Long-term Development of TERM and Related FTA Data and Analytical Capabilities

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Introduction

The US Department of Transportation (USDOT), the Federal Highway Administration (FHWA), and the Federal Transit Administration (FTA) report to Congress on the status of the nation's highways, bridges and transit infrastructure in a periodic *Conditions and Performance Report to Congress.*[1] The report is very comprehensive and includes characterization of the current system, the condition of the system, the operational, safety and financial performance of the system, and investment needs and performance, among other measures. It is this report that guides Congressional and Federal Transit Administration (FTA) transit policy to an important degree. Analysts also use the report to make the case for addressing perceived deficits in infrastructure as an economic stimulus opportunity.

The purpose of this paper is to take a fresh look at the method by which projections of transit capital requirements are developed. It was commissioned by the Transportation Research Board (TRB) Committee for Review of the Federal Transit Administration's Transit Economic Requirements Model. The Committee wished to consider how TERM "might evolve or be succeeded by new analysis methods" to help guide federal transit policy. Among the specifications for the paper were the following:

- It should base projections of capital spending requirements on economic (benefit-cost and cost effectiveness) criteria
- It should support analysis of effects of transit agency management and operating practices (e.g., maintenance practices and pricing) on capital requirements
- It should support analysis of the effect on capital spending requirements and performance of alternative federal aid program structures (e.g., rules on use of aid for maintenance expenditures)
- It should be practical to build and maintain.

As will be discussed below, the focus on benefit-cost criteria is a central feature of the methodology proposed herein. Like most economists, the author believes that improving the linkage between capital spending and the net economic benefits of that spending is a crucial to assure the economic efficiency of public investment. The author also believes that cost-effectiveness analysis, although useful in static contexts, is not as useful a guide to future-oriented investment policy.

Thus, this paper emphasizes the manner in which a tool might be developed for evaluating the effects of transit agency asset management policy, operations and maintenance protocols on capital needs in a benefit-cost framework. Additionally, it discusses the implications of such an approach on the crafting regulation of the

[1] See USDOT (2010).

condition of transit capital assets and financing assistance for grantee agencies that enjoy the support of the FTA.

The challenge is to outline a method that accomplishes the TRB's objectives that is also practical to build and maintain. This means that it cannot be overly demanding of data or computational procedures.

The author of this report is an economist who, though practicing significantly in the transportation area for 30 years, comes also from a quantitative investment management and econometrics background–both academically and professionally. Consequently, readers will not be surprised to see that the approach taken here is influenced by the theory and practices in these broader fields.

The paper first discusses the process of asset management from a general, theoretical perspective and elucidates the relationship between financial asset and physical asset management policy. From there, it identifies some of the features of the current Transit Economics Requirements Model (TERM)[2] that might be revised to improve the investment guidance that it and the Conditions and Performance Report provides Congress and the FTA. The broad features and data requirements of a revised methodology are presented as well as some generalizations about how the Congressional guidance might be different if such a procedure were implemented.

A Primer on Asset Management

It is worth a brief digression on private market financial and physical asset allocation and management to establish a benchmark for the discussion of process reform in the transit arena. Illuminating the contextual similarities and differences between the conventional private market asset management context and the public transit industry is an aid in identifying how to improve upon the measurement and reporting of transit capital requirements.

What is the Objective of Asset Management?

One cannot manage assets without first articulating the objective of that management. In the private, financial assets world, that objective takes the form of maximization of total return on a risk-adjusted basis of a portfolio of assets. Portfolio managers, brokers and financial advisors labor to achieve this objective on behalf of individuals and institutional investors. The managers are guided by the risk and return postures of their client-investors. [3]

Financial asset management is not as distant from the purpose of managing physical assets as one might assume. In deed, in the process of allocating investible funds among various financial asset classes for investors, however, asset managers indirectly influence the composition and performance of the macro economy at

[2] FTA (2011)

[3] See, for example, Brigham and Ehrhardt (2002) and Grinold and Kahn (2000) for introductions to financial asset management.

large. Thus, there is an implicit consonance of private and social objectives in the private practice of asset allocation and management and the real economies need to husband portfolios of physical assets.

An important feature of private asset allocation processes is the balancing of risks and rewards. It is guided the risk preferences of the investing public as a whole because they are the ultimate holders and beneficiaries of the investments. Massive allocations to long shot, unproven projects or industries are therefore rare, and relegated to specialized venture and private equity managers and investors with selectively high-risk tolerances.

Risk/return optimization is achieved by building portfolios of assets with different potentials to yield returns with varying degrees of uncertainty with regard to those returns, and with varying correlations among the expected returns of the various assets. The portfolio is built by applying weights to individual assets or classes of assets, and thus are the mechanism for altering asset allocation. Differences in these weights determine the ultimate, aggregate risk-return profile of the asset portfolio.

Much of the effort of asset managers is dedicated to determining the weights to be given the individual assets and the investment or disinvestment actions needed to achieve the desired portfolio allocation. The portfolio of assets is enlarged by acquiring more cash to allocate or shrunk by returning cash to investors. Economically and arithmetically, there is an analogy that can be exploited in refining transit asset management practice.

The bottom line is that financial asset management is, at its essence, a method for making sure than scarce resources are well husbanded–in effect, an analog to Benefit Cost Analysis (BCA) methodology applied in a world of risk and uncertainty.

Financial versus Physical Asset Management

The fact that portfolio theory has been developed primarily in the setting of financial asset allocation and management does not negate its usefulness when one moves to the largely physical, capital asset setting of transit systems. The agents performing the asset allocation process are different, of course. In the private markets, it is investors, investment managers and business management who are agents in the implementation of the asset allocation process. In the transit setting, it is local, state and federal policy makers and transit agency management who are the analogous agents.

Like the money managers operating in financial markets, transit asset managers ultimately serve the larger, social efficiency objective as they manage their slice of the physical assets world. It is an underlying premise of this paper, therefore, that Congress and its implementing agencies have the same focus on a societal efficiency objective. Hence, fundamentally, the objective of policy makers or public providers of transit service should not be dramatically different from that of managers of financial or physical asset portfolios in the private sector.

The return to investment to particular financial assets has an analogue in the physical asset world of the net economic benefit of investments in assets that constitute transit properties. Portfolio balancing and asset allocation through periodic portfolio weighting of individual assets that have differential returns prospects and correlations with other asset returns also has an analogy in physical systems. In these systems, the various component capital assets make different contributions to net societal benefits. In addition, the constituent transit asset classes display different risk characteristics (e.g., reliability) and synergy characteristics as important system attributes. Thus, optimization procedures and the types of data relied upon will display similarities and, as in the financial context, investment and disinvestment are the primary means to optimize asset portfolio allocation.

There are, however, differences in the context in which transit asset allocation and management decisions are made. The fact that most transit systems in the US operate as public monopolies, for example, is one obvious and important contextual feature. It means that those who operate or oversee public investments in transit are not automatically subject to the discipline of market forces. In a way, this raises the stakes for transit asset management practice. It is easier in the transit arena for the investment, operation, and maintenance of assets to become imperfectly aligned with efficiency-maximizing behaviors. This is not out of bad intention, but because the punishment for departing from efficiency objectives to other objectives is less immediate and less ruthless than in the private market context.

In the private market, the analysis and investment allocation processes seek to avoid unproductive investments in the process of "seeking alpha", i.e., the best possible premium in return over the normal return for a given risk tolerance. Failure to do so leads to punishment of managers, for sure, but also helps marginalize investment in inefficient projects and firms. The social benefit of this discipline is enormous. In effect, the scrutiny to which stock analysts and financial analysts subject the constituent investments, companies, and industries disciplines the behavior of those economic agents and, derivatively, the performance of the economy as a whole.

The challenge of trying to emulate in public monopolies the resource allocation guidance that competitive, private market forces yield is significant. Doing so with a process that is simple and data sparing only amplifies this challenge. The author does not pretend to have found a silver bullet that has been staring transit policy makers and asset managers in the face, only to be ignored. Rather, this author proposes a methodology that is different enough to possibly better inform the transit investment needs and asset management process.

The TERM Process in Perspective

It is worthwhile discussing the current TERM and related processes from this conceptual viewpoint. We will turn to the challenges of suggesting modifications to the approach later in the paper.

At the risk of oversimplifying or misrepresenting how the TERM operates,[4] the author would describe it as pivoting off of the existing asset stock with a mainly cost effectiveness-focused scheme for developing investment priorities. That is, it starts with a fairly detailed inventory of assets by class, and then subjects that inventory to various measurements that are then merged into an investment prioritization process guided mainly by cost-effectiveness as the operating objective. The investment prioritization process appears to employ a combination of continuous and categorical indicator variables, depending upon the category of impact being measured.

The process involves five categories of measurements, not all of which (understandably) are investigated with the same degree of rigor.

- Asset condition
- Benefit-cost ratio or cost effectiveness[5]
- Safety / risk impact
- Reliability impact
- O&M cost impact

The lodestar of the investment prioritization process is the investment objective (or objective "function" in the mathematical sense). Currently, the TERM process implicitly supports three objectives, depending upon which modules and versions of TERM are evoked.

- The Rehab-Replacement Module computes the investment needs that follow from the objective of preserving the quantity of transit agency assets.
- The Asset Expansion Module (with Performance Held Constant) computes the investment needs that flow from offsetting system performance deterioration, as measured by such things as speed and occupancy metrics.
- The Performance Improvement Module computes investment needs associated with particular performance improvement metrics, notably speed and occupancy.

The TERM process is not devoid of BCA elements, and the consumer-surplus perspective appears to be implemented faithfully for user benefits.[6] Benefit-cost

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[4] It is a bit unclear when and if a "prototype" investment prioritization process is invoked in the current model as the primary prioritization scheme. If so, that process appears to be a weighted integration of mostly discrete rankings in five measurement categories. (FTA (2011), Exhibit 2-17)

[5] Where the latter is discussed, it is measured as the "reinvestment cost per rider impacted".

[6] The author has been involved in the development of techniques for BCA application in both highways and transit from his 1975 dissertation to the present. This has included providing much

analysis enters into the process by using measures of the effect of investments on user costs with and without the investment, and advancing only those investments that have a benefit-cost ratio in excess of 1.0 in the investment prioritization process. There are two variations of the BCA computations depending upon whether market conditions are static (i.e.. Rehab-Replacement and Asset Expansion with Constant Performance) or usage-inducing (as under the Performance Improvement Module).

Implementation of either of the first two modules implements a variation of cost effectiveness analysis (CEA), whereby engineering and/or non-economic performance characteristics are to be preserved. Cost effectiveness analysis is only a means of containing the cost of the *status quo* level of performance, which, in turn, is only a surrogate for a societal benefit measure. It thus does not directly target a social efficiency objective and, lacking a dynamic context, does not provide the most important guidance needed by investors–adapting the portfolio to future conditions.

In the first two modules, the BCA modules function simply to filter investments. Implementation of the Performance Improvement Module with its particular BCA module is a bit closer to what economists would call a BCA process whereby net user benefit in excess of asset expenditure under induced patronage conditions is emulated. However, it still has an asset-inventory focus and a mechanical way by which the value of maintaining or enlarging the investment is computed. In some modules, it is clear that investment is “triggered” by compliance with thresholds constructed by averaging from a distribution of cross-agency values. I also do not detect a means in TERM of liquidating and reallocating assets among the transit asset classes, or significant incorporation of considerations of risk and uncertainty, for example.

Issues with the Existing TERM Process

Before going further, it first should be said that the authors of the TERM procedures deserve praise for developing and documenting a transparent and modular process that says what it does and presumably does what it says. There are no, seriously-black boxes and there is clarity of how parameters are sourced, even if one may not always agree with them. It should also be said that this author only spent time with the manual, and did not implement TERM. It is almost certain that this paper contains some misrepresentation of how asset allocation actually functions under TERM.

There are, however, a few primary issues with the approach as I understand or interpret the TERM process.

COST EFFECTIVENESS EMPHASIS

First, as already mentioned, despite inclusion of BCA computational processes for investment qualification, the model has a strong, cost-effectiveness emphasis. This

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more specific guidance for benefit cost computations. See, for example, AASHTO (2010) and TCRP (2002).

is unambiguously the case of the Rehab-Replacement Module and Asset Expansion module applications, of course. But even in the Performance Improvement Module application, the process of the speed and occupancy improvement submodules involves a performance goal seeking that is CEA-like. Given that, as I understand it, the speed and occupancy improvement modules are presently de-activated, it can be said that the TERM provides investment guidance mostly from a CEA perspective at this time.

Linear Characterization of Transit Asset Performance

Second, the historical asset inventory focus creates a linear model of transit system performance and enhancements to that performance through asset enhancement. That is, there does not seem to be any avenue through which the network topology of an agency is explicitly engaged in the analysis except very indirectly via the composition of the asset inventory. We know that transit systems are networks, and we know that the effect of improvements to networks is very non-linear with respect to its components.[7] Hence, the addition of a new, average increment of, say, vehicle assets will not have the average effect of that asset class.

There appears to be widespread use of average values for parameters that are likely, in fact, to be variable not only across transit properties, but with respect to the productivity of more (or less) investment in a particular class of transit assets. Without a method for respecting network complexity, therefore, the investment guidance is likely to be exaggerated to an unknown degree and in an unknown direction.

Limited Consideration of Risk and Uncertainty

A third issue is that there is little formal accommodation of risk and uncertainty considerations in the measured investment advice. It appears that the notion of risk that is contemplated (if not implemented) in TERM refers only the cost implications of “asset failure”. In fact, however, many less terminal processes carry risk, including short- and long-term variability in patronage and operating costs, whether or not the network and service enjoy redundancy features, and the uncertainty in the potential of agency funding (among others) all introduce non-trivial risk and uncertainty. Such risk considerations bear upon the commitment to the number of vehicles of various lives and depreciation and performance characteristics, choices of fixed- versus flexible guideway topologies, exposure to variability in ambient economic conditions, etc. These are analogues to the problems that corporations encounter managing large portfolios of physical assets under conditions of uncertainty.[8]

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[7] See, for example, Barabási A., A. Réka, and A., H. Jeong, (2000), Barabási, A. (2002a), Barabási, A. (2002b), Economides, N., and G.A. Woroch (1992), Economides, N. (1996), Fonseca, A. (2007), Katz, M. and C. Shapiro (1986), Shapiro, C. and H. Varian (1998) and van der Mandele, M. (2006).

[8] See, for example, Bruno, S. and C. Sagastizábal (2011).

Risk considerations in asset choices, in turn, figure importantly in the economic performance of a transit agency, the ability to sustain maintenance routines, and to provide reliable and responsive service under variable conditions. As this is being written, private autos and (limited) bus transit are providing what little access to downtown Manhattan exists. Fixed rail systems, both above and below ground, have limited functionality at the moment.

Engineering versus Economic Measurements

A fourth observation is that the TERM process largely embraces engineering, versus, economic concepts for some key measures. The discussion of asset depreciation, for example, employs two alternative measures: age-related or condition-related depreciation. This is by no means an uncommon approach.[9] Moreover, such measures are useful in CEA contexts where the world is otherwise static, and one simply wishes to maintain a maintenance regime that trades-off the effects of these measures of depreciation versus the costs of maintenance or rehabilitation. However, it is economic depreciation, not necessarily the age or condition of an asset *per se*, that is germane to optimizing investment. This is clearly true in a world where the services of transit are changing in quality and value. I believe it will be more so in the future as phenomena such as telecommuting make obsolete todays patterns of commutation to traditional, physical office locations.

To exaggerate the point with a hopefully humorous example, one could lament the advanced age or deteriorated condition of the assets in a buggy-whip plant, too, and reach the conclusion that remedial investment is needed. However, to the extent that the buggy whip product is no longer strongly desired, such investment would be economically inefficient. Continued use of old and/or decrepit equipment might well be optimal. The main point is that it is the *value in use* of the flow of services from the asset, not the age or condition *per se*, that should be guiding the measurement of depreciation. Here, private asset markets have the advantage that secondary markets in assets can be used to mark-to-market the value of endowed assets–offering a rough approximation of economic depreciation.

There may, or may not, be useful correlations between economic depreciation and other measures, but that is an empirical matter. I also believe that there are econometric issues with estimating depreciation rates from the survival behavior of assets of various ages across transit properties.[10] In addition, depreciation and maintenance practices are endogenously determined with the value in service. This makes it difficult to conclude that, just because a vehicle is old, or in poor condition, that it has either been suboptimally maintained or in need of new investment.

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[9] See, for example, NCHRP (2006).

[10] Assume hypothetically, for example, that for some properties, transit use is declining and vehicle utilization along with it. Regressing age against fleet survival, in that setting, will yield the impression that age contributes rather little to the rate of depreciation. Condition or miles-in-use measures might capture the decline in services somewhat better, but interact with the maintenance regime practiced. Measurement of condition in the absences of value in use considerations tends to introduce rather subjective and lumpy condition categorization schemes.

FORCES ACTING TO DISTORT TRANSIT INVESTMENT DECISIONS

A final overarching issue concerns the abstraction of the analysis from some of the political economic forces that are influencing investment and maintenance behavior. This is a long and complex topic in itself, and I will only turn to it briefly.

The provision of transit services In the US has evolved in the context of numerous, serious distortions affecting agency behavior. The most important of these is the underpricing of peak use of highway capacity–what is commonly referred to as the lack of congestion pricing. This has demonstrably impaired the market viability of private high-occupancy transport in general and transit services in particular. If and as road pricing becomes more ubiquitous and efficiency-focused, the market prospects of transit services will change. It is thus important to use appropriate indicators of the cost of highway capacity (as the competitor and/or guideway supplier to transit) in evaluation of the societal benefits of transit vs. highway investment.[11]

A derivative distortion is the adoption of (near) monopoly public supply of transit services, in lieu of public subsidy of high-occupancy vehicle use within the context of private supply. The latter approach would have kept market disciplinary forces in operation regarding optimization of transit service flows and investment decisions–under the given user-subsidy regime. The ubiquity of the public supply model bears to some degree on the challenges in emulating the transit investment decision process, since there are few private market observations that could be used to benchmark public agency behaviors. Arguably, the adoption of the public supply model has in turn has fostered duopolistic labor/management conditions that influence transit operating costs and capital asset management decisions.

A few, rare studies of comparative efficiency and labor costs of public- versus private supply of transit services have been performed in the bus transportation context. If one accepts as relevant the academic comparisons of private- versus public labor cost and efficiency in Japanese transit, the cost distortion may be on the order of 12 to 20 percent, at least for bus transport.[12]

The manner in which subsidies are provided to public providers may have tendencies to affect the observed pattern of investment and maintenance. There are two dimensions to this issue. The first is that, to the extent subsidies are offered to underwrite certain assets selectively (e.g., through subsidy of asset acquisition or maintenance), the industry may be dominated by relative capital intense delivery systems. To the extent that such public subsidies are obtained non-locally (i.e., from

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[11] There is not room in this short paper to discuss this issue in detail. However, it is concerning to economists that the operating costs of transit services in some settings exceeds (on an incremental, per passenger mile basis) estimates of properly-priced highway user costs.

[12] See Mizutani, F. and T. Urakami (2002).

higher levels of government than the local jurisdictions served by the transit agency), the asset composition and topology of the agency may be distorted.[13]

These comments are not offered here as a case for privatization of transit supply or elimination of selective subsidy. Rather, it is to make the point that the existing composition of transit agency assets, asset maintenance behavior, and other features of agency behavior are affected by these public policy postures. From a statistical analysis perspective, this may constrain our ability to model certain kinds of systems that have been "selected out" of the population of systems.

What Should One Do Instead?

I first want to reiterate that the existing TERM process is not an atypical transportation asset management program and, in fact, does what it aims to do in a transparent and computationally practical matter. For the reasons I have given above, I think likely will not yield an efficient investment plan, but it is always easier to be an editor than an author.

In this section of the paper, I describe a different approach that might yield solutions to the contextual and computational issues I have outlined above regarding the existing process. Its basic features are:

- It is a closer approximation to an investment plan with a social net-benefit maximization objective, rather than a mostly cost-effectiveness objective with a secondary, screening role for BCA.
- It offers the possibility of incorporating risk and uncertainty more explicitly.
- It recognizes the network-complexity economics inherent in transit agency cost functions.
- Like the existing TERM process, it derives its parameters from industry-wide, rather than transit property-specific data, but has the potential to abstract from the inertial influence of distortionary practices noted earlier.

I first lay out the efficient investment planning procedure in broad detail, and then address issues of implementing it in practice.

The Basic Notions

The basic notion is that transit agencies and Congress need investment guidance that is focused on BCA-type efficiency genesis, rather than cost-effectiveness. Highlighting the distinction is best done with a little arithmetic notation.

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[13] Arguably this process introduces price illusion regarding relative prices of transit agency production inputs, and weakens the link to risk/return preferences of the local population that otherwise might be expressed. Since federal and state subsidization of transit asset acquisition is close to a zero-sum game at each level (at least for urban taxpayers), one is hard pressed to make a purely fiscal case for this practice since the benefits of transit service are overwhelmingly local in nature. A case can be made for demonstration project financing, but the case is more uneasy for an on-going program.

Specifically, an asset management program that had economic efficiency as its objective would look roughly like the following:

Equation 1: Stylized Benefit-Cost Objective Function

$$MaxPV\left(\sum_k (B_k - C_k)\right) s.t. PV\left(\sum_k C_k\right) \leq \bar{C}$$

That is, one wishes to find the various investments indexed by *k* that maximize the present value of system benefits minus costs (summed across all investments) subject to the constraint (if any) that total investment costs not exceed some exogenously determined present value of costs (denoted by *C-bar*). Cost effectiveness analysis, in contrast, is a program with the objective in Equation 2– that is, one seeks to find investments that minimize the cost of producing benefits that are at least as great as some target level (denoted by *B-bar*).

Equation 2: Stylized Cost Effectiveness Objective Function

$$MinPV\left(\sum_k C_k\right) s.t.\left(\sum_k B_k\right) \geq \bar{B}$$

Putting aside the CEA objective, we can elaborate a bit on the specification of the investment program in Equation 1 with the following definitions:

Equation 3: Benefits as Changes in Consumer Surplus

$$B_k = B_k\left(\overset{-}{V}_{without\ k}, \overset{+}{V}_{with\ k}, \overset{+}{G}_{without\ k}, \overset{-}{G}_{with\ k}\right)$$

where

V = the volume of travel (e.g., passenger miles)

G = the generalized cost of travel

= the value of travel time + fares paid

\+ any private vehicle ownership and operating costs

Equation 3 is simply the generalized form of the consumer surplus calculation widely employed in transportation BCA to measure user benefits.[14] The "+", "-" and "+/-" superscripts in the arithmetic indicate the likely direction that the right hand side variables have on the left hand side variable (holding other things constant).

Dropping the aspects of the benefit calculation in Equation 3 to avoid clutter, we can return to the system perspective. In particular, in Equation 4, we focus on the link between transit service supply drivers and benefit computations.

[14] For simplicity, environmental and other non-user benefits are not elaborated upon here.

Equation 4: Variables Involved in Investment-Benefit Computation

$$k = \text{an investment increment or decrement in the transit system}$$

$$B_k = \text{consumer surplus increment associated with } k \text{ versus the base case}$$

$$= B_{k_i}\left(\overset{+}{k}_i, \left[\text{"}\ \overset{+/-}{(k)} \neq k_i\right], \overset{+/-}{S}, \overset{+}{T}, \overset{+/-}{F}, \overset{+}{Q}\right)$$

where

$$\left[\text{"}\ _{k_i} \neq k\right] = \text{ investments other than } k_i$$

$$S = \text{ conditions on the non-transit (street and road) network}$$

$$T = T\left(\overset{+}{L}, \overset{+}{N}, \overset{+}{H}\right) = \text{connectedness of transit network topology}$$

$$F = \text{level and disposition of fares}$$

$$L = \text{number of links}$$

$$N = \text{number of nodes}$$

$$H = \text{number of hubs (unimodal or multimodal)}$$

$$Q = Q\left(\overset{+}{A}, \overset{+}{E}, \overset{+}{W}\right) = \text{ service quality indicators}$$

$$A = \text{a vector of rolling stock quantities by mode}$$

$$E = \text{ a vector of operator line hours by mode}$$

$$W = \text{maintenance deferral (per TERM-type calculations)}$$

This is obviously a simplified rendering of the investment plan,[15] but introduces the concept of connectedness, *T*, to characterize transit supply-side topological characteristics. Recent innovations in the economics of networks argue strongly for inclusion of such a concept as a driver of the likely benefits of an incremental investment in a network. Here, the sign superscripts indicate that connectedness is assumed linked positively to the number of links, nodes and hubs in the transit network. Connectedness, in term, is likely to contribute positively to the incremental benefits of an investment plan (everything else being equal). The notion is that, in a highly connected network, any associated performance enhancement would propagate to a large geography of users.

Equation 4 also introduces a different approach to incorporating the quantity and quality of transit vehicles operating on the network. The variable Q is a generalized abstraction for this aspect of a transit system. The right hand side variables are all

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[15] For example, for simplicity operating costs are assumed to be netted out in the consumer surplus increment, *B*, in present value terms. In a world of constrained capital budgets (as assumed here), B/C ratios are useful in prioritizing the limited plan budget. Hence, the present value of operating costs belongs in the numerator of a B/C ratio, and thus is netted out of benefits, not costs. If budgets are completely unconstrained, it does not matter where they are accounted for because all investment plans with positive net benefits in excess of capital and operating costs would be pursued.

defined in such a way that the expected sign of their effect on benefits is positive for service resources, and negative for maintenance deferral.

Implementing the Investment Plan

An approach to operationalizing the model described by Equations 1, 3, and 4 is to use a large panel of time series and cross-sectional (agency) data that exists to fit reduced-form equations. Reduced-form equations have the property that they their right hand side variables are factors that are believed to be largely-exogenous, and the left hand size are outcomes of the right hand side conditions.

To develop a tool that performs benefit-cost analyses quickly on a variety of investment alternatives, for example, one might wish to have a reduced form equation that explained passenger volumes as a function of descriptors of network topology (T) and service quality (Q). Coupled with a second and third equation that linked service speed and operating costs, respectively, to these same descriptors would give one the essential information to derive benefits per Equation 3. Since most investment strategies involve changes to network topology or service quality drivers, one could quickly evaluate a variety of investment increments (k) to populate an investment plan.

It goes without saying that the mathematical form of the equations and the variables included has to explored so as to respect the underlying behavior of transit systems in diverse operating environments (weather, income, highway conditions, etc.). But the approach is self-validating, in the sense that one can see if the method explains the behavior of the components of benefit measurement adequately (in a statistical sense) across a wide range of agencies and settings.

Optimizing Asset Portfolios and the Investment Program

If the development of reduced-form relationships described above is promising statistically, the development of net benefit-maximizing portfolios of investments in transit assets is potentially greatly simplified. If one accepts net benefit maximization as the appropriate objective of transit investment planning, the task involves seeking combinations of investment increments that achieve this objective.

The computation of net benefits of individual asset increments is a matter of implementing the reduced form equations the form the net benefit calculation. Optimization of a portfolio of investments over some planning horizon is a matter of implementing these equations repeatedly to discover the k investment increments that maximize the present value of total net benefits per Equation 1, subject to budget constraints over the same horizon.

The formulation of the investment program presented here abstracts the time dimension of an investment plan by use of present valuation of objectives and constraints. In fact, of course, the time dimension of an investment plan requires the optimization to consider such things as investment timing, path dependencies, and appropriate discounting considerations as various investment increments, or portfolios of increments, are explored. Similarly, depending upon agency access to funding instruments, there can be time-dependency of budget constraint considerations. This paper cannot go into that detail, but suffice it to say that algorithms and tools for implementing such optimization are widely available.[16]

Incorporating Risk and Uncertainty

This approach also affords the opportunity to more rigorously incorporate considerations of risk and uncertainty. As with any portfolio optimization process, there are two primary stochastic phenomena that need to be considered. The first is the uncertainty that is inherent in the computational process that yields the values incorporated in the measurement of the objective function (e.g., the net-benefit computations made in Equation 1). In the method proposed here, these computations are comprised of explicit econometric representations. Thus, if one wishes to do so, the variance-covariance matrix of the constituent reduced-form equation coefficients can be used to provide information about the uncertainty with which investment benefits are measured.

The second type of stochastic consideration is associated with the uncertainty about external factors that drive the representation of the operating context of the agency (income trends, investment costs, funding availability, etc.). This introduces market risk to the investment program. This is typically addressed in numerical optimization settings by using Monte Carlo[17] type simulation, with variances around estimated values and correlations of those values across factors.

In building portfolios of financial assets, the variances and correlations among the various asset class returns is typically derived from examination of the historical performance of the returns of the asset classes. That can be done here, too, using historical series for the exogenous factors identified in the reduced-form modeling. Formal consideration of risk issues using Monte Carlo-type techniques is practiced to highway cost analysis.[18] [19] This author is not familiar with formalized use of this practice in the transit investment context.

The bottom line, however, is that the econometric approach sketched here provides convenient means of incorporating risk and uncertainty in a theoretically appropriate fashion. Whether it proves practical to do so, remains to be seen, of course. However, by linking the investment planning process more directly to historically revealed user benefit behavior of transit investments, analysis of risk and uncertainty could certainly be performed more readily.

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[16] See, for example, Bazaraa, M., S. Hanif, and C. Shetty (2006), and More, J. and S. Wright (1993). Lindo®, MatLab®, Analytica® and other software tools are potential platforms for implementing the computations.

[17] See Glasserman, P. (2004) for discussion of Monte Carlo procedures in financial settings.

[18] The State of Washington's DOT, for example, has a two-tier process (for highway investments of small and large scale, respectively) called the Cost Risk Assessment (CRA) and Cost Estimate Validation Process (CEVP™).

[19] See Li, Z. (2007) for a formal discussion of highway investment planning under conditions of uncertainty.

Integration with National Processes and Programs

To be useful to the FTA and Congress, any revised TERM-type process needs to be compatible with national-level concerns and processes. These include:

- Providing Congress with an overarching view of the condition and performance of the transit industry at the national level.
- Measuring the influence of national transit funding and regulatory policies, thereby helping define those policies.

In this section, I address each of these issues in turn.

Aggregating Local Agency Needs to the National Level

As I have indicated earlier in this paper, it is this author's view that the investment planning process has to be modeled at the grain of the local transit authority. Transit agencies are operating networks, and the economics of networks reveals that the performance of investments will be idiosyncratic to the features of that network. There are likely many non-linearities in the various relationships that constitute a benefit-cost (or cost effectiveness) measurement scheme.

This suggests that it is appropriate to build up the national investment needs picture by aggregating across agency-level measures. The advantage of this is that individual transit authorities' investment needs may be better characterized, and the agencies would enjoy access to a tool that might be of use in their own planning, cost environment, etc. The disadvantage is that more data than is currently used by the TERM process is needed to implement the "bottom up" computation of investment needs.

Specifically, most of the data that is required of the investment-programming problem laid out in Equations 1 to 4 is available from the same sources on which TERM currently draws. The important exception is the topological descriptors that are needed to introduce sensitivity of the analysis to network configurations. It may be no small effort to reconstruct these measures historically for some agencies. The suggested topological indicators, however, are not fundamentally complex. In addition, since the reduced form equations can be estimated on a subset of agencies that have, or can easily construct, historical measures of network topology, it is still possible to apply the model to all properties for whom current (and future) topology is described.

Thus, this author is cautiously hopeful that this additional data demand is not a fatal flaw to implementation of some network dimensionality as is discussed here.

Measuring the Effects of Transit Funding and Regulatory Policy

It was observed earlier in this paper that the traditional policy of subsidizing the acquisition of transit capital with non-local funds likely imparts a bias toward capital scale and intensity that may not constitute the most cost-beneficial transit service and network configuration. Similarly, I have hypothesized that a program goal that seeks to bring all assets up to a certain measured condition level may not always be productive. It may be that the depreciated assets–even if rehabilitated or replaced–are in service in settings where a commensurate improvement in user benefits will not be realized.

The potential virtue of the program described herein is that it affords a means of assessing these effects, to the extent they are statistically important. For example, if non-local subsidy of transit capital spending is hypothesized to tilt the pattern of transit's capital assets in an inefficient direction, then one should find that investments that tend to be funded by these means demonstrate a penalty in net benefits.

One way a weak impact on net user benefits could occur from a particular financing policy is if it induces a technology or topology of service that does not significantly improve user costs, for example. Alternatively, capital intensity may compel spending on types or quantities of labor or other operating costs that diminish net benefits, or reinforce some other labor pricing or utilization distortion. I have observed in my own client work that it is not unusual for transit agency operating costs to be growing at twice the rate of passenger miles. This *may* be telling us something about capital spending–either that it is in the range of diminishing returns in terms of providing attractive user benefits and thus attracting utilization, or that the operation of expanded capital induces inefficient responses in labor or other operating costs.

Similarly, one might find that the coefficient on a condition measure (as part of the quality of service (Q), measures) is not a statistically-significant driver of user benefits. If this were the case, then one might either revisit the policy, or refine the condition target in a way that tailors it to its consequences for user benefits.

This issue is a particularly important one given the MAP-21 regulatory direction that the FTA is seeking.[20] Specifically, the FTA is refining its regulations regarding the target condition of transit industry assets as part of MAP-21 Section 20019 grantee reporting requirements. As I interpret this section, the FTA is seeking to (1) get agreement on the term "state of good repair" (2) set objective standards for measuring the condition of capital assets and (3) establish performance measures for state of good repair and targets for grantees.

The analytical posture taking in this report might be helpful in this regard if the econometric equation specifications reveal an interesting association between benefits and conventional measures of asset condition. It is possible this could be transformed into a useful way to measure performance-related targets for condition regulation.

This is likely to be very idiosyncratic to individual agency settings. Having a stock of some vehicles that are in a poor state of repair may also be optimal from a risk-

[20] FTA (2012)

management standpoint even if they are unappealing to users. During periods of emergency demand, or loss of fixed-guideway service, for example, an old, unreliable bus may provide considerable net benefits despite its condition and operating cost or reliability penalties attendant that condition. This argument carries less weight for rail-based services where a single malfunctioning vehicle can freeze service on large parts of the network. This, once again, argues for incorporating network topology, as well as asset class, in the modeling of investment needs.

Comparison with Other Asset Management and Investment Efforts

In the context of existing literature and practice in management of transportation assets, the approach presented here should be seen as (1) a way of more formally incorporating benefit-cost analysis and risk considerations in asset management processes and (2) suggesting a way of using econometric methods to simplify the assembly of the data necessary to apply financial asset-like management techniques to the transit asset setting. The literature on financial and traded real asset management and investment is very large, whereas the literature on applications to fixed transportation assets is much smaller.

What work hat has been done in the transportation realm has focused primarily on highway, rather than transit, assets because they are somewhat less idiosyncratic. They thus yield more widely useful data than transit properties, which are thought of as more "one-off" in nature and contextual setting. Even then, however, most highway asset management effort has focused on small subsets of highway assets (e.g., pavements), rather than program-wide portfolios.

Indiana's work in this area is one exception that closely approaches the principles employed here. The work, done at Purdue, is an effort to apply dynamic planning and incorporating risk and uncertainty considerations. (See Li and Sinha (2004), and Li (2007)). Most states use non-economic decision processes because the investment and asset management processes are so strongly influenced by political-economic, rather than strictly economic, considerations. Indeed, few states perform benefit-cost analyses at all, even as part of a multiple-criterion decision process, let alone embedding them in dynamic portfolio management strategies.[21]

In the private sector, there is greater interest in optimizing investment and management of real assets because of competitive financial performance pressures. It is also more feasible, in some sense, because asset cash flow yields are routinely measured, and assets can be bought and sold––establishing market data than can help guide investment. This is in contrast to public infrastructure assets that tend to be perceived as fixed, public assets.

In the private sector, one can find applications of relatively complex, dynamic decision modeling techniques to optimizing the quantity and timing of investment activity. The so-called "real options" approach is a long-standing method that

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[21] See Li and Sinha (2004), table 3.

businesses use to optimize real asset investment in a manner close to that used in financial asset settings. (See, for example, Paddock, J. Siegel, D. Smith, J. (1988), Trigeorgis, L. (1996) and Schwartz, E.; Trigeorgis, L. (2001).)

As public private partnership (PPP) and other such privatization or semi-privatization practices become more common, transit and other transportation assets may be managed more formally than is currently the case, although transit is slow to be affected by the privatization movement. J. P. Morgan's infrastructure asset management practice, for example, presently includes portfolios of toll roads, bridges, tunnels, airports and seaports but not, notably, transit properties.[22]

Conclusion

This paper does not provide a step-by-step process for improving upon the TERM methodology for guiding transit investment needs measurement. Rather, this paper presents suggestions for TERM enhancements that this author believes would be useful departures from the current TERM procedures. Specifically, this paper does the following:

- It urges a primary focus on user benefit-cost maximization as the appropriate guide to agency- and national transit investment planning.
- It hypothesizes adopting an econometric method to abstract from the detailed, but highly linear, implicit representation of investment performance in the current TERM process.
- It urges incorporation explicitly of transit network topological measures in the performance evaluation process (and the econometric abstractions developed). This is both to recognize the reality of the fact that the network nature of transit systems introduces important non-linearities and also to better accommodate the evaluation to idiosyncrasies across transit agencies in this regard.
- It urges consideration of a more comprehensive characterization of risk and uncertainty than is currently practiced on the grounds that the economic benefit impacts associated with network topology, service redundancy, financial and other contextual uncertainties, etc. go unarticulated in the current evaluation process.

The paper does not address many important issues. These include:

- How to address the evaluation of the benefits to the transit-dependent user class.
- How to specifically address safety issues.
- How to address environmental or other externalities associated with transit use.

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[22]http://www.jpmorganinstitutional.com/pages/jpmorgan/am/ia/investment_strategies/investmentsGroup> accessed November 2012.

- How to implement the methodology in a particular computational platform.

These issues go unaddressed not because they are not important, but because I see from my own work and that of others ready means of accommodating these issues. It is hoped by this author that, these lapses, and despite the abstract nature of this presentation, it provides some useful guidance to the FTA and others charged with the real-world task of having to allocate (increasingly) scarce economic resources to transit investment.

References

AASHTO (2010). *User and Non-User Benefit Analysis for Highways*, Washington, D.C. : American Association of State Highway and Transportation Officials

Barabási, A. (2002a). *The New Science of Networks*, Cambridge, MS: Pesseus Publishing.

Barabási, A. (2002b) *How Everything is Connected to Everything Else and What It Means*, New York: Perseus Books

Barabási A., A. Réka, and A., H. Jeong, (2000), Error and attack tolerance of complex networks, Department of Physics, University of Notre Dame: Notre Dame, IN. p. 14.

Bazaraa, M., S. Hanif, and C. Shetty (2006). *Nonlinear Programming: Theory and Algorithms*, 3rd Edition, Wiley

Birk, M., and R. Geller (2006). Bridging the Gaps: How the Quality of a Connected Bikeway Network Correlates with Increasing Bicycle Use. TRB Annual Meeting, p. 26.

Ross, Westerfield, and Jordan, "Fundamentals of Corporate Finance", 5th edition (or later), Irwin McGraw-Hill, 2000

Brigham and Ehrhardt (2002). *Financial Management: Theory and Practice*, 10th edition, Southwestern Publishing.

Bruno, S. and C. Sagastizábal (2011). Optimization of a Real Asset Portfolio using a Coherent Risk Measure *Optimization and Engineering,* Volume 12, Issue 1-2.

Chang Lin, C. (2006). A Link-Based Approach for the Generalized Hub-and-Spoke Network Design Problem. TRB 2006 Annual Meeting, 2006: p. 24.

Church, J., and N. Gandal, 1990, Complementary Network Externalities and Technological Adoption, International Journal of Industrial Organization 11, 239-260.

Economides, N., and G.A. Woroch (1992). Benefits and Pitfalls of Network Interconnection, Discussion Paper no. EC-92-31, Stern School of Business, N.Y.U.

Economides, N. (1996). The Economics of Networks, *International Journal of Industrial Organization* vol. 14, no. 2

Fonseca, A. (2007) *Contemporary Network Theory: Concepts and Implications for Transportation Asset Management*, Thesis, Virginia Polytechnic and State University

FTA (2012), "Moving Ahead for Progress in the 21st Century, 49 U.S.C. Section 5326 Fact Sheet", www.fta.dot.gov/map21.

FTA (2011), *TERM Transit Economic Requirements Model User's Guide*, prepared by Booz, Allen Hamilton, May 13, 2011.

Glasserman, P. (2004). *Monte Carlo Methods in Financial Engineering*, Springer

Grinold, R. and R. Kahn (2000), *Active Portfolio Management*, 2nd edition, McGraw-Hill, 2000.

Katz, M. and C. Shapiro (1986), Technology Adoption in the Presence of Network Externalities, *Journal of Political Economy* 94, 822-841.

Li, Z., and K. C. Sinha (2004), Methodology for the Development of a Highway Asset Management System for Indiana, FHWA/IN/JTRP-2003/21, Joint Transportation Research Program, Indiana Department of Transportation0 and Purdue University, West Lafayette, Indiana.

Li, Z. (2007). Optimal Investment Decision-Making for Highway Transportation Asset Management under Risk and Uncertainty, MRUTC 07-10, Midwest Regional University Transportation Center University of Wisconsin-Madison.

Mizutani, F. and T. Urakami (2002), A Private-Public Comparison of Bus Service Operators, A Paper Prepared for the 42nd European Congress of Regional Science Association Dortmund, Germany, August 27-31, 2002

More, J. and S. Wright (1993). *Optimization Software Guide*, SIAM Frontiers in Applied Mathematics, Vol. 14.

NCHRP (2006). Report 551: Performance Measures and Targets for Transportation Asset Management, Transportation Research Board.

Paddock, J.; Siegel, D.; Smith, J. (1988)."Option Valuation of Claims on Real Assets: The Case of Offshore Petroleum Leases". Quarterly Journal of Economics 103:479-508.

Satorras, R., A. Vázquez, and A. (2001). Vespignani, Dynamical and Correlation Properties of the Internet. APS Physics, Review Letters 87(25): p. 4.

Schwartz, E.; Trigeorgis, L. (2001). Real Options and Investment Under Uncertainty. Classical Readings and Recent Contributions. MIT Press.

Shapiro, C. and H. Varian (1998). *Information Rules: A Strategic Guide to the Network Economy*, Harvard Business School Press, New York.

TCRP (2002) Report 78: Estimating the Benefits and Costs of Public Transit Projects: A Guidebook for Practitioners

Trigeorgis, L. (1996) Real Options: Managerial Flexibility and Strategy in Resource Allocation; MIT Press.

USDOT (2010) *2010 Status of the Nation's Highways, Bridges and Transit: Conditions and Performance Report to Congress*, Washington, DC

van der Mandele, M. (2006). Policy Development for Infrastructure Networks: Concepts and Ideas. *Journal of Infrastructure Systems, ASCE*, 12(2): p. 69-76.

Dias, Marco and K. Rocha, J. P. Teixeira, The Optimal Investment Scale and Timing: A Real Option Approach to Oilfield Development (*Petrobas*)