assignment of dollar values is largely arbitrary, these variables should be reported separately. The purpose of cost-benefit analysis is to aid decision making, not to decide the issue.

# CHAPTER 5

# METHODS FOR CHOOSING AMONG RESEARCH PROPOSALS

The methodology of NPV gives the agency an economically justifiable and manageable way in which to rank proposals. It is most useful in situations of limited resources as it yields allocations which are efficient.

In some situations, an agency may decide it wants to set goals for itself and the state in addition to economic efficiency. These goals are extensions of societal or regional benefits which the agency seeks to emphasize. As such, several research proposals may achieve these goals to varying degrees. Since proposals will differ in value, it is not obvious what mix of investments will be optimal in the sense of satisfying the goals as well as maximizing the discounted value of the research.

There is also a high likelihood that agencies will not be able to initiate all research proposals which make a positive contribution to societal welfare. Limited budgets and the growth of expensive technologies mean that some will go unfunded. As suggested in Chapter 3, NPV can be used to assist in selection of socially optimal proposals. If the desired projects exceed the agency budget, then the technique used for evaluation must be modified.

The implication of such a situation is that agencies must now discern amongst beneficial proposals. A portfolio of proposals which best matches agency goals, but fall within the defined budget must be selected. The solution to that problem will be explored in this chapter. Given that NPV is the optimal criterion for ranking proposals, the extensions to incorporate specific goals should involve some form of NPV as part of the solution.

The first procedure aiding in the choice of a portfolio of proposals is called the Excess Terminal Benefit (ETB) method. The advantage of the ETB method lies in its ability to standardize the inputs to the analysis through precise definition of goals. Once this is done, proposals which are more societally beneficial are indicated. The second procedure is called a Goals Applications Matrix. This involves the construction of a reference matrix. The matrix helps emphasize agency and societal goals as part of the choice process. The third procedure is linear programming. Its implementation requires more exact data than the other methods and for that reason this method is not as highly recommended as Excess Terminal Benefit or Goals Applications Matrix.

## EXCESS TERMINAL BENEFIT

Mishan (1988) recommends the Excess Terminal Benefit (ETB) method for choosing a portfolio of proposals when several objectives or purposes are to be met. The portfolio chosen by this method is optimal in the sense that society necessarily prefers it to any other portfolio.

The agency first lists the goals to be met and the number of alternative investment proposals which fulfill each goal. After deciding upon the length of the benefit period (the same number of years for all proposals), the agency subtracts the terminal costs (the future value of the cost stream, which takes into account compounding over time) from the terminal benefits for each investment. This amount is divided by the terminal cost giving Excess Terminal Benefits (ETBs) per dollar for each proposal. For each individual goal, the ETBs corresponding to that goal can be listed across investment proposals. There are as many rows as goals, and as many columns as investment proposals. This array of ETBs is the data used to guide selection.

The constraints for the solution of this problem are a) that any dollar not invested in the proposals will be placed in private sector investment which is compounded at the social rate of discount (a political constraint), b) there is no likelihood of private enterprise completing the same proposals, and c) the initial capital budget is raised entirely by additional taxes so as not to shift existing income or welfare distributions.

For ease of computation, the terminal values of the costs for each alternative are given (in brackets) in Box 5.1 as well as the ETBs. All ETBs have to be positive or they cannot be included in the array. As organized in the array, each proposal meets certain goal criteria with specified excess terminal benefits per dollar. For example, Proposal 1 with respect to the goal of improved safety has an Excess Terminal Benefit ratio of 0.07 with associated terminal cost of $2 million. The last figure, 0.14, represents the total terminal benefits (TTB) for this goal. It is calculated by multiplying together the Excess Terminal Benefit per dollar and the Terminal Costs (in brackets). This is the critical number in the calculation because it is the sum of these numbers for chosen goal/proposal combinations which is to be maximized for highest economic efficiency.

Box 5.1 lists 3 goals and 3 proposals. The hypothetical budget is $7 million. For the proposal/goal combinations chosen, the sum of the relevant terminal costs cannot exceed this amount. When trying to achieve desired goals, if a single proposal satisfies a particular goal then that goal does not have to be satisfied by any other proposals. For example, if proposal 1 satisfies the increased mobility goal, then proposals 2 and 3 need not. It may also be that a single proposal meets

BOX 5.1

## EXCESS TERMINAL BENEFIT (ETB) METHOD

The following is a list of choices among three goals and three proposals. The Excess Terminal Benefits are the first figures listed in each cell and the Terminal discounted costs of each goal/proposal combination are in brackets. The figures on the second line of each cell represent the Terminal Benefits per dollar invested for that goal/proposal combination.

| Goals | Proposal 1 | Proposal 2 | Proposal 3 |
|---|---|---|---|
| A) Increased Mobility | 0.10 (2.3)<br>0.23 | 0.15 (1.9)<br>0.285 | - |
| B) Improved Safety | 0.07 (2.0)<br>0.14 | 0.20 (3.0)<br>0.60 | 0.22 (3.1)<br>0.682 |
| C) Leverage Investment in Transport | 0.12 (2.5)<br>0.30 | 0.15 (2.8)<br>0.42 | - |

Example of a portfolio choice satisfying all three goals given a terminal discounted budget of $7 million:

Choose; Increased mobility through Proposal 2, with an ETB of 0.15
Improved safety through Proposal 1, with an ETB of 0.07
Leveraged investment through Proposal 2 with an ETB of 0.15

**For this portfolio, the Total Terminal Benefits (the sum of the terminal benefits for each cell chosen) equal 0.845 per dollar invested. The Total Terminal Costs sum to $6.7 million, which is feasible given the budget of $7 million.**

**We can do better by increasing Total Terminal Benefit. However, we must stay within the budget of $7 million.**

**Such an example would be:**

**Choose; Improved safety through Proposal 3, with an ETB of 0.22**
**Leveraged investment through Proposal 2, with an ETB of 0.15**

**For this portfolio, the Total Terminal Benefits equal 1.102 per dollar. The Total Terminal Costs sum to $5.9 million, which is within the budget. Note this portfolio does not achieve the improved mobility goal, but given the data does maximize Total Terminal Benefits.**

all goals more efficiently than some combination of proposals. In this manner, the ETB method (using the criterion of maximization of Total Terminal Benefits) aids the analyst trying to choose a portfolio of proposals which best satisfies predetermined goals and is economically efficient.

Given the criterion of total terminal benefits and the various constraints, the problem can be algebraically (or in some simple cases graphically) solved. With many rows and many possible investment proposals the solution may require a suitably programmed computer.

Mishan suggests a simplification. If the terminal costs of a goal are equal for every proposal satisfying that goal (terminal costs may be different across goals or columns, but must be the same across proposals or rows), then one can simply choose the highest ETB in each row and list them in descending order starting from the greatest. Going down the list, we sum the terminal capital costs (the numbers in the brackets) until the sum is as close as possible to the available terminal capital without exceeding it. This shortcut works sometimes even in cases where the condition on the terminal outlays in the rows is only approximately met. In the example of Box 5.1, the optimal solution by the shortcut method is 0.22 for B with proposal 3, 0.15 for C with proposal 2, and 0.15 for A with proposal 2. However, the budget of $7 million is exhausted with goals B and C so that goal A cannot be included in the optimal choice. Implementation of this methodology requires the same attention to detail over the issue of standardization of the inputs as described in Chapter 3. Further guidelines that serve to help with standardization are as follows:

- If a similar goal is required in different localities or regions, then these should be considered as separate goals.

- Within the same region, if two or more goals can be produced together by one investment proposal, then each objective is to be evaluated separately.
- If two or more proposals have to be combined together to satisfy a goal (such as aircraft and airports for improved mobility) then each combination should be regarded as one investment.

These guidelines are extensions of external impact effects described in Chapter 3. They are tailored to improve construction of the ETB array and to ensure that unbiased information is presented to those making the selection.

A similar methodology is used by the Federal Highway Administration a part of the computer program (HERS) for analyzing highway investments (Weinblatt, 1991). HERS performs a CBA selecting only improvements producing positive net discounted benefits. With budget constraints, proposals can be implemented until a specified goal (such as pollution abatement or safety improvement) is reached.

## GOALS APPLICATIONS MATRIX

When conducting NPV analysis, one of the most important elements in the calculation is the standardization of inputs. Only with this can the analyst compare different research proposals and make a decision as to investment, based upon the hierarchy formed by the NPV.

To aid the process of standardization, the agency can construct what is called a goals-applications matrix, as in Figure 5.1. This is similar to the CBA method advocated by Hill (1968). The research proposals form the columns, and the benefits or goals form the rows. It is a heuristic device to enable the benefits from each research proposal to be tracked accurately. It is used in conjunction with standard

Fig. 5.1. Research goals and applications for California

| Priority | GOALS \ APPLICATIONS | Highways Private Vehicles | Highways Commercial Vehicles Goods Movement | Transit Bus or Rail | Railroads | Air Transport | Non-Motorized | Demand Management | Internal Operations & Management |
|---|---|---|---|---|---|---|---|---|---|
| | Improve Mobility & Accessibility | | | | | | | | |
| | Improve Safety | | | | | | | | |
| | Reduce Air Polution | | | | | | | | |
| | Reduce Energy Consumption | | | | | | | | |
| | Facilitate Economic Prosperity | | | | | | | | |
| | Leverage California Investments in Transportation | | | | | | | | |

NPV. In this way, particular goals can be singled out by the agency and proposals which contribute meaningfully to these goals can be chosen for investment. This methodology can be used as well by the agency to try to meet qualitative (difficult to measure) rather than specific quantitative goals.

The goals applications matrix is created in the following manner. The first step is to calculate the discounted net benefits for each proposal (NPV). Next, these figures are to be placed in their relevant column (by type of proposal) and row (by type of goal) creating cells (by type of proposal and type of goal). Each research proposal may have as goals any listed in the rows of the matrix, perhaps all. Each individual cell now lists the discounted net benefit of proposals which share common goals and relate to common modes.

The column labelled "Priority" is a weighting attached to the importance of that goal. This weighting, when multiplied by the NPV, creates a new goal-adjusted net benefit for decisionmaking.

After the goal-adjusted net benefits are calculated, it is a matter of choosing those proposals which have the highest discounted net benefits, or achieve the goals more efficiently than other proposals in the cell. This allows choices within rows, but it is up to the analyst to decide what transport modes (listed in the columns) will be chosen to meet the goals. A quantitative solution to this problem is to prioritize modes on the top of the matrix with numerical weights. Columns (modes) can now be chosen according to these weights.

Smart corridor study

This is a case study illustrating the use of a method resembling the goals applications matrix. JHK and Associates (1990) completed the study to evaluate potential SMART corridors in California. A SMART corridor is a road which provides real-time information to drivers about road and traffic conditions. The research study was designed to rank corridors before seeking federal funding for improvements.

Description of corridor evaluation

The Corridor evaluation (Box 5.3) summary is similar to a one-dimensional (single column) goals application matrix which uses as inputs benefits measured on a nonmonetary scale.

The column labelled "criteria" lists all the relevant benefits desired from highway corridor investments by the agency. Rather than place a money value on any one of them, the analysts decided to measure as objectively as possible the "corridor rating" on a scale of 1 to 10 relative to all highway corridors studied. A one (1) means "poor" or "no help" and a 10 means "good" or "great help." In this fashion each corridor (for example, I-405 between I-10 and US 101) was given a relevant value. The column labelled "weight" serves the same purpose as the priority column in the goals-applications matrix. This column was the same for all the different corridors studied. The "Extension" column results from multiplying the weight by the rating. The sum of these numbers across all criterion is called the "score" of the corridor.

Box 5.3 shows the two methods used to evaluate each corridor in the study. The upper section lists the qualitative goals that each corridor was expected to satisfy. The column labelled "Data Value" shows those goals which could be measured by objective means. The other criteria were evaluated in a judgmental manner, like the Delphi peer review method. The weights were also chosen by a panel of experts to show the relative importance of each criterion. The lower portion is the calculation of a Benefit-Cost ratio measure for the corridor. While costs and benefits are expressed we cannot be certain that they have been properly discounted. The Net Present Value criterion would have been more helpful for this decision making process. However, it must be stressed that the SMART corridor study was consistent in its methodology and made valid comparisons between proposals.

The study was an attempt to rank objectively the various highway corridors and decide which proposals the state should consider for investment. It is interesting to note that the benefit-cost ratios and the evaluation matrix yielded similar rankings. However, on some roadways the differences between the two were large (see Box 5.2).

If the corridor evaluation method were equivalent to the goals application method as described earlier, then the proposals chosen for investment would be dictated by their ranking with respect to the extension score (as listed in Box 5.3) for each criterion. The corridor with the highest score for environmental goals (if we were only considering corridor investment proposals) for instance, would be invested in to meet agency goals for environmental standards. The corridor evaluation method used in the SMART corridor study ranks projects by their overall usefulness. This may be considered sound, but if the agency has specific goals it wishes to meet then the corridor evaluation method may not achieve them. The goals applications method helps the agency satisfy all the goals in the most efficient possible manner while considering amongst all investment possibilities. The SMART corridor study data can be used to easily reevaluate the highway corridors in a goals-application framework. The example thus also serves to illustrate a nonmonetary approach to the goals application methodology.

| RANKING OF CORRIDORS BY CATEGORY | | | | | Exhibit ES-4 |
|---|---|---|---|---|---|
| District | | | Initial Cost | 10 Year O&M Cost | |

BOX 5.2

**TRAFFIC OPERATIONS CENTER COSTS**

| District | Initial Cost | 10 Year O&M Cost |
|---|---|---|
| 3 - Sacramento | $2,308,500 | $4,408,400 |
| 4 - San Francisco Bay Area | $5,182,650 | $10,332,400 |
| 7 - Los Angeles | $5,304,150 | $10,440,400 |
| 8 - San Bernardino / Riverside | $2,308,500 | $4,408,400 |
| 11 - San Diego | $3,469,400 | $6,160,400 |
| 12 - Orange County | $5,000,400 | $10,230,400 |
| Total TOC Costs | $23,573,600 | $45,980,400 |
| Total Category Costs (1,2, & 3) | $559,283,744 | $568,178,714 |
| Total Program Costs | $582,857,344 | $614,159,114 |

| District/ Corridor | Description | B/C Ratio | Score | Initial Cost | 10 Year O&M Cost | Annual Benefit |
|---|---|---|---|---|---|---|
| **CATEGORY 1** | | | | | | |
| 7 - 38 | I-405 between I-110 and I-10 | 9.94 | 714 | $17,443,904 | $18,559,819 | $35,773,200 |
| 4 - 15 | Route 980 / 580 between Route 880 and Powell Street | 9.01 | 783 | $11,378,803 | $10,771,306 | $19,951,200 |
| 7 - 4 | I-5 between I-605 & Route 60 | 8.96 | 766 | $11,771,473 | $12,289,720 | $21,556,800 |
| 7 - 2b | Route 60 between I-5 & I-605 | 8.45 | 621 | $11,043,590 | $13,777,898 | $20,977,200 |
| 7 - 40 | I-405 between I-10 and US 101 | 8.27 | 721 | $8,827,579 | $11,391,877 | $16,717,680 |
| 12 - 8 | I-405 from Route 22 to I-5 | 8.06 | 668 | $20,670,005 | $21,707,850 | $34,142,400 |
| 4 - 1 | Route 101 between Blossom Hill Road and Route 237 | 7.75 | 606 | $23,624,773 | $20,342,946 | $34,066,800 |
| 4 - 17 | Route 80 between Powell Street and San Pablo Avenue | 7.67 | 567 | $8,858,819 | $8,375,181 | $13,212,000 |
| 11 - 2 | I-8 from I-5 to I-15 | 5.71 | 711 | $19,306,811 | $17,590,421 | $21,056,400 |
| 7 - 20 | Route 91 between I-110 and Beach Boulevard | 5.04 | 614 | $16,656,839 | $17,014,675 | $16,984,800 |
| 4 - 22 | Route 280 between Magdalena Avenue and Route 101 | 4.33 | 502 | $24,535,076 | $19,314,517 | $18,997,200 |
| 7 - 27 | I-110 between I-405 and I-10 | 3.93 | 731 | $14,344,533 | $14,788,942 | $11,448,000 |
| 7 - 22 | US 101 between Valley Circle Boulevard and I-5 | 3.88 | 784 | $18,970,566 | $18,882,103 | $14,688,000 |
| 8 - 10 | Route 91 between Maple Street & La Sierra Avenue | 3.62 | 562 | $7,631,399 | $9,580,619 | $6,231,600 |
| 12 - 4 | Route 55 from I-405 to Route 91 | 3.41 | 600 | $12,698,946 | $13,459,805 | $8,917,200 |
| 7 - 1 | I-5, I-10, US 101 and I-110 (Downtown Los Angeles Ring) | 3.03 | 610 | $19,437,321 | $15,425,355 | $10,564,800 |
| Total Category 1 | | | | $247,200,437 | $243,282,034 | $305,285,280 |

**Corridor :** 7-40 **Description :** I-405 between I-10 & US 101

BOX 5.3

| Criteria | Data Value | Corridor Rating | Weight | Extension | Comments |
|---|---|---|---|---|---|
| 1 Freeway capacity/congestion level | 436 | 10 | 24 | 240 | |
| 2 Surface street capacity/congestion | | 2 | 21 | 42 | |
| 3 Local/Regional commitment | | 10 | 13 | 130 | |
| 4 Land use compatibility | | 9 | 11 | 99 | Commercial/Industrial in West LA, open space over Sepulveda Pass |
| 5 Accident/incident history | 68 | 7 | 9 | 63 | |
| 6 Environmental | | 4 | 7 | 28 | |
| 7 Number of jurisdictions | 2 | 8 | 6 | 48 | LA City, LA County |
| 8 Part of larger system | | 8 | 4 | 32 | |
| 9 In-place control features | | 9 | 3 | 27 | |
| 10 Data availability | | 6 | 2 | 12 | |
| | | | 100 | 721 | |

| | |
|---|---|
| **Costs** | |
| Initial (Capital and Implementation) | $8,827,579 |
| 10 Year Operations and Maintenance | $11,391,877 |
| Total | $20,219,456 |
| Annualized Cost | $2,021,946 |
| **Benefits** | |
| Annual Benefit | $16,717,680 |
| Benefit/Cost Ratio | 8.27 |

Source: SMART Corridor Study, JHK and Associates, 1990.

The goals applications matrix incorporates known decisionmaking techniques and allows for the inclusion of social, environmental, and urban design criteria. In this way, it is more suitable for a pluralist democracy with different interests to satisfy. It is a useful complement to the ETB method described earlier as it enables the agency to target specific goals. Standard CBA does not readily account for such specificity. The goals-application matrix is very similar to a weighted NPV calculation except that now the weights are chosen to represent broader objectives.

The goals application matrix is an uncomplicated way to organize goals through the benefits forecasted with agency goals for research proposals. When the proper data is available, more formal methods exist which can help the analyst make economically efficient decisions.

## LINEAR PROGRAMMING AND GOAL PROGRAMMING

Linear programming is a mathematical tool which can help the analyst make an optimal choice given some predetermined objective. This objective might be to maximize Total Terminal Benefits (TTB) or Internal Rate of Return (IRR) with a number of research proposals. Alternatively, goals can be established and optimally achieved within specified financial or political constraints.

Linear programming is a mathematical technique involving the maximization or minimization of a linear function subject to selected linear constraints. The formulation is :

Max (or Min) $c_1x_1 + .... + c_nx_n$

$$\text{Subject to;} \quad a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n \leq k_1$$

$$a_{21}x_1 + a_{22}x_2 + ... + a_{2n}x_n \leq k_2$$

$$\vdots$$

$$a_{m1}x_1 + a_{m2}x_2 + ... + a_{mn}x_n \leq k_m$$

$$x_1 \geq 0, x_2 \geq 0, ....., x_n \geq 0 \quad \text{(non-negativity constraints)}$$

x's are the n decision variables, c's and a's are constants and k is some cutoff value for the nth constraint. The constraints in this formulation can include societal considerations at the discretion of the agency; i.e., pollution carrying capacity, or amount invested in total budget for that year.

Having established constraints, the agency chooses a function or criterion to maximize. This criterion, for example, could be to maximize Total Excess Benefits as this can be readily formulated as a linear programming problem. A solution algorithm for linear programming exists which greatly reduces the time required to solve this type of problem. The algorithm checks all the possible solutions (called extremal points) and then gives as the answer the combination which provides the largest amount of the criterion to be maximized (total excess benefit) without exceeding any of the constraints. Note that there exists software which readily performs these calculations.

## CONCLUSION

NPV provides us with a useful framework within which to choose among research proposals in situations of limited resources. Simple NPV, however, may not be optimal for justifying more complex decisions. This chapter has introduced some extensions which can help the agency make decisions among a portfolio of proposals. Depending upon the data and information available, it is recommended that the agency use either the Excess Terminal Benefit method or the Goals Application Matrix. Unlike the Excess Terminal Benefit method, the Goals Application Matrix can be used when some of the necessary data are not easily expressed quantitatively. Both methods allow the construction of a portfolio of proposals that is economically efficient and satisfies the predetermined priority goals set by the agency.

When choosing among various research proposals, linear programming techniques help the analyst design optimal programs of investment to maximize (or minimize) certain criterion. Since total excess benefit can be used as the decision criterion chosen by the agency, linear programming becomes a useful addition to the CBA toolkit.

# CHAPTER 6

# CASE STUDIES

Transportation research assumes that people will benefit from the results. Although this is a common feature, studies are seldom organized to provide definitive answers on either who will benefit and when, or the magnitude of improvement. Careful analysis of the costs and benefits of each proposal, measured against a base case, is required to determine whether the proposal will improve economic efficiency.

This chapter demonstrates how the usefulness of recently completed research could have been improved had the authors followed the cost-benefit approach recommended in Chapter 3. This approach requires that research proposals and results include:

- A correct "base case" as the basis for estimating improvements which exceed those that could be achieved using sound and innovative management strategies.
- An assessment of the dependency of the proposal on related improvements in transportation.
- A comprehensive listing of forecasted costs and benefits together with the timing for both.
- Identification of the appropriate discount rate.
- An indication of how the net present value of costs and benefits will be calculated and expressed.

- Examples of how the results will be analyzed for sensitivity to changes in critical assumptions affecting costs, benefits, and demand. Sensitivity analysis should provide a reliable assessment of the risk and uncertainty inherent in the anticipated research results.

Compliance with these six criteria provides a methodology for assessing in advance the contribution of each proposal to economic efficiency. In addition, it provides a method for ranking topics when beneficial proposals exceed the budget. This can assist selection of portfolio of proposals to satisfy different goals including economic efficiency.

Goals are important because each proposal must be assessed against what the research claims will be achieved. Reduction in travel time, congestion, and air pollution as well as improvements in safety are frequently used as goals for transportation research. These are used as horizontal lines in Figure 51 to illustrate an agenda of research. The relative improvement in economic efficiency of each proposal, the NPV, can then be compared against other proposals seeking to achieve the same goals.

Few research proposals satisfy the six criteria. Most neither identify a base case nor discount benefits and costs. Some discount costs, but report inflated benefits! And research that tests the sensitivity of results to changes in assumptions is rare.

A uniform procedure for the conduct of both in-house and contracted research is needed. Without a procedure, the California Legislature cannot be assured that it is obtaining full value from investments in transportation research. Our assessment of research proposals is no better than the disappointing assessment of capital projects offered in Chapter 3. The Hickling Corporation (1991) found that only 6 out of 35 projects were competently evaluated! Given that only 17 percent of capital projects are adequately appraised, many of them in the multi-million dollar cost range, it should be no surprise that research proposals are inadequate.

Diffuse research statements are an obstacle to the performances of research. Normally, the goals for research proposals are wide reaching so as to embrace many transportation problems. As a result, proposals touch upon issues that may be only peripherally related to the central issue, and their merit is difficult to evaluate. However, if the research statement embraced only an individual, or a small related set of goals, and these were set out as objectives to be achieved, then the prospect for satisfactory completion would be increased. The six criteria stated above provide the basis for creating research statements which would both improve the assessment of research and increase the likelihood that the results would contribute to efficient and effective operation of transportation systems.

Many deficiencies in research could easily be corrected. Frequently the data needed for adequate appraisal is already available; it merely requires uniform analysis. Three case studies have been selected for reappraisal. Each represents a separate mode and each is designed to fulfill different goals:

1. Highway: automatic traffic surveillance and control in Los Angeles.
2. Transit: alternative fuels for transit vehicles in Southern California.
3. Rail: high speed rail passenger service in the Los Angeles- Las Vegas Valley corridor.

# CASE STUDY: ALTERNATIVE FUELS FOR TRANSIT VEHICLES IN SOUTHERN CALIFORNIA

Southwestern urban areas, especially the Los Angeles basin, are faced with concentrations of air pollution that exceed health standards. As a means to alleviating this problem, both the Environmental Protection Agency (EPA) and the South Coast Air Quality Management District (AQMD) have placed limits on emissions and sponsored research to investigate alternative fuels that lower emissions.

Both agencies see diesel engines, especially those used in transit buses, as a means to demonstrate how regional air quality can be improved. AQMD's twenty-year plan calls for buses to meet emission standards based on alternative fuels or zero emission technologies by the year 2007 (SCRTD, 1992). Air quality requirements have caught the transit industry by surprise. The diesel engine is efficient and requires less maintenance than gasoline engines. The fuel is safe to handle and readily available. Alternative fuel programs are almost nonexistent. As a result, many transit agencies have initiated studies with different fuels to determine whether lower emission alternatives are available.

This case study focuses on the Orange County Transit Authority (OCTA) and the Los Angeles Rapid Transit District (RTD). Both agencies are testing alternative fuels as part of their operating bus fleet. OCTA is conducting a $2,300,000, five-year study financed by the Federal Transit Administration (FTA) and the AQMD. RTD is currently testing alternative fuels with $122,379,604 in funding from AQMD, Los Angeles County Transportation Commission (LACTC), and the FTA.

Buses of all sizes rely on diesel fuel for 99 percent of their energy needs. Diesel's widespread use is attributed to low cost, availability, and the reliability of engines. The cost savings has its drawbacks, however, as particulate emissions from diesel engines exceed safe standards. This problem is compounded with the high volume of transit vehicles on urban streets.

Concern about the effects of air pollution on health has resulted in mandating federal and state legislation. And since current bus emissions will not meet the proposed standards, alternative fuels or methods of reducing pollution must be investigated. One solution is to use particulate traps on diesel buses to catch released air pollutants. The alternative is to use cleaner burning alternative fuels.

Both OCTA and SCRTD have conducted research to evaluate methods to attain the goals of reduced emissions using alternative fuels. And in both instances, their results would have been more conclusive had they followed the NPV strategies suggested in chapter 3. Various alternatives to the current diesel bus will be reviewed together with an assessment of their emission reduction potential and cost. The case study concludes with suggestions of how the research procedure might have been improved.

The base case

Particulate traps are designed to capture particulate matter from diesel exhaust. A particulate trap replaces the muffler of the bus, requiring very little adjustment to the vehicle. Another feature of adding particulate traps is that no engine replacement or expensive alterations to fuel handling are required. The trap is an exhaust filter made of metal-clad ceramic filters that remove the soot and particulate matter from the diesel exhaust. When installed on a diesel engine they reduce up to 80 percent of the particulate emissions, but do not alter gaseous pollutants such as nitrogen oxide (NOx). While having no major adverse effects on performance or noise level, particulate traps are a technological improvement that can be introduced relatively easily.

Use of exhaust traps to reduce particulates represents the best use of current technology. It should have been used as the "base case" for both studies, but was not. As a result, the conclusions reported in the subsequent sections represent benefits and costs measured against emissions from buses without particulate traps rather than the best available technology.

Alternative fuels

Alternative fuels under study for use in buses are methanol, methanol/avocet, compressed natural gas (CNG), and liquid propane gas. Each fuel has advantages and disadvantages from both an operations and pollution point of view.

Methanol is a clear, colorless liquid produced mostly from natural gas, but can also be made from coal, wood, or methane. Compared to diesel engines, the emission advantage of methanol is that it can reduce ozone-forming hydrocarbons by up to 90 percent. Particulate emissions, a serious problem with diesel fuel, are virtually eliminated.

Disadvantages to using methanol fuel are the significant costs for new production systems, its hazards, and lower energy ratio. Current production of methanol is geared to satisfy the needs of the chemical market; increased demand would result in price increases as users compete for supplies. There are also conversion costs, currently $45,000 per vehicle. This includes not only conversion of the diesel engine itself, but also the modifications, including the stainless steel tanks and lines, special fuel pumps, filters, and flammable vapor-detection equipment.

Methanol is a dangerous fuel to handle; it burns without a visible flame, and vapors collect as they are slightly heavier than air. Both necessitate much tighter safety measures. On-board fire suppression systems must be added to the engine compartment to extinguish fires, and vapors must be recovered during bus filling. An additional problem with methanol fuel is its corrosiveness. This destroys the fuel distribution parts and requires separate and more expensive storage tanks for methanol vehicles.

Due to methanol's low energy value, almost twice as much fuel is required to travel a similar distance as a diesel bus. The theoretical mile per gallon ratio of methanol to diesel is 2.3:1, but the field average is 2.7:1. This requires either doubling the vehicle storage capacity or refueling, which reduces the driving range almost by half. Table 6.1, comparing alternative fuels in miles per gallon, illustrates the efficiency of diesel fuel.

Table 6.1. Alternative fuels (miles per gallon) summary

| Diesel | Particulate Trap | CNG | Methanol | Methanol/Avocet | LPG(1)* |
|---|---|---|---|---|---|
| 3.08 | 2.77 | 2.51 | 1.13 | 1.31 | 2.92 |

Source: Alternative Fuels - Cost Model Estimated Operational Maintenance. Southern California Rapid Transit District - Attachment A, pg. 30.
* LPG data from Dennis Elefante at Orange County Transportation Authority

In addition to buses running on 100 percent methanol, there are transit engines converted to use a 95 percent methanol and 5 percent avocet. Avocet is a costly chemical ignition enhancer allowing for compression ignition without the use of glow plugs.

Compressed natural gas (CNG) is composed of methane and small amounts of other gases. It has many benefits: it reduces hydrocarbons 40 to 90 percent, lowers carbon monoxide 50 to 90 percent, and lowers benzene and other toxic pollutants. Extra costs associated with CNG fueled buses are the large, heavy, pressurized tanks needed to hold the fuel and the added cost of compressing the gas before fueling. The added 3,300 pound tanks decreases fuel consumption. CNG is not used widely in the U.S. for transportation as the refueling infrastructure is rarely available. This start-up barrier will add costs of $300,000 or more per refueling station (Sperling, 1989).

Liquid propane gas (LPG) is a mixture of petroleum and natural gas that becomes liquid under pressure or at a reduced temperature. This source of LPG is natural gas processing and crude oil refining. LPG produces an estimated 50 percent fewer hydrocarbons than diesel fuel and may have equal benefits for reducing carbon monoxide. Exact figures are not known since there currently are no manufacturers producing transit engines which run on LPG. LPG vehicles will add $15,000 to the engine cost per vehicle (Topaloglu, 1991). Disadvantages of LPG are the decreased driving range, added costs for vehicle LPG tanks, and limited facilities for fueling.

RTD believes methanol is cost effective and has ordered an additional 303 methanol-powered buses to add to their current fleet of 30. Orange County Transit

Authority (OCTA) currently has six alternate fuel vehicles. They are testing liquefied Petroleum Gas (Propane), CNG, and Methanol/Avocet. RTD and OCTA believe methanol/avocet bus operating expenses are too high and would like to see further research on other fuels.

Air pollution consequences

Air pollution studies of bus emissions have concentrated on a number of harmful pollutants. However, the volume and pollution characteristics of different fuels have not been agreed upon, and we have used the most reliable reported values from different tests (Table 6.2). In addition, the study focuses on the following gaseous emissions: hydrocarbons (HC), carbon monoxide (CO), nitrogen oxide (NOx), particulate matter (PM), methanol, and unburned hydrocarbons (HCHO).

Table 6.2. Air pollution characteristics (grams per mile)

| | HC | CO | NOx | PM | Methanol | HCHO |
|---|---|---|---|---|---|---|
| Diesel | 06.90 | 59.00 | 30.00 | 5.60 | -- | .59 |
| Diesel w/ Particulate Trap | 06.90 | 59.00 | 30.00 | 0.61 | -- | .59 |
| Methanol DDC engine(1) | -- | 67.00 | 11.00 | 0.88 | 183.00 | 3.50 |
| Methanol M.A.N. engine(1) | 21.00 | 28.00 | 12.00 | 0.12 | 045.00 | 2.60 |
| Methanol/Avocet(2) | -- | 05.10 | 22.18 | 0.50 | -- | -- |
| Liquid Propane Gas(3) | 10.50 | 45.10 | 35.30 | 0.04 | -- | -- |
| Compressed Natural Gas(4) | 02.50 | 00.50 | 13.80 | 0.30 | -- | -- |

Note: Particulate trap figures are estimates.

(1) Source: Alternative Liquid Fuels in Transportation (1991), SAE International, pg. 19.
(2) Source: Alternative Fuel Section Status Report (June, 1992), SCRTD, pg. 11.
(3) Source: Dennis Elefante at OCTA (September, 1992)
(4) Source: Assessment of Transit Bus Propulsion Options in Ontario (March, 1991), Ministry of Transportation pg.79.

Exhaust emissions are an important factor in determining the best alternative fuel to be used. Methanol engines provide exhaust emissions substantially below the standards, especially for NOx and PM benefits as compared to diesel. An alternative methanol fueled vehicle is produced by M.A.N. ((Maschinenfabrik Augsburg-Nurenberg, Federal Republic of Germany).

CNG exhausts of hydrocarbon emissions are typically seventy to eighty percent methane which is considered a benign, natural component of the atmosphere. It does, however, add to the greenhouse effect. The major concern with CNG is the refueling time. There are two options for refueling, either one bus at a time (fast filling), as in the case with diesel buses, or with all buses in the fleet simultaneously (slow filling). In both cases, sufficient compression capacity must be installed to deliver the required amount of gas within the typical eight-hour period in which buses are available for fueling. A fast refueling station is the preferred alternative, and a facility capable of supporting 100-150 buses would cost approximately $4,000,000 (Davis, 1990).

CNG has not received as much interest in the United States as methanol. Though the start-up barriers are substantial, the long-term, pollution-reducing potential is greater; therefore, CNG deserves a more careful look. A possible second explanation for methanol's prominence is the resistance to CNG by oil marketers.

Liquid Propane engines are not currently available from bus and truck engine manufacturers. Today, propane engines are obtained by converting existing gasoline engines. Figures show propane engines emit extremely low levels of hydrocarbons, carbon monoxide, particulates, and smoke. One disadvantage of LPG engines is the high level of nitrogen oxide emissions, a dangerous pollutant.

The major impact resulting from the choice of any of the alternative fuels will be the lowering of particulates. Vehicles using unleaded gasoline emit very low levels of particulates, but diesel trucks and buses are important sources of inhalable particulates, particularly in central city areas. Particulates are of special concern because of their proven correlation to health damage (Frederick, Morrison & Small, 1987). The reduction of NOx is also an important effect. NOx health effects occur through a complicated path of photochemical changes in the atmosphere that is more difficult to trace. Therefore, both particulates and NOx reductions are beneficial.

The air pollution characteristics table shows the dramatic effect alternative fuels have in reducing pollution emissions. Methanol decreases NOx by over 60 percent over diesel buses. Reduction by other alternative fuels is almost as dramatic except for liquid propane gas which does not help reduce NOx.

The table shows a dramatic drop in particulates (PM) released with alternative fuels. The addition of the particulate trap decreases PM by 90 percent. The reduction of NOx achieved with methanol is also impressive at approximately 85 percent. Both LPG and CNG obtain the best results with almost a 100 percent elimination of PM.

However, the value of the results is reduced by two omissions: first, comparing emissions from diesel engines (Row 1 of Table 6.2) with alternative fuels overlooks the advantage of the particulate traps (Row 2), and second, the dependency of some alternative fuels upon changes in operating procedures is not recognized. These deficiencies will become more apparent when the reported costs and benefits are analyzed.

Costs of alternative fuels

There are many costs associated with changing from diesel to an alternative fuel system. Using a diesel bus with a particulate trap should be considered the base case. And even this change is relatively expensive at approximately $20,000 beyond the cost of a traditional diesel bus. There is an added $750 per year to maintain the traps and a periodic $3000 expense for trap replacement (Topaloglu, 1991).

To modify a diesel engine to run on methanol/avocet costs approximately $17,000. With increased demand, the production cost differential could come down to $7,000 per vehicle. The bus costs have been estimated and reported in Table 6.3.

Table 6.3. Bus capital costs

| | |
|---|---|
| 1989 Diesel Bus | $186,000 |
| 1991 Diesel Bus/ Particulate Trap | $202,000 |
| Propane Bus | $200,000 |
| Natural Bus | $220,000 |
| Methanol Bus | $200,000 |

Source: Assessment of Transit Bus Propulsion Options in Ontario. Ministry of Transportation. March 1991, pp. 83.

It should be noted that alternative fuel buses have been purchased at higher prices that reflect the relatively high development costs for special orders.

The additional infrastructure costs, above and beyond those incurred by typical diesel fleets, are significant for some of the alternatives. In calculating these costs per bus, a typical garage handling 350 transit buses has been considered (Table 6.4).

Table 6.4. Infrastructure capital costs per bus

| | Fueling Equipment | Garage Modifications |
|---|---|---|
| Propane | $2,000 | $4,000 |
| Natural Gas | $24,000 | $4,000 |
| Methanol | $4,000 | $4,000 |

Source: Assessment of Transit Bus Propulsion Options in Ontario. Ministry of Transportation. March 1991, pp. 84.

The use of methanol is seen as the future for alternative fuels by RTD. This raises the question: From both an environmental and service point of view, is methanol the most cost effective use? Due to the lack of available data, transit agencies have each performed demonstration projects to provide data for the costs and reductions of nitrogen oxide (NOx), particulates, and carbon monoxide.

RTD used a cost effectiveness approach and claims, "the demonstration showed that using methanol could meet state and federal clean-air laws, while keeping costs within reasonable bounds." (SCRTD, 1992). The problem is defining what signifies reasonable bounds. According to SCRTD's own information, methanol/avocet and methanol vehicles were the most expensive to operate. Even these figures can be misleading. According to Frederick, Morrison, and Small, "The instability of the world oil market implies instability in the price of diesel fuel, increasing or diminishing its present price advantage over methanol" (Frederick, Morrison & Small, 1987). Any evaluation of fuel cost needs to consider not only the most price, but also the highest possible price within the Cost-Benefit time frame.

To analyze the total cost associated with alternative fuels, the cost of each bus and infrastructure capital costs per bus needs to be included in the stated cost per mile of operation. Also, the sensitivity of the cost to price changes needs to be assessed.

Adding the bus capital costs (Ministry of Transportation, 1991) and the infrastructure capital costs (Ministry of Transportation, 1991) per bus arrives at a total capital cost per bus. The total cost per bus is equivalent to the principal borrowed. Using 12 years as the average life of a bus and a 10% interest rate gives the annual payment (PMT/year) required to amortize each vehicle and associated infrastructure. Dividing the Pmt/year by forty thousand miles, the average traveled per bus in Southern California, equals the capital cost per mile (Table 6.5).

Table 6.5. Total capital cost per bus mile

| Fuel | Total Capital Cost/Bus | PMT/Year | Cost/Mile |
|---|---|---|---|
| Diesel | $186,000 | $27,297.98 | $.68 |
| Particulate Trap | $202,000 | $29,646.19 | $.74 |
| Methanol | $208,000 | $30,526.77 | $.76 |
| LPG | $206,000 | $30,233.24 | $.72 |
| CNG | $248,000 | $36,397.30 | $.91 |

Combining fuel, parts, labor, and operational maintenance costs (Southern California Rapid Transit District, 1992) with the bus and capital costs from the preceding table produces the total cost per mile (Table 6.6).

Table 6.6. Alternate fuels: total cost estimates

| | Diesel | Particulate Trap | CNG | Methanol | Methanol/ Avocet | LPG(2) |
|---|---|---|---|---|---|---|
| Fuel/Mile(1) | $0.18 | 0.20 | 0.35 | 0.39 | 0.70 | 0.25 |
| Parts/Mile | $0.38 | 0.50 | 0.43 | 0.49 | 0.43 | |
| Labor/Mile | $0.45 | 0.46 | 0.46 | 0.51 | 0.55 | |
| Bus & Capital/Mi.(3) | $0.68 | 0.74 | 0.91 | 0.76 | 0.76 | 0.74 |
| Total Cost/Mi. | $1.69 | 1.90 | 2.15 | 2.15 | 2.44 | |

(1) Fuel Costs as of 7/1/91
(2) Source: OCTA, 1992.
(3) Using LA-SCRTD data from total cost per bus mile
Source: Alternate Fuels - Cost Model Estimated Operational Maintenance. Southern California Rapid Transit District--Attachment A, pg. 30.

Although the particulate traps increase the cost per mile 12 percent over the standard diesel bus to $1.90 per mile, they represent the appropriate base case to use for the analysis of pollution since they can be introduced easily and inexpensively. Using either methanol or CNG results in a 13 percent increase over the base (Table 6.6). The Methanol/Avocet alternative is even more expensive and will not be examined further. Decisions about which alternative fuel to use should be determined after comparing the relative benefits in reduced pollutants over costs.

While both the OCTA and the SCRTD studies contain valuable information, neither study examined the costs as they applied to a full range of alternative fuels, or amortized these costs to a vehicle-mile basis. This illustrates that the necessary data is often available, but not used to provide a uniform comparison of alternatives. Additional deficiencies occur in the analysis of benefits.

Benefits

Assessing the benefits of alternative fuels is difficult. The effects of emissions on health are poorly understood, population segments differ in susceptibility to harm, and the concentration of pollution varies throughout the Los Angeles Basin. Both the OCTA and the SCRTD studies avoid calculating benefits; they assume that lowered emissions are beneficial because they are prescribed by law. Their goal was to achieve emission control standards at least cost. They are cost-effectiveness rather than cost-benefit studies.

Cost-effectiveness studies are unwise in public policy because they eliminate alternatives that may achieve the same outcome at a lower cost. For example, neither the OCTD nor SCRTD studies considered electric buses utilizing fuel cells.

It is beyond the scope of this case study to analyze the benefits of alternative fuels so as to integrate with the excellent data assembled on cost. However, the following information on the benefits achieved through reducing particulate matter is intended to illustrate how benefits should be analyzed and why it is important for public agencies to organize research using the cost-benefit framework outlined in Chapters 3.

Ozkaynak and Spengler (1985) conclude that as much as 6 percent of the mortality in urban areas can be attributed to particulates and sulfates, a derivative of sulfur oxides. Other exhaust gases affect health, but as their effects are uncertain our analysis of benefits will be restricted to particulates and sulfate.

The resulting changes in mortality rates and total mortality have been calculated using methanol fuel for the South Coast Air Basin. The elasticity of mortality with respect to ambient air concentrations is .0119. This is the percentage change in total mortality rate divided by percentage change in ambient air pollutant concentration. Elasticity times pollutant reduction, times total mortality rate, equals .41 annual deaths per million particulates. Multiplying the reduction in total mortality rate times the population of L.A. Basin (12 million) equals 4.92, the reduction in annual deaths in L.A. Basin (Frederick, Morrison & Small, 1987). The reduction in mortality due to methanol conversion is displayed in Table 6.7.

Table 6.7. Reduction in mortality due to methanol conversion

| Pollutant | Elasticity of Mortality with Respect to Ambient Air concentrations | Reduction in Total Mortality Rate (annual deaths per millions) | Reduction in Annual Deaths in L.A.Basin |
|---|---|---|---|
| Particulates | .0119 | .41 | 4.92 |

The total pollution reduction can be expressed in dollars using the average willingness to pay for a reduction in risk. This requires multiplying the reduced mortality rate by a dollar value assigned to the reduction in risk of death which varies from $1.5 to $8 million, depending on the willingness to pay for risk reduction (Frederick, Morrison and Small, 1987). Using both the low and high estimates of the value of life, the pollution reduction saves $7.38 million to $39.36 million per year.

Using alternative fuels will reduce pollution. The lower pollution values affect the ongoing risk of fatality experienced by people living in the region. Such a risk reduction will lower the expected annual death rate by 4.92 people

(Frederick, Morrison and Small, 1987). There are additional advantages with lower particulate emissions of improved visibility, lower crop damage, and less street-level exhaust. These added benefits do not have price values associated with them, but must be taken into account when benefits are assessed.

Saving will occur annually over several years. The duration of assessment must be decided and the saving discounted to present values. Calculation of the NPV of alternative fuels is a demanding task, but the magnitude of investment mandate for public transit agencies warrants this type of analysis.

Sensitivity analysis

Values for pollution and mortality reduction are critical when assessing the need for alternative fuels, but different prices of fuel and the relative value of life may alter the relationship between costs and benefits. Frederick, Morrison and Small conclude that given people's willingness to pay for lower mortality risk, the policy (replacing diesel with methanol) seems justified over a wide range of methanol prices. Methanol's benefits exceeded costs even when methanol prices were as much as $2.93 higher than diesel. On the other hand, the same study using the lower estimated value of life ($1.5 million) was not as favorable.

Costs rise dramatically as the price of the per mile of alternative fuel increases. Using $0.21 as the difference between the cost to operate diesel buses with and without particulate traps, times the total bus mileage, or OCTA and SCRTD (120.6 million miles), the total added costs are $25.2 million. Using the low value of life ($1.5 million) the costs outweigh the benefits by $18 million, but using the higher value of life ($8 million) the benefits outweigh the costs by $14 million.

The estimated value of life requires further study to determine the best value to use, but under different assumptions alternative fuels look promising.

If fuel prices were to double from $.21 per mile to $.42 cents per mile, the total added costs would rise from $25 to $49 million. The additional cost of the fuel would not justify a change to alternative fuels, even at the higher value of life. The different assumptions with the value of life and the relative cost of alternative fuels make significant changes in the results and deserve consideration in policy analysis.

## CONCLUSION

The results are promising for converting transit buses with the current assumptions. Changes in costs could limit the potential, but due to the potential reduction in health hazards, alternative fuels look promising. Whether one fuel will be better than another depends on the costs of the change-over as well as the effect on health. As yet, knowledge of the health effects of various hydrocarbon gases is inadequate for damage assessment.

The purpose of the case study has been to demonstrate how the proposed research strategy could be applied to transit management. In the alternative fuels study, the goal is clear: to reduce air pollution. However, the research studies conducted by OCTD and SCRTD, while yielding helpful information on cost and interaction between fuels and operations, were not structured so as to produce unambiguous results. Both could have been improved by describing particulate traps as the base case by treating all alternatives uniformly, including other feasible alternatives such as the fuel cell, and by estimating benefits and discounting them to present values. Then, the NPV of each alternative fuel would have been apparent.

# CASE STUDY: AUTOMATED TRAFFIC SURVEILLANCE AND CONTROL IN LOS ANGELES

Central Los Angeles is plagued by traffic congestion, and the anticipated increase in traffic in the near future will only make the situation worse. The potential for street widening in this area is limited. Any attempts to improve traffic flow must come from improved signal timing capabilities and other types of operational improvements.

Over the past twenty-five years, the City of Los Angeles has implemented various traffic signal control systems which have utilized both analog and digital computers. The Los Angeles City Department of Transportation developed a goal of reducing congestion through implementing advanced, computer-based traffic surveillance and control systems. The focus of the project is to alleviate the central city gridlock.

This case study is based on two documents. The first is the Department of Transportation's <u>Automated Traffic Surveillance and Control Request for Proposal</u>. This document outlines the requirements for submitting proposals for ATSAC. The second document, <u>Automated Traffic Surveillance and Control 1987 Evaluation Study</u>, is used as an outline for what the Request for Proposal should have included.

## The base case

The City of Los Angeles determined that a computerized signal timing plan would result in positive benefits and meet the goal of reducing traffic congestion; however, the Request for Proposals failed to indicate a base case. The base case would yield benefits although probably not in the same range as the optimal scenario. It is hard to characterize a base case for this project since ATSAC proposes an improvement upon infrastructure.

The base case in this instance could have been a better coordination of the existing electromechanical three-dial, three-offset, fixed-time controllers. The fixed time controller could be replaced with a variable time controller. Based on the time of day, signal timing could be altered to facilitate the smooth flow of traffic. Since the greatest congestion problems result from traffic backing up at a few key intersections, another option would have been to install more actuated controllers in the most troublesome intersections. The costs and benefits required to update existing technology instead of supplanting it should have been the basis for a cost-effective comparison.

Project area

The proposed area for automated traffic surveillance and control (ATSAC) covers the downtown Los Angeles/Coliseum area with 508 signalized intersections and 52 mid-block crosswalks. The system controls most of the traffic signals contained within the area surrounded by freeways. The signals form a tight grid of heavily traveled streets. Congestion is a problem during most of the day, but the afternoon peak is the worst.

Along with the operational improvements of ATSAC, ride-sharing and short term transit improvements have been implemented in the downtown area. The case studies should have analyzed the dependency of ATSAC on these related improvements. By including the impact from these other programs as resulting from ATSAC, the benefits of the system are overestimated.

The ATSAC area is bound by Venice Boulevard on the North, San Pedro Street on the East, Santa Barbara on the South, and Western Avenue on the West. Special events at the Coliseum or Sports Arena add to the delays caused by congestion. To alleviate congestion, the goals of the Systems Manager, the head of the ATSAC program, will be to develop an overall system implementation plan and schedule in conjunction with City officials.

Automated traffic surveillance and control system

The proposed automated traffic surveillance and control system will be composed of five major subsystems: surveillance, communications, local intersection control, computer, and control/displays. ATSAC will use the enhanced First Generation (UTCS) Software if it is available. Multiplexed communications will be used to minimize the amount of cable necessary to service the system. Induction loop detectors placed in the pavement at strategic locations will provide the central computers with traffic data that will be used to make traffic-control-system decisions. Microprocessors will send the commands to local intersections to handle the current traffic situation and provide backup timing capabilities in case of system malfunction or a shut down.

The ATSAC control center will be located in City Hall and all functions of the system will be controlled from this location. The Western District Office, Administrative Offices of the Department of Transportation, and the Piper Technical Center will all be equipped with terminals. The Radio Operation Dispatch and Control Center in City Hall East will have a printer which will print system malfunction messages. Remote terminals will relay the information to field personnel.

Forecasted costs and benefits

The Request for Proposal projected a schedule for ATSAC of approximately six years with a budget of $12.15 million. The cost considerations include material, equipment costs, labor costs, and inflation. Unfortunately, the time line for the projected costs stops after the expected completion of the construction phase. Operation and maintenance costs over the life of the project are not estimated.

The Request for Proposal determined the benefits to be gained from the installation of a computerized traffic signal system in the downtown area. The study concluded that significant improvements, with reduction in stops and delays in the range of 13 to 17 percent, could be made in the flow of automobile and bus traffic by installing an automated, computerized, signal-control-system. The study also verified that improved traffic flow in the study area would reduce vehicular fuel consumption and exhaust emissions by 6 to 9 percent. These findings were extremely important given the chronic air quality problem faced by the Los Angeles Basin. Based on these findings, the study concluded other areas of the city could enjoy similar benefits by implementing the system. However, these estimated benefits are not converted to a monetary form, and neither the cost nor the benefits are discounted to present value. Unless both the costs and the benefits are adjusted for inflation, the net present value of the project cannot be estimated.

The 1987 Automated Surveillance and Control Evaluation Study gives an example of the benefits and costs the original proposal should have included (Tables 6.8 and 6.9).

Table 6.8. Annual Benefits of ATSAC

| | |
|---|---|
| Reduction in stops ($.03/stop) | $4,411,500 |
| Reduction in fuel consumption ($1/gallon) | $1,337,000 |
| Reduction in time travel ($2/hour) | $2,091,000 |
| Total annual benefits | $7,839,500 |

Table 6.9. ATSAC Annualized Costs

| | |
|---|---|
| Construction and engineering costs | $654,200 |
| Operation and maintenance costs* | $148,400 |
| Total annualized costs | $802,600 |

*Operation and maintenance costs are only partially variable and will not increase in proportion to future increases in traffic signals.

In the Evaluation Study, both costs and benefits are expressed in monetary values. The benefits are composed of a reduction in stops, fuel consumption, and travel time. The costs are expanded to include operation and maintenance as well as construction costs. The evaluation study discounted the costs by 8 percent over 15 years to reflect the present value of the costs. A 15 year period is appropriate, albeit conservative, given that the estimated life for the project is 20 years. The 8 percent discount rate is the current cost of money to the City of Los Angeles and is an acceptable real interest rate.

Sensitivity analysis

By changing the value of a variable, the net present value of a project can be drastically altered. As long as the same real interest rate is used for discounting both the costs and the benefits, changing it will not alter the benefit/cost ratio. Although the ratio is not sensitive to changes in the real interest rate, the net present value would change in response to changes in the discount rate. What would be ideal is the use of a range of interest rates to see the outcome under various conditions given the difficulty to predict long-term trends.

Another area where the choice of value for a variable influences the net present value is the value of time. The $2/hour estimate for time travel savings is extremely low. Caltrans uses a moderate estimate of $6.35/hour whereas $12.00/hour might be a more generous estimate of the value of travel time savings. A third variable whose value may change is the price of gasoline. This will affect estimated values for reduced fuel consumption. A range of values should have been used to reflect probable changes. Sensitivity analysis examines high, low, and most likely values for variables affecting net present value as a way to check on how possible changes might affect decisions based upon outcome.

The Evaluation Study estimates pollution reduction for hydrocarbons and carbon monoxide emissions. However, the benefits are not included in the annual benefit calculations (Table 6.8). Although the primary goal was to reduce traffic congestion, the indirect benefits of the proposal should have been included. This would have increased the benefits of ATSAC.

## CONCLUSION

The principal weakness in the ATSAC Evaluation Study is the failure to discount benefits in the same way as costs. The same discount rate over the 15 year period should have been applied to the benefits to avoid the inflating of the benefit/cost ratio. By applying the same 8 percent over 15 years as used on the costs, the adjusted annualized benefits from ATSAC amount to $4,471,820.09. The benefit/cost ratio drops from 9.8 to 5.57. The project remains sound, but the magnitude of the benefit is reduced.

When the project is evaluated properly, the results are still favorable. Net present value is a helpful method for analyzing research and development proposals such as ATSAC. Frequently, the data used in the evaluation is available during the proposal stage, but it is not used with the precision expected for economic analysis.

## CASE STUDY: EVALUATION OF PROPOSED RESEARCH ON ALTERNATIVE TECHNOLOGIES FOR SUPER-SPEED TRAINS

Favorable consumer response to high-speed rail in France, Germany, and Japan has sparked interest in replicating these rail systems in the United States. Potential corridors between San Francisco and Sacramento; San Francisco and Los Angeles; Los Angeles and San Diego; and Anaheim and Las Vegas have been examined (Hall et. al. 1992).

Research has focused upon corridor identification and potential ridership. Technology research has been neglected with consultants relying upon generalized data from foreign locations. However, it would be appropriate for Caltrans to sponsor research on different technologies in terms their suitability, cost, and influence on ridership within one California corridor.

We advance this idea as a research proposal that can be examined using the recommended evaluation strategy. *This is not a study of these technologies; rather it is an assessment of what might be learned as a result of the research.* In other words, will the cost of the research yield sufficient savings so that the net present value of the research is positive.

Our assessment will be tentative; there are many gaps in our knowledge that the research will clarify. Nevertheless, it is important to set out what is known already, and what might be learned from the research so the contribution of the proposals to the California economy can be assessed and compared with competing proposals for scarce research funds.

Previous studies

Southern California is the largest origin of visitors to Las Vegas. Traffic between the two areas is dominated by auto travel with a small number of people using buses and air transport. As a consequence of inflationary oil prices during the 1970s, Las Vegas civic officials became interested in constructing a high-speed electric-powered ground transportation link between Southern California and Las Vegas.

Two studies were funded, Phase I and Phase II, to investigate the possibility of implementing high-speed rail in the Southern California-Las Vegas Corridor. The Phase I study concluded such a system was feasible, and the best technology for this application was determined to be the Transrapid Maglev, an advanced, non-contact system. Under Phase II, five parallel studies were conducted to encompass ridership, environmental impacts, socioeconomic impacts, technology assessment, and financing. The conclusions of Phase II studies confirmed the feasibility of the project; however, other candidate technologies were identified: the Alsthom "Tres Grande Vitesse" (TGV) wheel-on-rail, the Transrapid electromagnetic Maglev, and the Japanese Railways (JR) electrodynamic Maglev.

After completion of the phase II studies, the states of California and Nevada established the California-Nevada Super-Speed Ground Transportation Commission. The Commission draws authority from Chapter 568 of the Nevada Revised Statutes and from Chapter 149 of the California Statutes of 1988. Section two of each Statute sets forth five objectives to be achieved through development of the super-speed train:

- Provision of economic benefits to southern Nevada and Southern California.

- Reduction in reliance on petroleum-based transportation and encouragement of the use of alternative energy sources.
- Reduction in congestion on I-15.
- Demonstration of a transportation system that could play an essential role in the future commuter services within the Los Angeles Basin and the Las Vegas Valley.
- Provision of quick and convenient transportation service for residents of, and visitors to, southern Nevada and southern California.

In this assessment, we focus on the fifth objective, time savings, as it is the most reliable predictor of future use and will provide economic benefits for both regions.

Southern California- Las Vegas Valley corridor

The California-Nevada Super-Speed Ground Transportation Commission has the authority to establish a super-speed alignment while controlling costs and environmental impacts through right-of-way conditions. To facilitate the analysis of ridership for different combinations of candidate terminal and station locations, eight scenarios were defined and considered:

- Ontario-Las Vegas (1)
- Anaheim-Ontario-Las Vegas (2)
- Anaheim-Las Vegas (3)
- San Fernando-Palmdale-Victor Valley-Barstow-Clark County-Las Vegas (4)
- Anaheim-Ontario-Victor Valley-Barstow-Clark County-Las Vegas (5)
- Anaheim-Riverside-Victor Valley-Barstow-Clark County-Las Vegas (6)

- Palm Springs-Anaheim-Riverside-Victor Valley-Barstow-Clark County-Las Vegas (7)
- Palm Springs-Anaheim-Riverside-Victor Valley-Barstow-Clark County-Las Vegas (8)

Scenario six, the Anaheim to Las Vegas Route is closest to the existing system and will yield a comparison of travel time savings. The existing line is almost three hundred and forty miles long and takes a conventional train approximately seven hours to travel between Los Angeles and Las Vegas

Super-speed ground transportation systems

The Phase II study recommended use of either a wheel on rail or Maglev high-speed system. Maglev, otherwise known as magnetic levitation, is an application of noncontact suspension/propulsion technology. Conventional ground transportation, such as wheel on rail, relies on contact with a guideway for suspension and propulsion. Noncontact suspension/propulsion (NCS/P) eliminates the need for physical contact with the guideway. Lack of friction allows for higher speed with lower energy consumption for a more efficient form of transportation (Money, 1994).

Maglev technology can be classified into two distinct categories, electromagnetic and electrodynamic. In the electromagnetic (German) design, the lower part of the body carries suspension magnets and is extended under the rail. When the magnets are energized, the car is lifted up and hovers beneath the rail (Fig. 6.1). The Japanese approach, electrodynamic, entails electrical current repulsion. When the cryogenically cooled magnets on the vehicle pass over a sheet of conducting material on the guideway, the currents produce a magnetic field which repels the vehicle from the guideway underneath the train (Fig. 6.2). This system relies on wheels until a speed of twenty five miles per hour, the velocity necessary for the vehicle to maintain levitation, is attained (Money, 1984). The design speed is two hundred and seventy to three hundred and twenty miles per hour; however, a functional speed of two hundred and fifty miles per hour is more reasonable given comfort and safety considerations (drawn from a conversation with Robert Niehaus). Along with the speed and energy implications, Maglev technology is also a quieter form of transportation than conventional wheel on rail trains and contributes to a reduction in noise pollution.

TGV is a technology developed for and currently used in France. The system relies on overhead electric lines and utilizes conventional wheel on rail contact for guidance. The use of a banking system allows the trains to achieve greater speeds than previous wheel on rail systems while maintaining a high level of passenger comfort.

<u>Base case</u>

Although the TGV system is currently in service , the technology has not been used outside of France. Similarly, Maglev technology, although being tested in Germany and Japan, is still in the experimental stage in the United States, and no high-speed Maglev system has ever been placed in revenue service (United States General Accounting Office, 1993). Maglev and TGV may not be the best option for the Southern California-Las Vegas corridor given the risk associated with technologies yet untried in the United States. Uncertainty exists about whether such systems could generate enough revenues to cover operating costs, let alone show a positive return on capital.

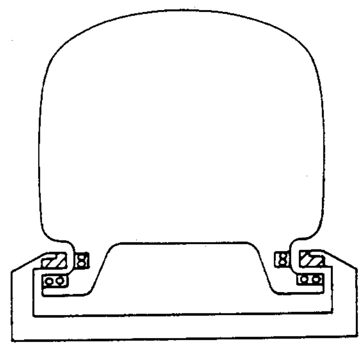


Fig. 6.1: Electromagnetic (German) design.
Source: Money (1984) pp. 50

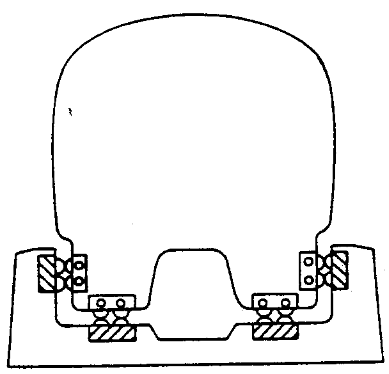


Fig. 6.2: Electrodynamic (Japanese) design.
Source: Money (1984) pp. 50

A base case, using the best available technology, is provided in data from electric tilt trains currently in use on the Northeast Corridor. As a technology currently in use in this country, this system does not have the uncertainty associated with the TGV and it is an improvement over the current Amtrak service using diesel-electric engines. Built by ABB Traction, the X2000 reduces travel time by maximizing speeds on existing rail lines, where Maglev requires the construction of an entirely new set of tracks. The X2000 utilizes steerable, radial trucks rather than the fixed axis used on Amtrak trains. To further minimize the effect of centrifugal force, a system of hydraulic actuators are used to tilt the train inward as it passes through a curve. Approximately one-third of its speed advantage over conventional trains is due to the ability to travel faster in and through curves (Electric Lines, 1991). The X2000 would reduce travel time to Las Vegas to approximately two hours and sixteen minutes; a four hour and thirty nine minute savings over current Amtrak service.

Aside from the increased feasibility of electric tilt trains over Maglev, the X2000 has another advantage, cost. As the speed of ground transportation systems increase, their costs rises at a faster rate. The implementation of the X2000 or similar system with speeds reaching one hundred fifty miles per hour could cost up to ten million dollars per mile (United States General Accounting Office, 1993). A Maglev system does have the potential to reach higher speeds, between two hundred seventy and three hundred and twenty, but at a cost between twenty and sixty million dollars per mile (a two hundred mile Maglev system would cost about thirty two million dollars per mile, United States General Accounting Office, 1993). Caltrans needs to decide if the speed difference is worth the cost before investing in research on advanced railroad technology.

This case study does not estimate the costs and benefits of constructing a super-speed corridor between Anaheim and Las Vegas. Our purpose is more limited; to examine whether the increased speed gained by super-speed trains over base case using known technology and management is worth the investment of scarce research funds.

Forecasted costs and benefits

The report on Ridership, Economic Development, and Environmental Impacts of Super-Speed Train Service for Selected Sites covers the travel time for both Maglev and TGV systems for scenario six: Las Vegas- Clark County- Barstow- Victor Valley- Riverside- Anaheim.

Table 6.10. Travel Time in Minutes for TGV and Maglev between Las Vegas and Anaheim

| TGV | Maglev |
|---|---|
| 124.4 | 102.3 |

Source: Canadian Institute of Guided Ground Transportation, 1989.

Given the conventional train travel time of seven hours, time savings of the proposed technologies can be calculated. Time savings benefits for the X2000 system, the base case, over the existing system should also be included in a proposals estimated benefits. The X2000 benefits can be calculated given the three hundred and forty mile route at an average speed of one hundred and fifty miles per hour.

Table 6.11. Time Savings in Minutes to Las Vegas

| X2000 | TGV | Maglev |
|---|---|---|
| 278.94 | 290.76 | 312.66 |

While these numbers are helpful, a proposal should convert the time saved to a monetary form. Caltrans established the value of time to an individual at $6.35/hour in 1987 (City of Los Angeles Department of Transportation, 1987). Assuming a five percent inflation rate, the value of time in the year 2000, the expected date to begin operation of the new system, is 11.97/hour. By multiplying the time saved (in hours) by the value of time and the projected number of passengers over a fifteen year period, we come up with the Present Value of Benefits attributable to the reduction in travel time for each system.

The projected ridership for the year 2000 is given in the report for the TGV and Maglev systems. The difference in ridership between the two is approximately 13,286 passengers per year for each mile per hour in speed difference. Given this data, ridership for the X2000 in the year 2000 can be established. Since the X2000 runs at an average speed thirty miles per hour slower than TGV, about 398,571 fewer passengers are expected.

Table 6.12. Projected Ridership for the Year 2000

| X2000 | TGV | Maglev |
|---|---|---|
| 1,811,429 | 2,210,000 | 3,140,000 |

Ridership represents one-way trips.

Annual ridership over the fifteen year period from 2000 to 2015 is estimated by increasing ridership proportional to the 2 percent population growth projected for California (State Department of Finance, 1993). Ridership estimates begin with the Canadian Insitute for Guided Ground Transport estimates for the year 2000.

Table 6.13. 2000-2015 Ridership of the Los Angeles-Las Vegas Corridor

| X2000 | TGV | Maglev |
|---|---|---|
| 33,763,743 | 41,192,821 | 58,527,354 |

Ridership represents one-way trips.

Given the value of time in the year 2000 and the projected ridership of the three systems over a fifteen year period, Net Present Value of time savings for each technology can be calculated in conjunction with the time savings projected for scenario six in the report Ridership, Economic Development and Environmental Impacts of Super-Speed Train Service for Selected Sites in the Southern California-Las Vegas Valley Corridor. The Present Value of time savings for TGV is about half a billion dollars greater than the time savings for the X2000, and the Maglev exceeds TGV in time savings by about 1.2 billion dollars and the X2000 by 1.7 billion dollars.

Table 6.14. Present Value of Time Saved from 2000-2015

| X2000 | TGV | Maglev |
|---|---|---|
| $1,878,902,665 | $2,389,456,314 | $3,650,682,919 |

Present value represented in year 2000 dollars.

The report on Ridership, Economic Development, and Environmental Impacts of Super-Speed Train Service for Selected Sites in the Southern California-Las Vegas Valley Corridor focuses on the benefits or reduced energy consumption and air pollution in justifying development of the project. A proposal requesting funding for this project must assess these benefits as well as include a comprehensive listing of construction costs along with the projected maintenance and operation costs over the lifetime of the project. By discounting both costs and benefits by a uniform discount rate over the recommended period, fifteen years, the net present value can be obtained. Using this information, Caltrans could make an informed decision on the funding of the proposal. This case study has not attempted this analysis. We are only trying to show the Present Value, in the year 2000, of the travel time savings for passengers using the three technological options between 2000 and 2015. TGV and Maglev have $510,553,649 and $1,771,780,254 respectively in time savings benefits over the base case.

Sensitivity analysis

By changing the value of costs and benefits, the net present value of a project can be altered. As long as the same real interest rate is used for discounting both costs and benefits, changing it will not alter the results. Although the cost-benefit ratio is not sensitive to changes in the discount rate, the net present value will change in response to changes in the discount rate. Variations in the value of time can also influence the net present value. Using a range of values of time will give a range of time savings benefits. By using a range of values for variables which change, a proposal can accommodate the uncertainty inherent in future predictions. For example, if population growth was estimated at 1 percent instead of 2 percent, the benefits would decrease substantially. If the value of time was estimated to increase by 3 percent rather than 5 percent per anum, the benefits would also substantially decrease.

A listing of time saved benefits for each year during the period between 2000 and 2015 is included in Table 6.15. These calculations assume a 2 percent per annum growth in passengers and a 5 percent per annum increase in travel time benefits. The difference in benefits between the base case (X2000) and the other two technologies indicates the that might be gained if the results from technology research were implicated.

Table 6.15. Monetary Benefits of Time Savings for 2000-2015

| Year | Maglev | TGV | X2000 |
|---|---|---|---|
| 2000 | $195,873,200 | $128,202,100 | $100,806,023 |
| 2001 | $199,790,664 | $130,969,020 | $102,822,167 |
| 2002 | $203,786,477 | $133,381,464 | $104,878,602 |
| 2003 | $207,862,199 | $136,049,112 | $106,976,162 |
| 2004 | $212,019,452 | $138,770,071 | $109,115,681 |
| 2005 | $216,259,857 | $141,545,502 | $111,297,996 |
| 2006 | $220,585,037 | $144,376,390 | $113,523,941 |
| 2007 | $224,996,737 | $147,263,896 | $115,794,461 |
| 2008 | $229,496,643 | $150,209,179 | $118,110,335 |
| 2009 | $234,086,626 | $153,213,401 | $120,472,511 |
| 2010 | $238,768,308 | $156,277,663 | $122,881,989 |
| 2011 | $243,543,684 | $159,403,184 | $125,339,604 |
| 2012 | $248,414,564 | $162,591,240 | $127,846,414 |
| 2013 | $253,382,881 | $165,843,106 | $130,403,365 |
| 2014 | $258,450,507 | $169,159,944 | $133,011,402 |
| 2015 | $263,619,501 | $172,543,145 | $135,671,639 |

Values represented in year 2000 dollars.

# CONCLUSION

When projects are evaluated in detail, Caltrans has a chance to efficiently allocate research funds. A comprehensive study includes identification of all costs and benefits to the best ability of the researcher. Researchers writing proposals should take care to only include cost and benefits which can be estimated with some certainty, and those which can be expressed in a monetary form if net present value or a similar measure is utilized. Other pertinent variables can be considered outside the Net Present Value by ranking the variable rather than including uncertain values in the calculation of the Net Present Value (see Chapter 5).

The results of this case study indicate that benefits of both TGV and Maglev technologies are substantial with the latter potentially more beneficial to the California and Nevada economies. Results from such research will allow Caltrans to better appraise the benefits of building super-speed rail facilities. And with more accurate construction and maintenance cost data, a complete cost benefit analysis of the corridor options can be performed.

A note of caution is appropriate. The time and cost savings have been calculated in a consistent manner to appraise the value of the research projects. These results can be used to compare the benefits that might arise from investment in competing transportation research proposals. However, the benefits should not be used to speculate on the magnitude of economic benefits that might be obtained if a super-speed corridor were constructed. Predicting benefits for the regional economy requires far more sophisticated modeling of benefits than used in this case study.

# CHAPTER 7
# RECOMMENDATIONS

Combined private and public capital investment influence productivity in transportation. Together, they positively affect output through scale economies: manufacturing enterprises expand when they achieve lower assembly and distribution costs, service industries benefit when warehouses can service larger territories, and retail stores can increase service area when reduced travel costs encourage customers to travel further and more frequently. Reduced travel time can translate into real improvements in productivity allowing firms to decrease costs and increase real wages when they have the knowledge and skill to utilize opportunities.

Research plays an important role. But, all transportation research is not beneficial. The recommendation of this study is that **decision makers must evaluate the net present value of proposals before investing scarce resources.**

Although California's transportation network is extensive, innovations in design and operation can improve efficiency. In this respect, R&D is crucial because it prepares managers for new ideas and encourages testing of potentially valuable techniques.

## Types of research

Research is usually characterized as basic, applied, or developmental. The critical distinction relates to how closely research activities are to applications. Basic research is characterized by no particular commercial product or process as a goal, but may give rise to commercial applications.

**The state should emphasize basic research.** The inherent uncertainty in basic research leads to its chronic underfunding. State supported research is most critical for both leading edge applications and basic science activities. And uncertainty can be lowered by sponsoring a portfolio of research projects.

**Applied research has a place in the research portfolio because it helps the state to utilize existing innovations.** In order to benefit from innovations in transportation, the state must have considerable technological expertise; it must be able to recognize the potential value of a new product or process, and it must be able to modify an innovation to suit local requirements. The state needs to employ scientists and engineers who are aware of innovations produced elsewhere, who can recognize potential applications, and who are able to modify innovation to local capabilities. Using technology requires time, effort, and money. While California should not attempt to independently pursue all lines of research, it must pursue an active research and development program of its own.

**All research need not be performed by state employees.** Various strategies to promote research and development are available:

- Direct funding of research activity is relatively easy to institute. Through grants, contracts, and loans, the state can address goals with some precision while retaining substantial control over expenditure.
- In-house research avoids the monitoring problems associated with contracting out research. The strategy provides a spillover benefit for the agency in the cadre of scientists who can evaluate outside proposals.

- Prizes for innovation in the form of procurement contracts or standards for regulated goods can encourage research in the private sector. In order for this strategy to work, the prizes need to be announced in advance. For example, the prize announced by the electrical utilities for a more efficient refrigerator has induced private firms to expand their research activities.
- Market guarantees: the government can guarantee a market for categories of innovations, although not for specific firms, in order to promote research. For example, California's government requires that automobiles sold in the state meet designated "low emission" standards.

Regardless of the method used to promote research, the current financial climate imposes constraints upon the allocation of research funds.

<u>Appraisal of research proposals</u>

California can no longer invest money in research without clear objectives and better knowledge of probable outcomes. **Techniques such as cost-benefit analysis must be employed at the proposal stage to identify the merits of, and guide in the choice between, competing proposals.**

Proper appraisal of research proposals will require the following:

- Uniformity in assessment across proposals must be preserved. Cost-benefit analysis relies upon the the art of creating uniform assessment of alternatives that may sacrifice information available for only some alternatives.
- A goal for the research defined in operational terms.

- Agreement on the rate of return that is expected from transportation investments.
- A base case, using the best current technology, defined so that there is a datum against which future improvements can be measured.
- Estimated timing of costs and benefits with values discounted to current dollars.
- And results tested for sensitivity to changes in critical assumptions, such as the discount rate used to value future benefits.

The criterion used is that of maximizing monetary returns (benefits) for a given amount of money invested (costs). Quantifiable estimates are preferred, but qualitative estimates can be used to rank benefits.

**The Net Present Value Method is recommended for the appraisal of proposals;** it emphasizes the discounting of costs and benefits to current values. Net Present Value (NPV) is the present-day value of benefits minus costs for each proposal. The discount rate must be decided in advance and applied uniformly so as to reduce future benefits to the equivalent of present and future costs. The result is expressed in current dollars.

The larger the value of net benefits, the more a project is economically justified. A positive NPV shows that the alternative yields a positive benefit over the base case which used the existing infrastructure more effectively. A warning note is appropriate, however. **NPV, like other methods of cost-benefit analysis, is a technique for appraising similar proposals. The results should not be used to predict the financial outcome of a proposal or project.**

Cost-benefit analysis is a powerful tool for analyzing alternate proposals. Its power lies in the ability to identify choices among options. However, some areas of cost-benefit analysis are controversial. **Caution is recommended before including the value of lives saved or the cost of environmental damage into NPV appraisals. These costs and benefits are more reliably assessed when presented separately.**

Methods used to quantify the value of life are problematic. One of the most important impacts of transportation is its effect on health. Valuing the the benefits of health effects has been controversial. The traditional approach is based on the economic contributions of individuals. This measure includes neither social losses, nor the value of life to an individual, and underestimates the value of life.

Another measure, contingent valuation, asks individuals to give a valuation contingent on a hypothetical, risky situation. The methodology is biased and problematic. First, estimates assume that lives are equally valued. Second, studies of risk assessment reveal inconsistencies in the methodology. Third, people respond differently when the exposure rate varies in the surveys. Reducing the small risk of a catastrophic event is sometimes more valuable than reducing a larger risk of a more common event. Futhermore, even the formulation of questions on surveys can affect valuations elicited. As surveys are hypothetical, most people are far more generous when expenditures are theoretical rather than actual, which inflates the "value" of life.

Quantifying environmental impacts is open to question. Quantifying environmental impacts, as with health effects, requires indirect methods. Hedonic analyses are reasonably accurate estimates of environmental benefits. Hedonic studies rely on a market comparison of measurable attributes in multiple regions where some regions are subject to environmental problems and others are not. Properly controlling for other, measurable, variations in cost, remaining price differences are equated to the "value" of the environmental problem. Hedonic analysis can not be used in all cases. For situations where a market comparison of measurable attributes is inappropriate, the problematic contingent valuation surveys are used. Difficulties with contingent valuations seriously undermine attempts to quantify the value of lives saved or environmental benefits.

Judicous use of cost-benefit analysis requires that some attributes are best left out of the cost-benefit study. **Health effects, lives saved, and some environmental benefits should be considered in conjunction with, but evaluated separately from, the quantified benefits and costs.**

Research portfolio

Given limited budgets and current economic circumstances, there exists the likelihood that Caltrans will not be able to initiate all research proposals which make a positive contribution to society. The implication of such a situation is the agency must discern amongst beneficial proposals. **A portfolio of proposals should be selected which best matches agency goals but falls within a defined budget.**

**A goals-applications matrix in conjunction with net present value is the recommended method for choosing research proposals.** The NPV of each proposal is calculated and listed in the matrix alongside the goal or goals that it satisfies. The matrix helps emphasize agency and societal goals as part of the choice process.

Proposals form the columns of the matrix, and benefits, or goals, form the rows. This allows net benefits from each research proposal to be associated with specific goals. Particular goals can be singled out by the agency and proposals which contribute meaningfully to these can be chosen for research investment.

While the goals-application matrix is useful for deciding between projects satisfying the same goals, Caltrans needs to make progress towards a method for choosing among projects with multiple goals; a method where net benefits are allocated proportionately between various goals. **The Excess Terminal Benefit (ETB) method is recommended for choosing a portfolio of proposals when several objectives or purposes are to be met.** A portfolio chosen by this method is optimal because society prefers it to any other portfolio.

The agency first lists the objectives to be met and the number of alternative investment proposals which fulfill each objective. After deciding upon the length of the benefit period, the agency subtracts the terminal costs from the terminal benefits for each investment. This amount is divided by the terminal cost giving Excess Terminal Benefits (ETBs) per dollar for each proposal. For each individual goal, the ETBs corresponding to that goal can be listed across investment proposals. This array of ETBs is the data used to guide selection.

While the goals-application matrix system is satisfactory for now, employees should be learning ETB. The Excess Terminal Benefit method should be used for future proposals. **A series of workshops should be developed to train employees in the use of ETB before switching over to the system.**

## CONCLUSION

The approach outlined in this report requires research proposals to include:

- A correct "base case" as the basis for estimating improvements that exceed those that could be achieved using sound management strategies.

- An assessment of the dependency of the proposal on related improvements in transportation.
- A comprehensive listing of forecasted costs and benefits together with timing for both.
- Identification of the appropriate discount rate.
- Calculation of the net present value of costs and benefits.
- Separation of value of life and environmental impact from CBA.
- Analysis of results for sensitivity to changes in critical assumptions affecting costs, benefits, and demand.
- Comparison of the net present value of individual proposals satisfying the same agency goal.

Compliance with these seven criteria provides a methodology for assessing, in advance, the contribution of each proposal to economic efficiency. Future extensions to this methodology, such as ETB, provide for the ranking of proposals when beneficial proposals exceed the budget. Using these criteria, Caltrans will be able to select a portfolio of proposals to satisfy different goals, including economic efficiency.

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APPENDIX I
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