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Methodology for Cost–Benefit Analysis of Space Launch Infrastructure

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Resources for improving space launch infrastructure are very limited and must be used in a manner that most effectively contributes to the safety and competitiveness of the launch vehicle industry. A benefit–cost methodology for assessing the impacts of investments in space launch infrastructure is defined. Potential infrastructure investments are categorized based on an analysis of existing project proposals, range requirements, and industry needs. The categories used include space launch vehicles, improvement/modification to an existing launch facility, and new spaceports. The uses and limitations of macroeconomic input/output analysis for assessing the impacts of space launch infrastructure investments is also covered. In considering the overall approach, economic drivers were explicitly considered, as well as performance and safety issues. Application of such a structured approach will yield sensitivities that provide an increased understanding of the relative importance of various economic, safety, and environmental concerns.

Introduction

INVESTMENTS in space launch infrastructure are considered by range operators, federal regulators, and launch firms to achieve a number of objectives: enhance the long-term economic prospects of the nation, increase the technology intensity of a state or region, improve efficiency or safety at a launch site or range, or increase the market share of a particular firm. In each case, potential investors need to understand the costs and benefits of a proposed investment strategy, how they are distributed, and what risks they carry.

Rationale for Methodology

A methodology for structuring cost–benefit analyses of investments in space launch infrastructure is presented. Because many such investments involve federal funds, the methodology complies fully with relevant federal standards and guidelines and incorporates consideration of broad economic factors of interest to government agencies, as well as more focused financial factors of interest to individual firms or range operators. There are many requirements and mandates to assess the costs and benefits of government actions. For example, a federal agency cannot promulgate a major regulation without demonstrating that its benefits exceed its costs, and the Office of Management and Budget publishes guidelines for performing benefit cost analysis of federal programs.[1–6]

Recently, members of the U.S. Congress advocated even stronger standards to ensure that consistent analysis practices are used to establish the costs, benefits, and risks of regulations and other government policies. Today, any agency defending its research budget is likely to be asked why it has made certain investment decisions and what benefits they will achieve to the nation. In part, this focus on analysis reflects the increasing attention government entities are paying to budget issues; at a time when the primary policy thrusts in the United States are deficit reduction and economic recovery and growth, value for money is a key discriminator among programs and policies.

Measuring value for money (costs and benefits) is, however, often difficult. Measuring benefits is especially challenging when they hinge on difficult to predict events such as new technology impacts on local and global markets or when small investments may be part of a much larger stream of costs and benefits.

Value of a Structured Approach

An approach is proposed to apply cost–benefit analysis to space launch infrastructure projects. Its purpose is to help to establish a consistent, effective approach to making investment decisions in space infrastructure for a wide range of projects. This is an important area for critical analytic discipline because of the potentially huge economic benefits of new space-related markets.

The Commercial Space Transportation Study (conducted cooperatively by six major aerospace firms) identifies longer-term markets that could include transportation, entertainment, new space missions, space utilities, extraterrestrial resources, and advertising.

Figure 1 shows the relationship among payloads, launch vehicles, infrastructure, and near-term economic growth and new industries. Space transportation costs are a major driver for space activities and limited transportation availability additionally restricts space access. Improved infrastructure can help to reduce costs and enhance access to space and the utilization of space.

There have been, however, many unsubstantiated and overly optimistic claims over the last decades linking space-related projects, investments, and programs to huge new space markets, which have yet to materialize. The space program and space activities suffer when advocacy is presented as predictive or forecast analysis because more realistic assessments of relationships between early investment and future benefits are perceived a priori as lacking credibility.

Framework for Analysis

The methodology presented focuses on identifying benefits and costs and comparing total benefits to total costs. This requires transforming difficult to quantify benefits into relative dollar terms, or in some cases, into consistent nondollar terms (such as lives saved).

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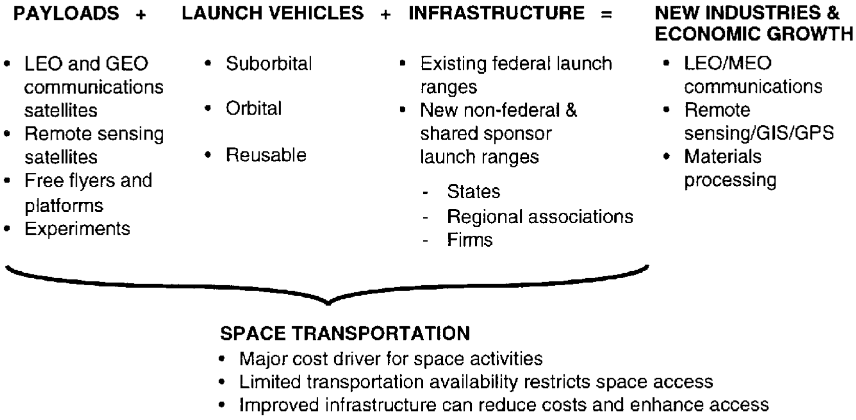

Fig. 1 Space launch infrastructure and economic growth.

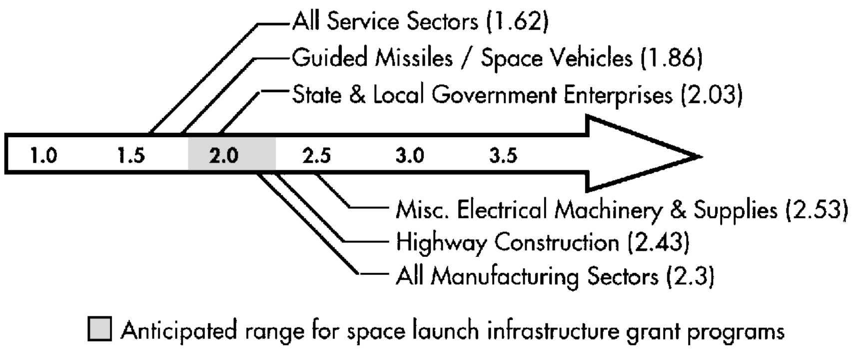

Fig. 2 Input/output multipliers predict macroeconomic impacts.

The methodology looks at the costs and benefits of a particular project or set of projects in terms of the specific impacts of that project (reduced launch costs, for example) and also in terms of the macroeconomic impacts that may be associated with such a project.

The classification systems developed for the different types of infrastructure investments and for the types of impacts that may result from them are summarized. Event trees are developed to link investments to impacts in a structured and consistent manner. (This paper does not populate the event trees; for any project or group of projects, estimates of the magnitude of impacts will vary, and the probability distributions associated with those impacts must be generated and applied individually.)

Analysis of the specific costs and benefits of a project is to be preferred over applying macroeconomic formulas when making federal investment decisions, but macroeconomic models may be useful in understanding long-term impacts or impacts relative to other types of investment (e.g., highways vs launch sites). Input/output analysis of macroeconomic impacts is discussed. Cost–benefit analysis of specific projects or programs is also summarized and is discussed in greater detail in the sections that follow.

Input/Output Analysis

Input/output analysis is a commonly used methodology for measuring how an increase in spending in one industrial sector affects the general economy. Input/output analysis traces the effects of an initial change in the output of any given sector on the outputs of all other sectors of the economy. It recognizes the interdependence of all sectors of the economy and that the production of any one good or service requires, directly or indirectly, inputs from other sectors of the economy. Input/output analysis is the only analytical methodology that can specify the relationships between economic sectors at the macroeconomic level for the entire economy. The result of an input/output model is expressed as a multiplier, which predicts the increase in output from other sectors of the economy.

The U.S. Bureau of Economic Analysis develops input/output models for the U.S. economy. Currently, no models specifically for the space transportation industry or the commercial aerospace industry exist. The multipliers associated with several related industry sectors, such as guided missiles/space vehicles, are shown in Fig. 2 (Refs. 7–9).

The multiplier for guided missiles/space vehicles is smaller than that for highway construction. This reflects, in part, that production of missiles and space vehicles draws on inputs and production capability drawn from within the same economic sector; much of the value-added work that transforms raw materials into space vehicles occurs in the guided missiles/space vehicles sector. On the other hand, additions to the transportation infrastructure through highway construction draw on a wide variety of value-added inputs from other sectors. The authors speculate that an input/output model for the commercial space transportation industry would generate an input/output multiplier somewhere in the range between guided missiles/space vehicles (1.86) and highway construction (2.43). This is based on the assumption that space launch infrastructures require both space vehicle engineering and facility/infrastructure construction.

Cost–Benefit Analysis

As noted earlier, input/output analysis considers general macroeconomic impacts based on the magnitude of expenditure. Cost–benefit analysis, on the other hand, is typically more specific to a project, program, or activity and is used to consider both financial and economic impacts based on the magnitude, type, and circumstances of an investment. Cost–benefit analyses typically measure monetized costs and benefits, taking into account the discount rate, which reflects the time value of money. (The time value of money refers to the fact that funds or resources available today are worth more than funds or resources not available until next year; therefore, the value of funds or resources in the future is discounted relative to the value of funds or resources of today.) The results of cost–benefit analyses may be presented as a ratio of benefits to costs, as net present value, internal rate of return (i.e., the discount rate at which net present value is zero), or net benefits (discounted benefits minus discounted costs) or in many other ways that show the relative value of alternatives.

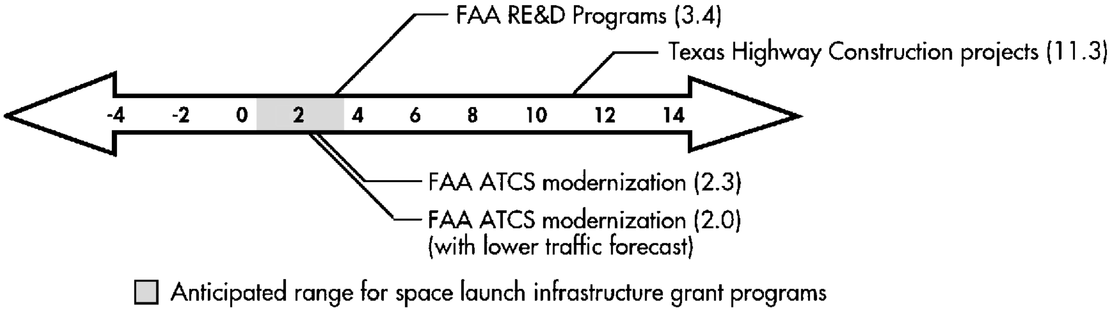

Fig. 3 Costs and benefits of similar programs.

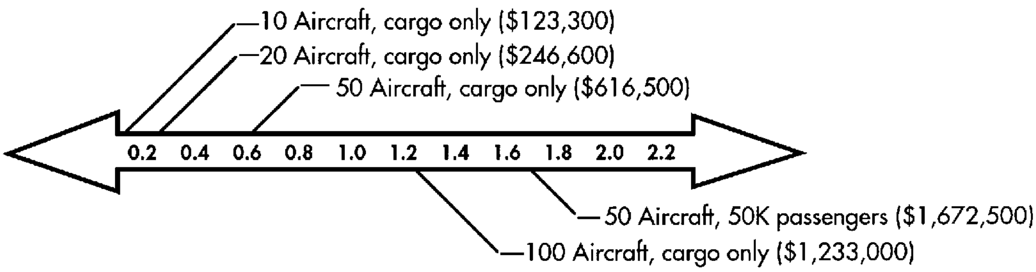

Fig. 4 Assessing regional economic impacts: total annual benifit to regional economy (in millions).

Cost–benefit analysis enables decision makers to compare alternative actions in terms of values that are important to them, such as economic growth, safety, risk, and the timing of events. It allows the measurement of the comparative strengths of different options. Cost–benefit analysis is an important input to a range of policy, investment, management, and program decisions, including program and project management, program evaluation, competitiveness assessments, and project-by-project comparisons.

There are limitations to cost–benefit analysis because it is difficult to quantify all effects of an investment or project in measurable units. In addition, there is always uncertainty associated with predicting both the costs (e.g., demands on financial resources, undesirable environmental effects) and the benefits (e.g., gains in industry market share, desirable impacts on regional employment rates) of a project. Even after the fact, some impacts (such as environmental effects) are difficult to measure reliably and accurately. Moreover, it is particularly difficult to predict the costs and benefits of space-related projects. For example, the cost associated with using new technology and the impacts of research and development (R&D) and technology development on the economy and on the environment are difficult to predict. In addition, economic benefits associated with commercial space activities are often contingent on the creation of new markets, which cannot be predicted with accuracy.

Cost–Benefit Analysis Results: Examples from Representative Projects

Some representative benefit-to-cost ratios for R&D, aviation, and transportation projects are presented in Fig. 3. The examples include benefit–cost ratios calculated for the Federal Aviation Agency's (FAA) research, engineering and development programs,[10] the Texas Transportation Institute's analysis of highway construction projects, and the FAA's assessment of the benefits and costs of its air traffic control system modernization. These examples were selected to provide a representative range of values that might have some similarity to space launch infrastructure projects. R&D, aviation, and transportation projects were considered.

Cost–benefit analysis may also address the economic importance of a project or industry in terms of the regional economic activity (goods and services it consumes), employment, and payroll that can be attributed, directly or indirectly, to the operation of that project or industry. Assessments of regional economic impacts vary widely in their assumptions about what impacts are directly attributable to the investment or project in question and some result in very high impacts because economic multiplier effects are used to magnify investment impacts.

An example of regional economic impacts due to airport development is given in Fig. 4. This analysis considered the value of time saved (by customers for aircraft services) and reductions in travel costs. Benefits were presented in terms of dollar benefits as a function of the size of the airport.[11]

Jobs created or eliminated are often used as a measure of impact; jobs may, however, be a poor metric of economic success, for several reasons. First, jobs are often transferred from one sector of the economy to another, rather than created. Second, jobs may be eliminated due to increased efficiency of a process or approach, leading to economic productivity gains; a jobs created metric would mask these benefits. Third, not all jobs are equal. New jobs for unskilled labor generate less income than engineering jobs in high technology industry. The skill mix of the target population must also be considered.

Methodology

Cost–benefit analysis of a space launch infrastructure project requires the following steps.

1) Link investment to impacts through causal relationships.

2) Quantify investment and impacts in terms of both magnitude and probabilities (in point estimates or distributions).

3) Determine net present value, internal rate of return, benefit–cost ratio, or other measure to compare alternatives.

A detailed structure for completing step 1 and a recommendation on the appropriate approaches for steps 2 and 3 are provided.

Compliance with Federal Guidelines

The Office of Management and Budget (OMB) Circular A-94 (Ref. 1) provides guidelines for conducting cost–benefit analysis for federal programs and projects. According to A-94, benefit–cost analysis (the terminology used by OMB) consists of a policy rationale for the investment under consideration, the identification of explicit assumptions, the evaluation of alternatives, and verification (in the form of retrospective studies or analyses). A benefit–cost analysis, according to OMB, requires analysis of incremental benefits and costs.[12] OMB discourages the use of output multipliers for measuring secondary effects on employment and outputs and encourages explicit analysis of uncertainty and sensitivity analyses of major assumptions, as well as analysis of significant distributional effects.

The analytic approach discussed complies fully with OMB's requirements. Further, an enhanced space launch infrastructure can foster economic growth in the United States by increasing the U.S. market share of existing space launch markets and by aiding in the

Table 1 Distribution of benefits (by type of benefit) among affected parties

Benefits to or impacts on the U.S. launch industry/project investors may be in the form of
Increased national and international market share
Increased revenue
Increased competitiveness
Increased launch demand
Lower third party liability insurance requirements
Reduced per-launch costs
Increased launch rate
Benefits to or impacts on spacecraft manufacturers/launch customers may be in the form of
Payload processing facility improvements
Launch campaign management
Data/telemetry capture and processing
Reduced per-launch costs
Benefits to or impacts on the local/regional/state economy may be in the form of
Generation of jobs
Construction
Launch support companies
Commercial aerospace firms established in area
Revenue into the local economy
Increased sales of products/services necessary to operate facility
Benefits to or impacts on the U.S. government/national economy may be in the form of
Lower system life-cycle costs
Lower operations costs
Increased international market share
More consumers of new products from new launch industry segments
New markets

creation of new launch markets based on reducing costs associated with new products and services. The approach discussed is based on making assumptions about causal relationships explicit, as directed by OMB. This is achieved through event trees probabilistically linking investment to outcomes (see Fig. 5).

Distribution of Costs and Benefits

The question of who benefits from an investment (and who does not) is a critical one for most policy makers and investors. Distributional effects are treated in detail using this approach. The distribution of costs and benefits on different parties raises issues of fairness (who pays and who benefits), efficiency (are those paying and benefiting facing incentives that will entice them to act efficiently), and practicality (will project implementation require the cooperation or involvement of new stakeholders).

Distributional effects may also be important in developing implementation strategies, such as whether to impose user or access fees or whether to require cost sharing by industry in infrastructure improvements.

Table 1 lists potential impacts from investing in space launch infrastructure and shows the parties to whom those impacts are likely to accrue. This list of affected parties can be used to structure an analysis of the distribution of impacts from a space launch infrastructure investment.

Risk and Uncertainty

It is also important to structure a cost–benefit analysis to explicitly consider the reliability of the information available. This can be accomplished using a number of techniques, ranging from conducting sensitivity analyses to identify the relative importance of particular information, to sophisticated modeling of risk and uncertainty (particularly uncertainty associated with difficult to quantify benefits). The methodology presented here considers point estimates of risk and uses expected values to determine costs and benefits. The methodology has the flexibility to consider uncertainty, where probability distributions are used rather than point estimates.

Types of Investment

The basis of the methodology discussed here is the approach to identifying clear relationships between an investment under consideration and the impacts that may result. Clear relationships between investment and outcome or impact (ideally the outcomes will be benefits, but often there are costs as well, for example, harmful environmental effects) are postulated to identify the probability of a particular impact and develop a quantitative estimate of the magnitude of the impact and its timing.

To support this process, a detailed investment/impact diagram was developed that can be applied to space launch infrastructure investments. This general set of relationships was then refined for specific types of projects that are currently of interest to the space transportation industry. Through analysis of dozens of proposed space launch infrastructure improvement projects, three major types of space launch infrastructure investment were identified: space launch vehicles, improvements/modifications to an existing launch facility, and development of new spaceports. (Projects were selected primarily from the April 1994 study on "Dual Use of the Space Launch Infrastructure" performed by Practical Innovations for the U.S. Air Force and also include additional projects added to reflect other infrastructure areas.)

Subcategories were identified for existing launch facilities (payload processing, launch vehicle processing, launch vehicle integration, launch operations, and logistics and infrastructure) and for new spaceports (spaceport planning, development projects, and mobile launch systems). An investment/impact diagram for space launch vehicles is shown in Fig. 5 (launch vehicle enhancements). Additional investment/impact diagrams have been developed for several other project types and are available from the authors by request. These additional investment/impact diagrams include the following project types: improvements/modifications to an existing launch facility, launch site upgrade, launch vehicle processing improvements, launch operations improvements, new spaceport facility, and mobile launch site.

These diagrams are designed to provide a consistent basis for identifying project outcomes. The diagrams can be collapsed to reduce the number of steps considered between investment and impact or can be used at the level of detail presented here. Application of these investment/impact relationships to alternative projects within an analysis, or even to separate analyses, will greatly increase the consistency and comparability of results.

For a particular project, this set of relationships must be populated with dollar values and probabilities. The dollar values must be anchored in time, so that they can be considered in terms of net present value or used to determine a project's internal rate of return.

Investment Costs

Assigning values to project investment costs (such as construction or research) is generally straightforward. Investment costs are typically in dollar terms and are usually fairly predictable; there is little uncertainty associated with whether a cost will be incurred. An exception is the estimation of the cost associated with achieving a technological breakthrough or research goal, which involves greater risk and uncertainty. However, standard program and project cost estimating methodologies that focus on the cost, schedule, and performance risk of space related research and hardware development can be used.

For public investments with social benefits apart from decreased federal costs, the impact of taxes must be considered, because taxes on specific products distort relative prices. OMB recommends that the marginal burden in excess of the revenues raised by taxes is 25 cents per dollar of revenue.[13] Exceptions to this rule are taxes that function like market prices, such as user fees, and costs that can be clearly allocated to providing cost savings to the federal government.

Investment Impacts

Assigning values to impacts is usually more difficult than assigning expected values to investments. There will typically be both positive and negative impacts. The first challenge is identifying the impacts that will result from a particular investment.

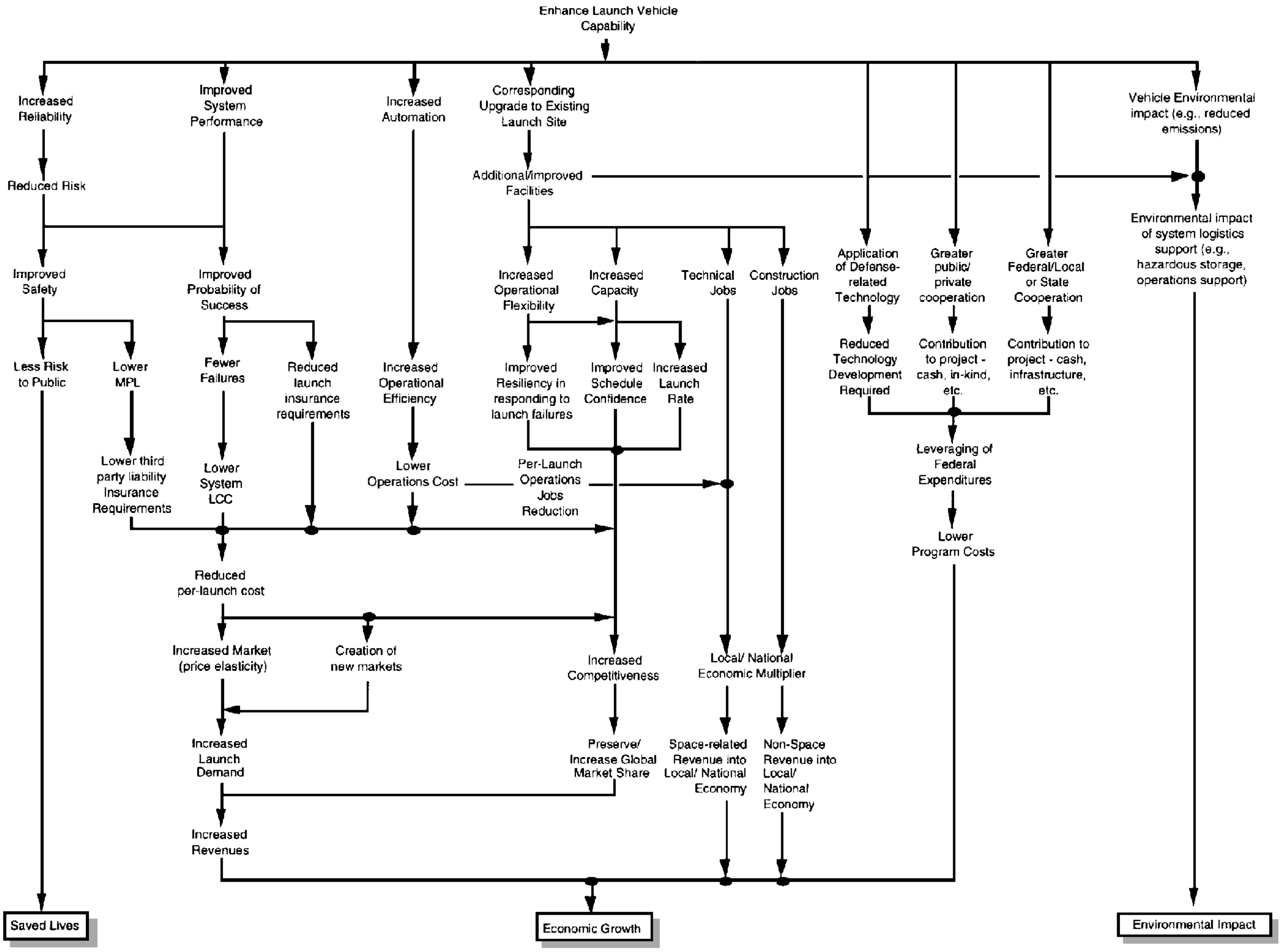

Fig. 5 Example impact diagram: launch vehicle enhancements.

For purposes of this analysis, end impacts are grouped into lives saved, economic growth, and environmental impacts. The use of three different categories measured in different units to characterize end impacts does not provide the ultimate comparability that representing all impacts in the same units (i.e., dollars) would.

On the other hand, transforming safety benefits (such as lives saved) or environmental effects into monetary terms is complex and often controversial. The categories as currently constituted provide the analyst with the flexibility to either present multiattribute outcomes or to monetize all outcomes and generate dollar values for comparing options.

To determine the end impacts of an investment, immediate impacts of that particular type of investment are defined, and the path that results in one of the three types of end impacts is detailed. For example, a launch vehicle enhancement may lead to increased automation, which results in increased operational efficiency, lower operations costs, and ultimately increased competitiveness. Each category of investment has its own investment/impact diagram. One such diagram is shown in Fig. 5 for enhancing launch vehicle capability.

Economic and safety impacts in these diagrams are characterized mainly as benefits (e.g., increased efficiency) because beneficial impacts are the goal of infrastructure investments and it is intuitively appealing to use benefit related terminology. However, outcomes are not always beneficial; efficiency may be impaired when vehicle safety is enhanced, for example. Assigning negative values to impact categories captures negative impacts.

Applications of This Methodology and Next Steps

In a time of increasingly constrained budgets and continued pressure to demonstrate sound management of resources, rigorous analysis of alternative expenditures is critical in government and industry. As already noted, the methodology proposed may be applied to both government programs and commercial investment decisions.

A flexible cost-benefit analysis model of space launch infrastructure applies to 1) determining international competitiveness impacts, 2) evaluating alternative programs and program options, 3) assessing programs and policies over time, 4) managing R&D portfolios for launch infrastructure projects, and 5) comparing investments in nonfederal launch facilities. The authors plan to incorporate the proposed methodology into a flexible computer-based model, enabling numerous sensitivity analyses, good documentation, and traceable results. Continuing work to develop the methodology will include analyses of specific markets (e.g., low-Earth-orbit communications systems) and more explicit treatment of risk and uncertainty.

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