Cost per User as Key Factor in Project Prioritization

Case Study of San Francisco Bay Area, California

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Efforts to accommodate increasing and dispersed demand for travel in the face of mounting traffic congestion, escalating construction costs, limited rights of way, and diminished air quality have caused planning agencies to adopt plans that would enhance transit choices. Faced with fiscal limitations, the need to prioritize the ever-growing list of improvement projects is paramount. To meet this need in the development of the Bay Area System Plan for Regional Express Bus Service in California, a survey of existing literature on capital investment prioritization in transportation was conducted. This review led to development of a simple prioritization methodology with which to analyze the projects. Unit costs per ride were calculated to facilitate comparisons between the various proposals. The cost estimation procedure involved a systematic sequence of analyses that included the development and quantification of conceptual design elements, application of unit capital as well as operation and maintenance costs, and matching of annualized costs with annual ridership to derive unit costs per affected ride. Results revealed that the greater majority of proposed improvements could be implemented at a relatively low total cost. The estimates also suggest that most proposed improvements will not add very significant additional costs per ride to existing operations. The case study demonstrates the utility of a prioritization method that emphasizes the user benefits of projects and illustrates an approach that could be used by other agencies.

As in most growing regions, demand for travel in the San Francisco Bay, California, area is increasing and becoming dispersed. Efforts to accommodate demand in the face of mounting traffic congestion, escalating construction costs, limited rights of way, and diminished air quality have led the region's planning agency, the Metropolitan Transportation Commission (MTC), to develop and adopt plans that would enhance transit choices. MTC proposes a plan to provide a regional express bus system running along high-occupancy-vehicle (HOV) lanes in major freeway corridors, with new transit stations (parking and boarding areas) located in the freeway medians or at interchanges. The California State Department of Transportation (Caltrans) commissioned the University of California Transportation Center (UCTC) at Berkeley to build on the MTC work by evaluating the need for additional parking, feeder services, and bus stop improvements and by identifying both freeway and arterial improvements that would facilitate express bus service. UCTC built on MTC's proposal and worked with transit operators to develop its final report, Bay Area System Plan for Regional Express Bus Service. The study included surveys of transit users, windshield surveys of vehicles at park-and-ride lots, and an evaluation of needed infrastructure as well as proposals for improving arterial and freeway operations and bus stop conditions.

Because transit operators are an important source of knowledge of operations problems and needs along the routes they serve, input was sought from them regarding capital improvements they would deem important for providing express bus service. Then field observations were conducted, relevant ridership data were gathered, and cost estimations related to their capital improvement suggestions were performed. A primary question was how to prioritize the capital project expenditures suggested by transit operators for the regional express bus proposal. Given fiscal limitations, the need to develop a prioritization methodology was paramount. To answer this question, a survey was conducted of existing literature on capital investment prioritization in transportation. After this literature review, a simple prioritization methodology with which to perform analysis of the data was developed.

PROJECT PRIORITIZATION APPROACHES AND STUDIES

The existing literature provides rich insights into the process of prioritization, identifies investment and project evaluation strategies, and details the unique requirements under which transportation providers operate. The literature includes several studies that may be grouped under three broad categories. The first is cost–benefit analysis (CBA). The second focuses on prioritization of capital investments in the public sector. The third group looks at performance measures. Review of the literature reveals that capital project prioritization can take many forms, and decisions involving service expansion or improvement, with regard to transportation, must incorporate easily quantifiable outcome measures and couple them with qualitative social goals. However, few agencies conduct a full CBA; rather, they have developed custom-tailored investment prioritization methodologies that use CBA concepts but focus on project responsiveness to agency goals and objectives.

Cost–Benefit Analysis

Generally, economists recommend use of CBA when prioritizing capital investments. This method is used to evaluate current input costs and future returns from an investment. Future costs and bene-

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fits are expressed in current dollars by using a discount rate. In other words, a dollar today is worth more than a dollar 20 years from now. Theoretically, benefit–cost ratios may be used to evaluate a project with more than one investment strategy, or they could be used to compare projects of similar magnitude. Projects yielding the highest benefit–cost ratios should receive priority in implementation. In reality, most public agencies are faced with budgetary constraints and must make investment decisions among projects of different sizes. Therefore, an evaluation technique commonly used is to compare marginal benefits with marginal costs to determine incremental net benefits, which is more rigorous and practical than benefit–cost ratio. By using this analysis, prioritization is given to projects that demonstrate benefits accruing at a faster rate than their costs.

A CBA framework is used in several widely recommended transportation project evaluation methods, including the U.S. Department of Transportation's software package known as HERS (Highway Economic Requirements System) and several manuals published by AASHTO. However, relatively few agencies use CBA to prioritize projects, despite its official support.

For most public agencies, full CBA for investment prioritization is usually infeasible for three key reasons. First, CBA relies heavily on quantitative data for accurate results, but in practice, key data often are missing or outdated, and agencies often lack the resources to collect new data. Transit agencies, for example, often lack basic data sets, such as current passenger origin–destination information, demographic characteristics of their ridership, passenger access, and wait and onboard travel time estimations. Second, social goals of public agencies may outweigh the nominal value resulting from CBA, especially when the distribution of costs and benefits help to redress societal inequities. For example, a transit agency may choose to provide "owl" service to customers, although relatively few use it and its costs are very high, on the grounds that owl services provide the means for certain low income workers to get to work and back home. Third, public agencies may also have mandates they must fulfill to address a variety of social goals. Regional transportation agencies are often responsible for developing plans to reduce traffic congestion, increase transit ridership, reduce vehicle emissions, and provide welfare-to-work transit service. Rather than reduce their evaluation to a single indicator, the benefit–cost ratio, many agencies prefer to provide decision makers with information on project effectiveness with regard to one or more specific goals. For all of these reasons, public agencies are often looking for simple evaluation methods with easily collected data that can be tailored to their specific mandates, concerns, and environments.

Prioritization of Capital Investments in Public Sector

Taking into account the difficulty of using CBA for programming public investment, Hatry et al. (*1*) provided a general methodology for setting priorities by using weighted criteria. They acknowledged that the criteria incorporated into an evaluation form are often based on objective goals, but the weight assigned to each criterion is subjective (*1*).

More specifically related to transit, Deakin et al. performed a review of investments (*1*). On the basis of interviews conducted with 21 transit operators, they found that most agencies prioritize their capital investments by using federal guidance and regulations (such as FTA's requirements for funding through its New Starts program) as an initial point of reference. However, after establishing a project's viability to meet federal requirements, they then incorporated local and state objectives into the prioritization process. These objectives and considerations are varied but typically included economic, social, and environmental objectives as well as land use and cost-sharing considerations. According to Deakin et al., almost all agencies used some sort of cost-effectiveness measure in their prioritization, but none used CBA (*2*).

In a survey of Canadian transit providers, Hemily shows that many transit providers have adopted a policy of incremental development, in which projects are funded for "specific or targeted infrastructure (e.g. off-street terminals and shelters), computer tools (maintenance, information systems, automatic passenger counting systems, etc.), as well as the development of transit priority measures at key points in the network" (*3*). Transit operators evaluate projects according to their primary goals, such as enhancing transit's attractiveness or improving system performance. Projects fulfilling these goals receive higher prioritization than the implementation of new systems or other projects not meeting these objectives.

By considering the Regional Transportation Authority (RTA) in Chicago, Illinois, as a case in point, Bennett championed use of analyses that focus on ridership and dollar costs (*4*). Bennett's approach focused investment dollars to achieve noticeable improvements that positively affect the most transit riders rather than diffusing investments throughout the system. As the author succinctly puts it, in the short term, "capital investments must be used to do the important things well and not everything to a mediocre level and in the long-term, forge a regional partnership that can find the resources to rejuvenate and expand a transit infrastructure that can spur growth and economic development" (*4*).

For the Southeastern Pennsylvania Transportation Authority (SEPTA), Lavoritano et al. evaluated methodologies adopted by other multimodal agencies (*5*). By focusing on project evaluation and prioritization, the authors developed a three-step weighting and scoring system. Step 1 is an initial evaluation of a project by management in the operating agency, which decides whether it is essential, a normal replacement, or discretionary, with essential projects getting priority. Step 2 is a rigorous analysis applied only to rail projects. Rail projects showing the highest benefit then proceed to the third step. Bus projects do not undergo the second step because of the bus system's low capital investment requirements, multitude of routes, and route flexibility but instead proceed directly to Step 3. The third step is then applied to all projects for final prioritization (*5*).

Washington, D.C., Metropolitan Area Transit Authority (WMATA) is also a multimodal agency that operates bus and rail transit. WMATA hired consultants to develop a prioritization methodology (*6*). Unlike SEPTA, whose investment prioritizations focused primarily on rail, WMATA's prioritization scheme was developed to evaluate across modes. The first step in the process requires WMATA to denote assets as primary, primary support, or secondary support types. The next step is to establish priority on the basis of the primary goals of projects according to a scale that corresponds with the asset types. These goals are defined by the agency as improvements to safety, service reliability, passenger comfort, and so on (*6*).

The Bay Area Rapid Transit (BART) district adopted a service expansion policy in 1999 in response to requests for extensions by areas not served by BART. In 2002, the BART board adopted seven service expansion criteria (*7*):

- Enhance regional mobility, especially access to jobs.
- Generate new ridership on a cost-effective basis.
- Demonstrate a commitment to transit-supportive growth and development.
- Enhance multimodal access to the BART system.

• Develop projects in partnership with communities that will be served.

• Implement and operate technology-appropriate service.

• Ensure that all projects address the needs of the district's residents.

The criteria are not individually prioritized, but together they form a minimum standard that cities or counties must meet before BART officials consider expanding service (*7*).

Performance Measures

Performance measures form an important basis for capital investment priorities in transportation. Although they are often used to evaluate current service provisions, performance measures may be incorporated into capital investment prioritization methodologies with clearly stated visions or goals, simple measurement techniques with easily obtainable data by which to measure the success in implementing each goal. A good performance measurement framework is presented in the *1998 California Transportation Plan* (*8*).

Customer-based performance measures are increasingly being used to inform transportation planning processes and differ from previous measures by distinguishing between outputs and outcomes. For example, a measure of output with regard to transit would be calculating the number of service hours, whereas a measure of outcome would be passenger travel time. This shift in thinking has meant analysis of transportation system performance has moved away from provision and toward measuring the effects of each provision on users within the entire system. The MTC developed performance measure guidelines, which established six goals for its regional transportation plan (RTP) using 11 performance measures. The agency developed a template in which goals were linked to performance measures wherever possible (*9*).

COLLECTION OF IMPROVEMENTS IN CASE STUDY

One set of essential outputs from the regional express bus study is the package of physical and operational improvements necessary to enhance both existing and future express bus service in the San Francisco Bay region. The collection of improvements falls into two broadly related groups: (*a*) network-related improvements—the list of major capital, HOV lane projects that focus on continuity within the regional network of transportation infrastructure and (*b*) service-related improvements—the list of other capital and operational improvements that focus on enhancing specific express bus services. This paper first introduces the collection of capital and operational improvements. Then it presents results of cost estimates and prioritization of projects within each of the two groups of improvement projects.

SERVICE-RELATED IMPROVEMENT PROJECTS

Conforming to the objectives of identifying this collection of projects, various operators were asked to indicate improvements that would enhance the operation of the express bus services they provide. The proposals range widely between short- and long-term projects and included minor capital, major capital, and operational improvements. There are many proposals for physical improvements, adjustments to traffic control, and priority treatments for express buses. Nearly 180 improvements were proposed overall. After duplications with projects in existing plans were removed, 164 proposed new projects remained to be analyzed.

The first step in rationalizing the list of projects was to categorize them into loosely similar types of improvements. A dozen types of improvements were identified, including new installations and adjustments to traffic signals and ramp metering lights; park-and-ride lots and transit center expansion; pavement markings for crosswalks, turn lanes, and so forth; rolling stock purchase; new bus stops; queue jump lanes; extensions and adjustments to HOV lanes; and provision or realignment of ramps and connectors.

Next, each project was tagged by the expected timeline for improvement. Short-term proposals include quick fixes at relatively inexpensive total implementation cost. Medium-term proposals are not major but will take some time to design, program, and implement. Long-term proposals will involve major capital expenditure.

FIELD INVESTIGATIONS

Many proposed service-related improvements are extensive in scope, requiring field investigations to develop definitive improvement concepts for analysis and costing. Although the scope of the regional express bus study did not include detailed engineering studies, field investigations were conducted as precursors to the more extensive engineering studies that should be done before adoption and implementation of many of the improvement projects. Field visits were paid to California sites in San Francisco, Napa County, Vallejo, Hercules, and El Cerrito. Key lessons from the field investigations were the following:

• The observation of physical conditions on site, in some cases, yielded the development of less costly improvement alternatives than initially proposed.

• If they existed, physical obstructions to proposed improvements in the form of topographical obstacles, right-of-way limitations, and utility lines were sometimes observable on site.

• Constraints to operational changes were discernible on site.

• Opportunities for potentially more efficient improvement alternatives were identified from field reconnaissance.

COST ESTIMATION

Given the widely ranging scope of proposed service-related improvements and of the potential incidence of benefits on express bus transit users, unit costs per ride were calculated to facilitate comparisons between the various proposals. The cost estimation procedure involved a systematic sequence of analyses that included the development of conceptual design elements, their quantification, application of unit capital as well as operation and maintenance costs, and matching of annualized costs with potential ridership to derive unit costs per affected ride. The steps in the sequence are summarized in the following subsections.

Development of Improvement Concepts

Most of the proposed improvements were presented at a broad planning level that did not include detailed definitions of projects. By using a combination of published schedules, route maps, and detailed street maps, elements of proposed improvements were quantified in broad terms for costing. For instance, a proposed improvement called for "transit signal priority and timing improvements on Grand Avenue between San Pablo Avenue and the I-80 westbound on-ramp." This improvement was redefined as "adjust signal equipment and retime signals; provide signal preemption for buses through 4 signalized intersections along the specified section of Grand Avenue."

It is understood that the redefinitions would provide at best broad estimates for planning purposes and for general comparisons between projects. The expectation is that more definitive engineering studies would be conducted as the projects advance along the planning stages toward programming and implementation. Data from such detailed studies would equally fit into the prioritization procedure presented in this paper.

Synthesis of Unit Costs

A key step involved the compilation of relevant unit cost data from various sources. The sources included state and local transportation agencies within the state of California, transit operators in and out of California, and published data on implementation costs of intelligent transportation systems. Information items collated included (*a*) unit capital costs, (*b*) related operation and maintenance costs, and (*c*) typical economic lives of improvements. The information was compiled to conform roughly to the 11 broad types of proposed improvements. Where necessary, unit costs were identified for subitems under specific improvement types. All cost data were converted to 2002 dollars.

Determination of Discount Rate

A discount rate is required to annualize capital costs. The rate was determined by examining the range of current money market rates for medium- to long-term investments. For a conservative estimate, a discount rate of 5% was assumed. This represented the outer envelope of the various rates examined.

Calculation of Annualized Costs

First, capital costs, C_1, were estimated for each proposed improvement. Total capital costs were converted to equal annual payments (AC) over the economic life, n, of each improvement at the discount rate, i, of 5%. The equation for equalized annual capital costs is as follows:

$$\text{AC} = C_1 * \frac{i(1+i)^n}{\left[(1+i)^n - 1\right]}$$

In these calculations, capital costs, discount rate, and economic life were all estimated or assumed so that the analysis tried to find the annual amounts that would make the capital investments go to zero at time n. For simplicity, no residual values were assumed for improvements at the end of their economic lives.

Next, annual operating and maintenance costs were calculated in constant (2002) dollars. For each improvement, the annualized capital cost and the annual operating and maintenance costs were added to obtain the total additional annual cost attributable to the improvement per year over its economic life.

Determination of Affected Rides

In addition to compiling the list of proposed projects, operators were asked to identify the specific express bus lines to be affected by individual improvements and to provide daily or annual ridership figures for these lines. Thus certain improvements would affect multiple bus lines and the services of multiple operators. All ridership data were converted to annual rides and summed for each proposed improvement to determine annual affected rides. It is worth noting that a particular ride could be affected by more than one proposed improvement. The determination of how many rides an improvement would affect is tantamount to assessing how much benefit the improvement would yield. This may be illustrated with the following simplified case. Assume there are two improvements of equal cost. Improvement A affects all the express bus rides in the region. The other, Improvement B, affects one heavily patronized route, but nonetheless only one route. When both improvements are implemented, the cost per affected ride will be lower for A than for B. Thus if because of financial constraints only one of them is to be implemented, it would be most beneficial to implement A. Similarly, if both projects are to be prioritized, A would be implemented before B.

Determination of Cost per Ride

Finally, annualized costs were divided by annual affected rides to obtain cost per affected ride. For a given amount of investment, the more rides affected, the better, since the cost would be spread over a relatively larger patronage. Conversely, the fewer rides affected, the higher the incidence of the cost on each patronage served. Budget constraints aside, the lower the cost per affected ride, the more attractive the proposed improvement.

RESULTS FOR SERVICE-RELATED IMPROVEMENTS

Distribution of Capital Investment Costs

A few very expensive service-related improvement projects skew the distribution of capital investment costs and consequently costs per affected ride. Unsurprisingly, the most expensive types of improvements are the major capital projects. The most expensive groups of proposed improvements, in descending order, are direct-access ramps followed by bus lanes, rolling stock purchase, and bus stops.

The total estimated investment cost of service-related improvements is approximately $505 million. Approximately one-third of the proposed improvements are estimated to cost $100,000 or less. Approximately 30% more of the improvements will cost between $100,000 and $500,000 each. Only about 15% of all improvements are estimated to cost between $1.2 million and $120 million each and together account for approximately 90% of the total estimated investment cost. Viewed from a different perspective, 85% of all proposed improvements could be implemented for a total of $50 million or 10% of the total estimated capital costs. These results are summarized in Table 1 and suggest that the greater majority of the proposed improvements could be implemented at a relatively low total cost.

Distribution of Costs per Affected Ride

Expectedly, the major capital projects indicate the highest and most out-of-the-norm unit costs per affected ride. If projects are to be

TABLE 1 Distribution of Capital Investment Costs

Cost per Project	Share of Analyzed Projects[a]	Share of Total Capital Costs[b]
Up to $50,000	21%	0.13%
$50,000 to $100,000	12%	0.27%
$100,000 to $200,000	14%	0.7%
$200,000 to $500,000	16%	1.7%
$500,000 to $1,000,000	5%	1.0%
$1000,000 to $1,200,000	17%	6.1%
Greater than $1,200,000	15%	90.1%

[a]Total projects analyzed are 164.
[b]Total estimated capital investment cost is approximately $505 million.

prioritized according to benefit level or cost per affected ride, then nearly 75% of the proposed projects could be implemented at approximately 12% of the total estimated capital costs. This will include projects that are estimated to yield additional costs per ride of 50 cents or less. Indeed, as much as 70% of proposed projects will yield additional costs per ride of 25 cents or less, and 50% of proposed projects will yield additional costs per ride of 5 cents or less. These results are summarized in Table 2.

These results suggest that most proposed improvements will not add significant additional costs per ride to existing operations. Besides, these improvements could generate additional ridership, which, if realized, would lower the estimated costs per affected ride.

PRIORITIZATION OF SERVICE-RELATED IMPROVEMENTS

Three classes of projects resulted from the analysis. The first includes 152 projects for which the entire cost estimation procedure was applied. Projects in this first group were ordered from the lowest cost per affected ride to the highest and divided into the seven groups of costs indicated in Table 3. The second class includes 12 projects for which partial analysis was conducted. Costs were estimated for these, but ridership data were not available to convert them into costs per affected ride. The third class of projects includes those that duplicated either other projects already included in existing planning documents or other projects in this analysis.

As shown in Table 3, the first class of projects is divided into groups to correspond with the existing denominations of currency beginning from $0.01 to $1.00. All other results higher than $1.00 are placed in the seventh and last priority group. Slightly more than half of all analyzed improvements fall into the two highest-priority groups. These groups of projects are estimated to result in $0.05 or less in additional annualized cost per affected ride. An additional 18% of proposed projects are estimated to cost an additional $0.05 to $0.25 per affected ride. Yet 10% more of proposed projects are estimated to cost additional $0.25 to $1.00 per affected ride.

TABLE 2 Distribution of Costs per Affected Ride

Cost per Affected Ride	Cumulative % of Analyzed Projects[a]	Cumulative % of Total Capital Costs[b]
Up to $0.05	52	3.8
Up to $0.10	62	6.3
Up to $0.25	70	8.5
Up to $0.50	75	12.3
Up to $1.00	81	29.6

[a]Total projects analyzed are 164.
[b]Total estimated capital investment cost is approximately $505 million.

COSTS OF NETWORK-RELATED IMPROVEMENTS

All improvements identified as gaps within the regional network of HOV lanes are considered major capital investments. They fall among long-term proposals because they involve major capital expenditures for which funds were not previously programmed, and it will take some time to design, program and implement them. This section deals only with the unit costs per user of the gap-related projects, which are also termed network-related improvements.

Similar to the treatment of the service-related improvement projects presented in previous sections, cost estimation for the network-related investments involved a systematic sequence of analyses to derive unit costs per affected ride. The analyses included the determination of total construction costs as well as annual operation and maintenance costs, annualizing these costs, and matching them with estimates of potential person usage of the high-occupancy lanes.

Estimated Major Capital Investment Costs

The total estimated investment cost of network-related, HOV gap projects was approximately $2.2 billion. In almost all cases, the estimates did not include the cost of right-of-way. At a broad planning level, the cost of construction was estimated at an average of $4 million per directional lane mile. The costs of right-of-way were not available for specific locations. Such costs were known to be widely variable and could double or triple the estimated capital investment costs. If condemnation of property is involved, costs could be even higher. In making comparisons between the projects related to the gap sections, therefore, only the estimated costs of construction were used. The total construction costs were annualized over a 20-year economic life at a 5% discount rate and added to estimates of annual operating and maintenance costs.

Estimated Costs per Affected Ride

Potential person usage volumes of the gap sections were estimated by using the most recent statistics on existing HOV lane usage from the Caltrans 2003 HOV lane report (*10*) and by using forecast model data from the MTC. The procedure is outlined as follows:

- For the collection of links in the MTC model along the section of highway identified as a specific gap section, vehicle miles of travel (VMT) were calculated as the product of link length (dist) and loaded vehicle volumes (vol_{4h}) for the 4-h morning peak period.

$$VMT = dist * vol_{4h}$$

- A weighted average of vehicle miles of travel (VMT_{avg}) was calculated for the gap section by dividing the sum over all links i of VMT values ($\sum_i vmt_i$) with the sum of link distances ($\sum_i dist_i$).

$$VMT_{avg} = \frac{\sum_i vmt_i}{\sum_i dist_i}$$

TABLE 3 Tally of Prioritized and Other Projects

Project Classification	Range of Costs per Affected Ride	Number of Proposed Projects	% of Analyzed Projects	% of All Initially Proposed Projects
Fully analyzed		152	93	85
Priority 1	Up to $0.01	35	21	20
Priority 2	$0.01 to $0.05	51	31	29
Priority 3	$0.05 to $0.10	15	9	8
Priority 4	$0.10 to $0.25	14	9	8
Priority 5	$0.25 to $0.50	9	5	5
Priority 6	$0.50 to $1.00	9	5	5
Priority 7	Greater than $1.00	19	12	11
Partially analyzed	n/a	12	7	7
Duplications	n/a	14	n/a	8
All initially proposed projects		178		100

• To estimate the portion of VMT that would be in the HOV lanes (VMT_{HOV}) within the gap sections, the weighted average VMT was multiplied by the factor of 15%. This factor was determined for the collection of HOV lanes in the Bay Area from the 2003 HOV lane report.

$$VMT_{HOV} = VMT_{avg} * 15\%$$

• The estimated portion of VMT in the HOV lane was doubled to account for HOV lane operation during both morning and evening peak periods.

• The estimated daily VMT of high occupancy vehicles was multiplied by facility-specific vehicle occupancy factors (occ) that were determined from the 2003 HOV lane report. This provided an estimate of average person miles in the HOV lane (PMT_{HOV}) within the gap section. The result was multiplied by 250 days to obtain the annual person miles of HOV travel on weekdays (excluding holidays).

$$PMT_{HOV} = VMT_{HOV} * 2 * occ * 250$$

Estimated annual costs were matched with estimated annual person miles (of HOVs only) to determine the estimated costs per affected mile of HOV ride. The projects were then ranked by cost per affected mile of HOV ride. By using annualized construction costs (excluding right-of-way costs), the analyses estimated a range of costs per person mile of from $0.07 to $0.55. If costs of right-of-way were included, these costs would jump to between $0.20 and $1.50 per person mile. The estimates, which are summarized in Table 4, indicate that nearly 60% of the capital project lane miles will result in costs per person mile of $0.15 or less with more than 40% between $0.10 and $0.15. Even if these costs tripled with the inclusion of right-of-way costs, they will remain within a manageable range of $0.30 to $0.45 per person mile.

SUMMARY OF CAPITAL AND OPERATING COSTS

Previous sections of this report describe how proposed projects are prioritized by benefits, which are measured as the inverse of the total annualized capital and operating costs per affected ride. It is recognized, however, that capital and operating costs of infrastructure sometimes come from different funding sources. In this section, the cost items are summarized over all projects and are differentiated between capital and operating costs. For convenience, the summary cost figures are stratified by priority lists of projects that were presented in tables that corresponded to the lists identified in Table 5.

Service-Related Improvements

There are seven categories of service-related priority lists of projects. The estimated costs are summarized in Table 5. The estimated capital costs of these proposed projects is slightly more than half a billion dollars, which is equivalent to $40.4 million in annualized capital costs. Related annual operating and maintenance costs are estimated at $7.9 million. In sum, therefore, responsible agencies would need to spend approximately $48 million per year during the next two to three decades to fund all the proposed service-related projects. It is apparent from the cost summary that the seventh list of priority

TABLE 4 Distribution of Costs per Affected Person Mile

Range of Costs per Affected Person Mile	Number of Projects[a]	Lane Miles of Projects[a]	Cumulative % of Total Capital Costs[b]
Up to $0.10	4	97	18
$0.10 to $0.15	18	223	59
$0.15 to $0.20	7	35	66
$0.20 to $0.25	3	32	72
Greater than $0.25	5	131	100
Total	37	518	100

[a]Total number of projects analyzed are 37 covering approximately 518 lane mi.
[b]Total estimated capital investment cost is approximately $2.2 billion.

TABLE 5 Summary Costs of Service-Related Improvements

Prioritized Project List	Total Capital Costs	Annualized Capital Costs	Annual O&M Costs
Priority List 1: $0.01 or less per affected ride	$2,259,630	$286,437	$35,649
Priority List 2: $0.01 to $0.05 per affected ride	$17,009,256	$1,668,825	$832,776
Priority List 3: $0.05 to $0.10 per affected ride	$12,663,210	$1,052,829	$351,873
Priority List 4: $0.10 to $0.25 per affected ride	$10,856,752	$922,147	$482,894
Priority List 5: $0.25 to $0.50 per affected ride	$19,246,908	$1,396,589	$100,219
Priority List 6: $0.50 to $1.00 per affected ride	$87,064,982	$7,955,476	$702,875
Priority List 7: more than $1.00 per affected ride	$348,245,824	$26,444,593	$5,124,789
List 8: partially analyzed projects	$7,265,970	$667,301	$246,139
List 9: duplicate projects	N/A	N/A	N/A
Total analyzed projects	$504,612,531	$40,394,199	$7,877,213

projects, which account for approximately 70% of the capital costs, are de facto major capital projects.

Network-Related Improvements

There are four groups of network-related priority lists of projects. The summary costs are presented in Table 6. The estimated capital costs of these proposed projects is slightly less than $2.2 billion, which is equivalent to $173.4 million in annualized capital costs. Related annual operating and maintenance costs are estimated at $10.8 million. In sum, therefore, responsible agencies would need to spend approximately $184 million per year during three decades to fund all the proposed network-related projects.

CONCLUSIONS

Service-Related Improvements

The greater majority of the proposed, service-related improvements could be implemented at a relatively low total cost. The estimates indicate that 85% of all proposed improvements could be implemented for a total of $50 million, equal to just 10% of the total estimated investment cost. The estimates also suggest that most proposed improvements will not add very significant additional costs per ride to existing operations. Slightly more than half of all analyzed improvements were estimated to result in $0.05 or less in additional annualized cost per affected ride. An additional 18% of proposed projects were estimated to cost between $0.05 and $0.25 per affected ride, and 10% more were estimated to cost between $0.25 and $1.00 per affected ride. It is worth noting that these proposed improvements could generate additional ridership, which, if realized, would lower the estimated costs per affected ride. In addition, other nonexpress bus services might benefit from the proposed improvements. If this happens, the accrual of benefits from the projects will further increase.

Network-Related Improvements

Despite the application of a uniform unit construction cost to all HOV gap related projects, significant variability in projected levels of use suggest a wide variation in the incidence of benefits attributable to them. The estimated annualized construction costs (excluding right-of-way costs) indicated a range from a relatively low $0.07 to a significantly higher $0.55 per person mile.

Approximately 60% of the lane miles within the gap sections were estimated to result in relatively manageable unit costs per person mile of $0.15 or lower with more than 40% between $0.10 and $0.15. Even if these costs were to triple with the inclusion of right-of-way costs, they would fall within a range of $0.30 to $0.45 per person mile.

Other motorists would use the HOV lanes during the off-peak periods, thereby lowering the estimated unit costs per person mile. However, the facilities would not have been built for these other users, who would ordinarily not need the extra capacity off-peak. This is why the analyses focused on benefits to HOV use.

TABLE 6 Summary Costs of Network-Related Improvements

Prioritized Project List	Total Capital Costs	Annualized Capital Costs	Annual O&M Costs	Lane Miles
List 10-1: freeway sections with gaps in HOV lanes but no congestion	$814,800,000	$65,381,660	$4,074,000	204
List 10-2: congested freeway sections with right-of-way limitations and potentially high construction costs	$883,600,000	$70,902,350	$4,418,000	199
List 10-3: non-freeway sections that pose gaps in HOV lanes and right-of-way limitations exist	$304,000,000	$24,393,747	$1,520,000	76
List 10-4: freeway sections with a bottleneck upstream or downstream that would limit the effectiveness of HOV lane operation	$158,000,000	$12,678,329	$790,000	40
Total HOV gap projects	$2,160,400,000	$173,356,085	$10,802,000	518

Service-Related Versus Network-Related Improvements

Expectedly, the network-related improvements, which are all de facto major capital projects, would yield comparatively higher unit costs per affected ride than the service-related improvements in general. As an illustration, assume that the average express bus ride was 10 mi long. Then the cost per person mile for 80% of the relatively low-cost, service-related projects would range from fractions of a cent to 10 cents. This range is significantly lower than 7 cents to 55 cents (excluding right-of-way cost) estimated for the network-related capital projects. The attractiveness of the HOV gap section improvements includes the unquantified, network interconnectivity that they would provide for expedited and seamless express bus travel.

The prioritization process presented is simple in scope but emphasizes an important criterion, the user benefits of projects. It can find wide application in many transportation projects and could easily be used by many agencies.

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