A Case for Breaking Down the Capital-Maintenance Barrier

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ABSTRACT

In many states, capital and maintenance budgets are distinct and separate. It is well-known, however, that new (capital) assets must be maintained over the long term; capital investments directly impact maintenance requirements. In the current situation, transportation agencies are unable to use funds for much-needed maintenance. In many instances, available overall funds are enough to provide a sustainable transportation network – yet budget restrictions stop these agencies from using funds in the most economic way. The condition of our roads will degrade as we continue to build more that we will not be able to afford in the future. In this context, pavement managers should be part of the discussion on whether it is more valuable to build a new asset or maintain an existing.

This paper makes an economic case for breaking down the capital-maintenance barrier, and considering capital and maintenance projects as alternatives in the same decision framework. It demonstrates that capital and maintenance investments are simply alternatives along the continuum of an asset’s life, rather than mutually exclusive investment alternatives. This perspective will help pavement owners to re-consider the way in which they structure their organizations and investment evaluation processes.

1 THE SITUATION: SCARCE RESOURCES AND THE NEED TO ALLOCATE OPTIMALLY

Every four years, the American Society for Civil Engineers (ASCE) releases its Report Card for America’s Infrastructure to inform the public and decision makers as to the current condition of the infrastructure across the United States [1]. The Report Card is based on an objective assessment of available data by national subject matter experts that consider the capacity, condition, funding, future needs, operations and maintenance, public safety and resilience of the infrastructure, and assigns letter grades from A to F.

The most recent findings [1] painted a bleak picture of the state of the national road infrastructure, assigning it a score of D. This rating level means the infrastructure is in fair to poor condition with significant deterioration, capacity constraints and risk of failure for a large portion of the national portfolio. The Federal Highway Administration (FHWA), in its 2010 Status of the Nation's Highways, Bridges and Transit: Conditions and Performance [2], further estimated that an additional $170 billion was required annually to make a significant impact on the condition and performance of all highways and bridges. To start to rectify many of these performance issues a number of investment projects were created, including MAP-21, the Moving Ahead for Progress in the 21st Century Act (P.L. 112-141) [3], which was signed into law by President Obama on July 6, 2012. MAP-21 is a funding and authorization bill for funding federal surface transportation that reduces the number of funding programs and alters some of the rules around them. This reform is aimed at reducing the budget deficit.

MAP-21 will fund surface transportation programs at over $105 billion for fiscal years (FY) 2013 and 2014 and is the first long-term highway authorization enacted since 2005. The introduction of MAP-21 creates new challenges, as it is founded upon the principles of asset management, which recognizes the need for a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions to minimize costs over the asset’s lifecycle (23 U.S.C. 101(a)(2), MAP-21 § 110) [3]. This lifecycle approach means that all treatment options, including maintenance and capital investment, need to be
considered mutually when deciding upon the most appropriate lifecycle pavement intervention. This new recognition of investments along the life of an asset runs counter to many current funding program structures and constraints, as well as the structure of many DOTs.

1.1 How capital and maintenance expenditures are related

As described in MAP-21, the goal of using the asset management process is to minimize the lifecycle cost so that the service that the asset provides is delivered with the least lifecycle cost. To show how these costs are sequenced through an asset’s life, the lifecycle of an asset is shown in Figure 1. In this cycle, the decision to build a new asset is based on an identified need such as improved safety, reduced congestion, or travel time savings. Once the construction phase is complete, the new asset transitions into an operations and maintenance phase, where it remains until the asset is either replaced or retired.

![Asset Lifecycle](adapted from [4])

The total lifecycle costs for the asset are the sum of costs within each sector of the lifecycle shown in Figure 1. These costs can be represented as:

\[
\text{Lifecycle Cost} = \text{Construction cost} + \text{Preventive maintenance cost} + \text{Routine maintenance cost} + \text{Disposal cost}
\]

This simple formula shows that construction costs (capital) and maintenance costs are both part of the lifecycle cost, and illustrates the interdependency that exists between capital, maintenance and disposal costs. Figure 2 illustrates this concept on a timeline and shows how total present value costs increase through an asset’s life. The timing and choice of capital and maintenance interventions influence the cumulative present value of costs. The lowest lifecycle cost strategy is the one that minimizes the area under the cumulative present value cost curve.
Throughout the asset’s operation and maintenance phase, there are many alternative treatments to extend the life of the asset. The extent, cost and impact of each treatment on the quality of the asset changes depending on its timing and the precise type of treatment selected. Selecting the right treatment at the right time is therefore a complex optimization problem; it is little wonder that entire teams are dedicated to optimizing maintenance costs.

Figure 2 illustrates the complexity of the cost optimization problem, where each maintenance decision at each year has the potential to flatten or steepen the cost curve to a greater or lesser extent.

To further demonstrate the interdependencies between capital and maintenance investments, the influence of one on the other can develop in several ways, including:

- **Capital investment implies future operational expenditure requirements:** Each new, replaced or re-built asset needs to be operated and maintained; each capital investment carries operational and maintenance requirements for many years to come.

- **Good maintenance and operations reduces the need for capital investments:** Existing assets can be operated and maintained differently (to a higher level, or more proactively) to defer the need to replace, upgrade or rebuild new assets.

- **Efficient maintenance leaves more funding for capital investments:** More efficient maintenance equates to lower cost of maintenance, which leaves more funds available for capital investments.

- **Reduced capital investments leave more funding to maintain existing:** Reduced capital investments have two positive benefits types: they ensure that no additional maintenance investments will be required, and they leave more funds available for maintaining and operating existing assets to an agreed quality.

While Figure 1 implies that only a capital intervention can be used to meet a need, oftentimes alternatives such as maintaining existing or demand management can produce the
same or greater benefits. Similarly, Figure 2 does not adequately reflect the complexity inherent in lifecycle cost decisions. External factors such as regulations, standards, and customer expectations change with relative frequency throughout the assets’ lives. The asset is initially built to meet these requirements as they are at the time of construction, but as requirements change through the assets’ lives, investments may be required to maintain the required level of service.

These investment requirements create a complex, dynamic relationship between capital and maintenance expenditure – that is, capital investments may be required simply to maintain an existing level of service, and maintenance requirements may change as a result of the new investment. Accordingly, identifying the least cost strategy requires not only the continual re-examination of the many possible treatments that can be undertaken throughout the asset’s life, but also other influences on the agreed level of service. This balancing act is often further complicated by the complex funding rules and large number of budgetary programs.

The lifecycle cost challenge created by the adoption of asset management principles can be managed by working within the budget structure and do the best job possible, or by challenging the funding, budgeting and organizational structures and developing a true lowest lifecycle cost approach. The idea of positively challenging imposed constraints to better the whole production process is summed up in the Theory of Constraints [6, 7]. The Theory of Constraints comprises five stages, but the following three are the most pertinent to addressing the lowest lifecycle cost challenge:

- Identify the system’s constraint(s). These may be physical (e.g., materials, machines, people, demand level) or managerial, such as processes or practices.
- Decide how to exploit the system’s constraint(s). If the constraint is physical, the objective is to make the constraint as effective as possible. A managerial constraint should not be exploited but be eliminated and replaced with a policy which will support increased throughput.
- Elevate the system’s constraint(s). If existing constraints are still the most critical in the system, rigorous improvement efforts on these constraints will improve their performance. As the performance of the constraints improves, the potential of non-constraint resources can be better realized, leading to improvements in overall system performance. Eventually the system will encounter a new constraint.

Using these three points as a start, the following sections are used to identify the highway least lifecycle cost systems constraints and the barriers to overcoming optimal lifecycle outcomes and subsequently to propose a different way of thinking that will facilitate fully optimal outcomes.

2 THE PRIMARY CONSTRAINTS ON OPTIMAL INVESTMENT: THE HUMAN DESIRE TO CATEGORY

As detailed in MAP-21, asset managers are expected to maximize the value obtained from their budgets and to minimize lifecycle costs. In the post global financial crisis world, where budgets become tighter and user expectations higher, this challenge becomes even more acute. To help manage these decreasing budgets, funders divide allocations into ever smaller portions and control each funding allocation with multiple restrictions. These restrictions
create the sense amongst organizations that the best is being achieved, as the funds will be spent in the “most efficient” manner.

Based on research carried out by Thaler [8], individuals separate money into these distinct accounts to overcome people’s propensity for short-term decision making. For each account that is created, different rules are used to stipulate what funds can be added and when funds can be withdrawn [8]. These rules act as a spending control device [9]. This creating of accounts, setting of funds and rules, and rational trade-offs between interventions is the process used in infrastructure asset management, as described in the previous section. However, money is fungible – that is, one unit of money, regardless of the account it is held in, has the same value as another unit of money that may be held in a separate account [8], and can therefore be spent on any work item. Creating separate accounts violates the fungibility of money, and leads to sub-optimal practices, including [9]:

- Under-used funds, where one budget is empty and another is still unused. Under-use reduces organizational effectiveness
- A tendency to select less preferable options, even when a higher standard would be appropriate

2.1 Implications of organizational structure on cost of highway maintenance

To ensure more optimal asset investments, the impact of mental accounting must be addressed in asset management decision-making. In developing lowest lifecycle cost solutions, the asset manager must identify the best balance between short- and long-term funding. Confirming the best balance will require a close working relationship between capital managers, maintenance managers and funding providers. The structure of many asset management businesses and funding programs, however, reflects human tendency to divide separate accounts or silos, and therefore restricts asset managers’ ability to minimize the costs of maintaining assets.

Many highway organizations in particular divide their business into entities that are separately responsible for pavement maintenance and capital works. This structure likely occurs because of the separate funding and budgeting processes that have arisen. These separate funding programs appear to view maintenance and capital as different issues rather than a continuum of the same issue, as illustrated in Figure 2. This division of funds is associated with differing rules for obtaining funding and evaluating alternatives, and so results in the violation of fungibility – artificially treating funds from different accounts differently, restricting them in different ways. Examples of the type of work undertaken within these two funding categories are provided in Table 1.

In addition to violating fungibility, these organizational silos do not promote an environment in which staff work collectively in decision making. In the absence of collaboration, staff are unlikely to discuss the required balance between level of service and future maintenance requirements, and lifecycle strategies are likely to be sub-optimal. This structure leads to the first constraint, the siloed nature of the funding allocation process.

**Constraint One:** The organizational structure does not foster consideration of capital and maintenance works as decisions along a continuum of the asset’s life
**Table 1: Typical activities undertaken within capital and maintenance funding programs (synthesized from [10] and experience with various US DOTs)**

<table>
<thead>
<tr>
<th>Program</th>
<th>Description</th>
</tr>
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</table>
| Capital Works      | • Construction of New Assets  
• Capital preventive maintenance comprised of planned activities that protect the pavement and thereby reduce the rate of pavement deterioration without increasing pavement structural capacity  
• Resurfacing  
• Replacement and Reconstruction (R&R) of existing assets |
| Maintenance        | • Routine Maintenance  
• Day to day maintenance activities initiated and carried out by maintenance personnel.  
• Could be repairing part of the asset in response to a safety concern.  
• Also sometimes referred to as reactive maintenance.  
• Heavy Maintenance  
• Usually more urgent work and generally form part of a capital project but cannot be funded from there due to time constraints.  
• Non-routine work (eg. concrete slab replacement).  
• Funding is from the maintenance budget, but this can at times be recovered from the capital funding stream. |

In addition to the organization’s structure, its maturity and size are two elements that can predispose it to a tendency to continue on its current path. Hannan and Freeman [11] were among the first to identify the ‘strong inertial pressures’ that organizations experience due to internal arrangements, such as politics, and the environment, including the public’s acceptance and expectations of the organization’s activities. These internal and external pressures are more significant than most researchers realized prior to Hannan and Freeman’s paper.

Hartley [12] also identifies the political risk associated with innovation in public sectors. A simple Improvement / Innovation quadrant illustrates that organizations can experience incremental improvements without governance innovation (Quadrant 2), and that there are real risks of failure with governance innovation (Quadrant 3). The quadrants demonstrate that without innovation, organizations can hope to achieve, on average, small improvements, while innovations bring the risk of failure. It is well documented in the behavioral literature that people’s desire to avoid losses is far stronger than their desire to gain [13, 14, 15].
These organizational resistances to change, however, have to disintegrate if state level Departments of Transportation are to meet the requirements of MAP-21, and the demands from legislatures for greater transparency and accountability. With these new requirements, as well as an increased reliance on external service providers, the inertia- and innovation-stifling elements, such as sunk costs in plant and personnel, ‘business as usual’, legal barriers, and political disincentives [11, 12], will begin to fall away. In the meantime, these barriers are still apparent in many organizations and thus lead to Constraint Two.

**Constraint Two:** The structural inertia in large, mature, traditional organizations makes it challenging to effect positive change

### 2.2 Implications of investment drivers and funding sources and rules on cost of highway maintenance

During times of economic hardship, or after extended periods of hardship, government frequently develops programs designed to stimulate the economy or to address some perceived maintenance or developmental backlog. These works often focus on ensuring as much capital work as feasible is carried out, largely because this type of work is more readily visible to the public. In these situations, a number of human behaviors arise. The first, as described by Thaler [8], is that the purchaser of the service (i.e., the asset manager) will likely...
“buy” something they would not normally be willing to purchase. This investment results in projects that are unlikely to deliver the lowest lifecycle cost and in fact may eventually exacerbate the maintenance backlog, as there is suddenly a new asset that has to be maintained. It is after extended periods of reduced funding that asset managers require the greatest level of flexibility to carry out the works that are required, otherwise counter intuitive outcomes are likely to be created. As an example, in response to the recent global 2008 - 2012 economic recession, governments around the world introduced national infrastructure stimulus programs, investing in public infrastructure aimed at creating jobs and promoting economic recovery. Programs were rapidly rolled out by governments with funding requirements defined and constrained timelines to respond resulting in a focus on larger scale capital projects with maintenance not considered.

In the United States, the American Recovery and Reinvestment Act (ARRA) saw over $48 billion provided for transportation programs administered by the U.S. Department of Transportation, with 57% of these funds allocated to highways. Meyer [16] examined the influence of ARRA Program requirements on decision making, and found that major rehabilitation projects (i.e. capital investments) represented the majority of projects selected. While the ARRA program no doubt had a significant impact on reducing the pavement performance backlog across the country, it largely created a bow wave of future maintenance liabilities. Furthermore, if a portion of funding could have been allocated to increased routine maintenance investments, this could have reduced future preservation and maintenance needs, by limiting the extent of deterioration for pavements requiring routine maintenance such as crack sealing and localized patching. This bias to capital investments leads to Constraints Three, Four, and Five:

**Constraint Three:** Capital and maintenance investments are evaluated using different criteria, creating a disconnect between the different parts of the asset’s lifecycle

**Constraint Four:** Capital investment commitments are not accompanied by commitments for the required maintenance associated with the new asset. The tendency to fund capital projects creates a future maintenance liability.

**Constraint Five:** Federal and state funding do not allow for transfer of funds between capital and maintenance funding programs despite the potential to deliver lower the least lifecycle costs.

### 2.3 Common practices that increase the long-term cost of highway maintenance

When developing and managing annual programs, managers are reluctant to reduce or redirect funding in the event that it could result in lower budget levels in subsequent years. While diverting these funds may be the correct decision from a pavement life-cycle management perspective, organizations do not always recognize this and create a protective budgeting environment that limits broader decision making to be applied. Federal funding for construction and maintenance activities unintentionally creates a clear delineation that obscures the continuous nature of capital-maintenance service delivery.

For many organizations, their traditional means of asset management better resembles a facility management approach, wherein the approach is to “find and fix as many faults as possible within the budget available”, with the level of service provided being an outcome of the works completed and with little formal thought about minimizing the least life costs.
Pavements are longer life assets that need to be properly managed along the entire deterioration cycle. Due to their long lives, effective pavement management requires longer term funding commitments, which the public sector’s short-term annual funding cycles typically do not provide. Hence, while many agencies use asset management systems to identify needs, actual investments are largely influenced by the budget cycle.

For highway pavements, Capital Works are used to construct and maintain the highway asset until such a point that it is assessed to have a Remaining Service Life (RSL) of zero to two years. At this point in time, Routine Maintenance tasks maintain the asset in a safe and functioning level of service until it can be rehabilitated. Some DOT’s refer to this as “Terminal Maintenance”, where the pavement should be reconstructed or replaced, but is instead maintained with shorter term and temporary treatments due to funding constraints. If rehabilitation is delayed, retrospective repairs to much more significant damage can be very costly. At present, Capital Works may attract Federal funding at a four to one ratio (i.e. Federal / MDOT) under federal funding guidelines. This subsequently plays a key role in the determination of activities that are defined as being within Highway Maintenance.

When capital projects involve federal funding, the process must follow federal rules for procurement and delivery. While not precluding a service delivery model that combines routine maintenance and capital works, this funding arrangement does encourage the continued separation at the delivery level nor empower DOT’s to fully embrace asset management.

Finally, in the authors’ experiences, managers in control of their respective accounts have avoided reporting potential savings initiatives, for fear they would permanently lose the “savings”. In an environment in which higher-level staff members are focused on reducing costs, and budgets are frequently determined based on historic allocations, it is little wonder that asset managers hold these fears. Needless to say, this type of behavior does not minimize the lifecycle costs of assets and leads to Constraint Six.

**Constraint Six:** Fear of long-term budgetary attrition

**3 HOW TO EXPLOIT AND ELEVATE THE SYSTEMS CONSTRAINTS: OVERCOMING SUB-OPTIMAL INVESTMENT PRACTICES**

The four main systems constraints identified in the previous section can be exploited by considering a lifecycle philosophy. This lifecycle philosophy can be introduced through the following principles:

1. Recognize that each asset has associated maintenance and operation costs through its life, and provide funding for each asset. Each asset should have its own reporting line.

2. Allow flexibility to fund capital or maintenance projects, based on which investments make the largest contribution to agreed levels of service. This flexibility will need to allow for changes such as greater traffic loads and new design standards.

3. Provide incentives for capital and maintenance staff to recognize lower lifecycle cost investment strategies, which may change from year to year, and may mean that funds are reduced in one account in one year and increase again when required.

Based on these principles, we have proposed an exploitation mechanism for each system constraint as shown in Table 2.
Table 2: Potential exploitation mechanisms to address system constraints

<table>
<thead>
<tr>
<th>System constraint</th>
<th>Exploitation mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organizational structure</td>
<td>Introduce collaborations between capital and maintenance teams when considering new works.</td>
</tr>
<tr>
<td>Organizational inertia</td>
<td>Identify the barriers and opportunities to organizational change. Introduce political and structural incentives for organizational innovation.</td>
</tr>
<tr>
<td>Disparate investment evaluation frameworks</td>
<td>Evaluate capital investments against agreed levels of service.</td>
</tr>
<tr>
<td>Limited lifecycle commitment</td>
<td>Introduce processes that require lifecycle funding committed to capital investments.</td>
</tr>
<tr>
<td>Rigid funding mechanisms</td>
<td>Allow discretion between maintenance and capital funds aimed at meeting level of service targets.</td>
</tr>
<tr>
<td>Fear of permanent budget loss</td>
<td>Incentivize staff to identify cost savings and ensure budgets are based on need rather than historic expenditure. Demonstrate commitment to a needs-based budget.</td>
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</table>

4 BENEFITS OF EXPLOITING SYSTEM CONSTRAINTS

Exploiting system constraints in the ways identified in the previous section will undoubtedly reduce the lifecycle costs of America’s pavement assets, by recognizing the least cost alternative to delivering an agreed level of service.

5 CONCLUSION

The authors have reviewed the reasons for “breaking down the capital-maintenance barrier”. These reasons are primarily based on reducing the costs of building and maintaining America’s highway infrastructure. The authors have proposed considering capital and maintenance projects as alternatives along the continuum of an asset’s life, rather than mutually exclusive investment alternatives.

To comply with the MAP-21 lifecycle philosophy, a number of additional reforms may be required to the structure of DOTs and funding programs. Many of these constraints can be addressed by introducing common evaluation frameworks based around meeting agreed levels of service, and by allowing funding to shift from one account to another based on demonstrated need. To ensure that managers identify least cost strategies, budget-setters will need to capture managers’ trust by demonstrating that budgets will be allocated based on need – not historical expenditures. They must demonstrate that budgets will be based on economic arguments, now and in the future.
6 REFERENCES


