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# FACTORS AFFECTING CONSTRUCTION PAYOUT CURVES ON TRANSPORTATION MEGA PROJECTS

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**Abstract:** North Carolina Department of Transportation (NCDOT) projects with construction costs of $50 million or more, known as mega projects, make up more than 50% of their total construction expenditures while representing less than 10% of the total project count. The estimated construction expenditures for these projects can vary significantly. This paper provides a new perspective on monitoring mega projects during construction to quickly recognize and mitigate developing problems. The research methodology included an extensive literature review that analyzed strategic milestones and expenditure payouts for recently completed transportation mega projects. . The paper contributes a new approach for identify projects that are not meeting their original construction performance baseline goals (and require intervention for corrective action) during construction, which can result in costly project delays.

## 1 INTRODUCTION

NCDOT transportation projects with construction costs in excess of $50 million (mega projects) comprise less than 10% of the number of centrally let awarded projects, but account for more than 50% of total construction expenditures. The planning and execution of mega projects are complex and need the strategic integration of both technical and political issues (Ardila and Salvucci, 2001). Mega projects influence the overall agency cash balance; hence, it is crucial to understand the factors that negatively affect mega project let dates and construction completion dates, both of which can immensely affect cost. The purpose of this paper is to demonstrate the use of the project payout rate to assess project performance during construction. Estimated construction expenditures for mega projects can vary significantly based on the type of project, work to be accomplished, and unpredicted events (e.g., delayed entry due to utilities that have not yet been moved). When anything happens to unexpectedly affect their estimated monthly payouts, mega projects can have a negative impact on transportation agencies' overall financial management performance.

This paper provides an assessment of recently completed mega projects. In doing so, it clearly shows how one can recognize projects that are falling behind schedule or below the cumulative estimated budget payout. Doing so enables early remedial actions to be taken to minimize negative impacts on the final cost and schedule.

Mega projects consist of thousands of activities performed by numerous contractors and subcontractors. Because of this, it is more difficult for state transportation agencies to efficiently and accurately track progress than it is for the contractor to do so. Still, one way for the agency to monitor progress is via project expenditures. Thus, the monthly project payout rate can be used as an indicator of project progress. This paper demonstrates how to use payout rate as one such indicator.

## 2 LITERATURE REVIEW

The literature review was conducted to better understand factors that affect the payout modeling for construction projects. The Building Research Board conducted an important study to review and improve the current practices performed by federal agencies in developing their early cost estimates (Morris, 1990). Their goal was to reduce inaccurate early estimates that result in inaccurate budget requests (the main cause of cost overruns). They suggested that terminologies, as well as estimating formats, be standardized and that cost data history be shared among different agencies.

Studies to create models with greater cost estimating accuracy had begun in the 1960s. Hardy (1970) emphasized the importance of plotting both time vs. cost and value vs. cost. In the 1970s, mathematical models were introduced that could be used if the total value and duration of the planned construction projects were known (Banki and Esmaeili, 2009). The majority of the models concentrated on developing S-curves that were standard and represented the cost of different past projects of a particular type. However, because construction projects are unique by nature and often do not conform to the performance of past projects, Kenley and Wilson suggested that such curves may not be applicable (Kenley and Wilson, 1986), a position also supported by the authors herein. Thus, researchers began to explore more customized models.

Numerous stochastic and regression models were tested using past data with promising results (Smith and Mason, 1997). The Virginia Department of Transportation (Gillespie and Kyte, 1997) enhanced their forecasting tool by incorporating two regression sub models to predict monthly construction expenditures and maintenance expenditures. Kaka (1999) sought to find the differences in S-curves based on the planning strategy. He indicated that a stochastic model, using data from past projects, had the highest probability of achieving accuracy. A regression model based on a standardized work program framework was proven to be accurate in the development of S-curve models, but was subject to reservations due to small model sample sizes (Blyth and Kaka, 2006). Gransberg et al. (2007) investigated the relationship between cost escalation and design fees, finding that, as the design fee decreases, the absolute percentage of construction cost growth from the engineer's early estimate increases.

Mills and Tasaico (2005) studied 4,128 progress payments for 336 highway projects from August 2000 through June 2002 to develop a statistical model that forecasts the payout for NCDOT construction contracts. They developed two models that forecast the monthly progress payments. The first model predicts monthly payments for individual projects and is used primarily by project engineers and managers. The second model predicts monthly payments for a portfolio of projects; agency financial managers are the primary users of this forecasting tool.

Asmar et al. (2011) developed a statistical approach to produce conceptual cost estimates for state highway agencies. This approach used an analysis similar to the program evaluation and review technique (PERT), which is more commonly used in project scheduling, to assign certainty factors to cost estimates. Bayraktar et al. (2011) proposed a tool to determine a project execution strategy that emphasized systematically monitoring project cost and schedule to increase the likelihood of success for capital projects. The approach suggested herein for monitoring during construction is similar.

A model developed by Ostojić-Škomrlj and Radujković (2012) concluded that sixth-degree polynomial regression was the best modeling approach to forecast cost. The results of using this approach correlated well (95% reliability) with the actual cost and time values obtained using data from real-time projects. Zhang et al. (2017) developed a parametric cost estimate model, using a least absolute shrinkage and selection operator approach, to forecast highway project costs. A unique contribution of this research was that it simultaneously explored project-related variables with a set of economic factors that are widely considered to be influential on highway construction costs.

## 3 METHODOLOGY

The *construction delay and cost overrun* work presented herein was based on construction payout data for completed mega projects. Insights from these data helped the research team to better understand internal and external factors affecting payout curve shape. Next, the study focused on the actual shape of the payout curve for individual mega projects, proposing standardized payout curve designs for both Design-Bid-Build (DBB) and Design-Build (DB). A preliminary study of payout curve termination points was performed and indicates that even though projects are planned to terminate at a cost and schedule factor of 1.0 (on time and within budget), they typically end up higher on one or both.

## 4 FINDINGS

### 4.1 Cost and Schedule Factors for Completed Mega Projects

Cost and schedule factors are calculated by dividing the estimated project cost and duration at completion by the original bid price and duration. A cost and schedule factor of 1.0 means that the project was completed at the original bid amount and duration. However, it is unrealistic to assume that both cost and schedule factors are always equal to 1.0 throughout the life of the project.

It is critical to note that there were only 7 DBB and 11 DB projects that had recently been completed – there are, simply, a limited number of such large projects. Thus, statistical methods cannot be applied for analyses and the assessment was made using a case study format. For DBB projects, the average cost increase was 3% (cost factor = 1.03) while the highest cost increase was 14% (cost factor = 1.14) over the bid amount. Overall, 71% of DBB projects met or exceeded their cost expectations. However, none of these projects finished within their original bid duration. Instead, they finished on average 14% (schedule factor = 1.14) longer than predicted, with one project taking 41% (schedule factor = 1.41) longer than estimated.

We also found that for DB mega projects, cost increased by 6% and duration increased by 14% on average over the bid amount. Thus, both contract types are performing at similar levels. Only 9% of DB projects met or exceeded the bid amount and only 36% were completed on time.

### 4.2 Construction Payout Curves for Completed Mega Projects

The research team used actual construction expenditure data (from let date to project completion) for the 7 DBB and 11 DB completed projects (>99% complete) studied. In order to normalize the data, we use % time (the actual project duration at a given point in time, divided by the duration established in the initial contract) and % cost (the actual monthly expenditure at a given point in time, divided by the total project contract budget established in the initial contract) on the vertical and horizontal grid axes. To illustrate, the payout curves for 5 DBB "New Location" projects are demonstrated in Figure 1. It is worth noting that the initial payout slope was steeper for DBB projects than it was for DB projects.

## 4.3 Timeframe of Payout Curve Development

Figure 1 shows a timeframe for predicting the construction payout for 5 completed DBB new location projects, reflecting the life cycle of the projects from inception to substantial completion. This figure also displays the preconstruction phase strategic milestones that, if met, improve the likelihood of meeting the scheduled let date; alternatively, missing any of these milestones may result in a negative impact on the project schedule.

Figure 1 also shows payout curves for five different DBB new location projects. These projects assume an initial schedule and cost factor of 1.0 (i.e., final cost and duration equal the original bid cost and duration). As can be seen, two of the projects finished with cost factors below 1.0 (Projects 3 and 4), while two of the projects exceeded 1.0 (Projects 1 and 5). In fact, Projects 1 and 5 both had cost factors greater than 10% of the original bid amount.

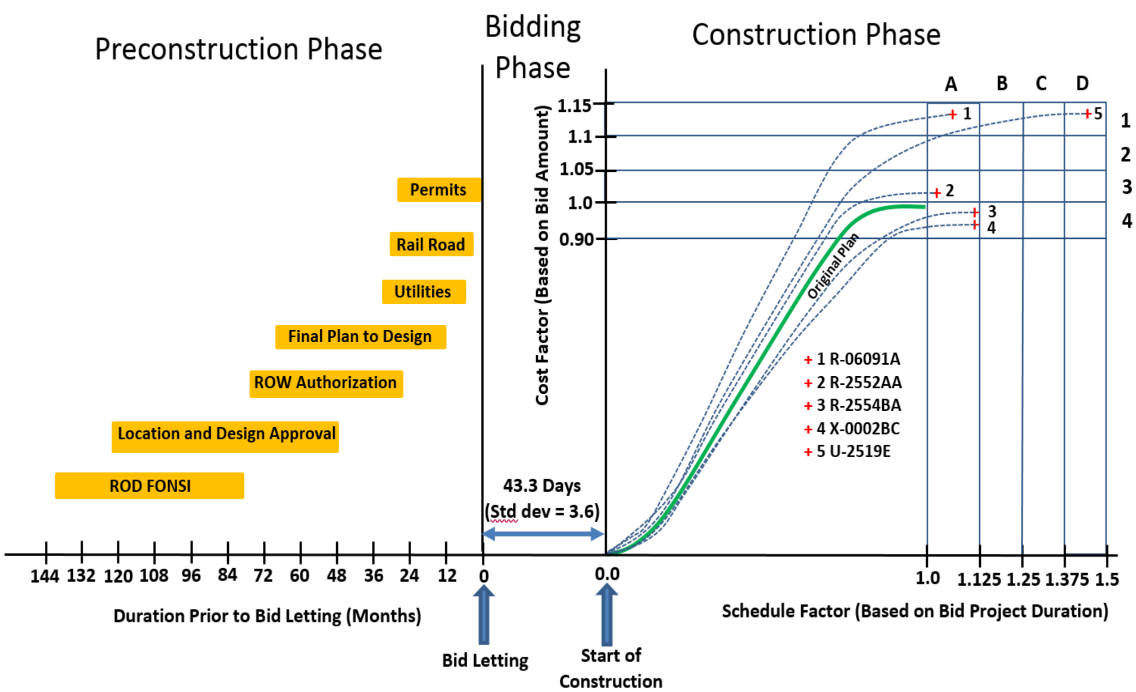


Figure 1: Time Frame of Payout Curve Development for 5 Design Bid Build "New Location" Projects

To understand the cost and schedule variability, figure 1 demonstrates in greater detail how the payout curve changed over time. For instance, project 5 (U-2519E) began on July 7, 2009, with a cost and schedule factor of 1.0 (as shown in the lower left corner of quadrant A-3). The bid amount was $52,553,157.52 with a 1,099-day duration. Within the first month of the project, the estimated cost was reduced compared to the bid amount, and thus, the cost factor went below 1.0 (see quadrant A-4 on August 8, 2009). An approximate $7.8 million supplemental was approved on February 8, 2011, increasing the schedule by 183 days and causing another payout curve change (from quadrant A-4 to B-1). Later, a new claim was filed, granting the contractor an additional 270 days to complete the project, again changing the shape of the payout curve (refer to quadrant D-1).

What we learn from this is that maximum value rests in the information they convey regarding cost and duration at the end of a project. While this information truly is quite valuable few differences in the curves are evident prior to the end of the project, thus limiting their utility in tracking performance.

In the section below on corrective action during construction, we suggest an alternative performance tracking approach (to S-curves) whose aim is to identify cost and schedule deviations quickly.

### 4.4 Predictive Models

Typical transportation infrastructure cost estimation includes six stages: 1) conceptual estimate, 2) feasibility estimate, 3) functional design estimate, 4) preliminary estimate, 5) Right of Way estimate, and 6) final estimate. Overall project estimation accuracy increases over each phase (beginning with a 45-55% range of uncertainty for the conceptual estimate, reduced to only 5-10% for the final estimate) as design details are further developed and more information becomes known to the engineers. The ranges of uncertainty for each estimate are reflected in the Miscellaneous and Mobilization factor (M&B) in their total cost. Adding the M&B cost to the total itemized cost yields the contract cost. The total construction cost includes the contract cost and other costs, such as those for engineering inspections and contingency. Linking construction costs to the schedule yields the predicted payout curve.

At the time construction begins, the contractor provides the transportation agency with an estimated payout curve for the entire project. This payout curve identifies the total estimated project cost and duration as well as the varying monthly payout amounts. However, only the total cost and duration, not the monthly estimates, are currently used by NCDOT to create the estimated average payout curve.

We suggest that NCDOT's average monthly payout can be used to identify serious project cost deviations (and their causes) and that this can be exceedingly valuable. Such deviations will eventually result in project disruption. Thus, it is important to quickly recognize deviations and initiate corrective actions to bring the project back to schedule and budget to reset completion targets that are now deviating from planned targets. Cash flow is an important indicator of not meeting a key milestone (spending) and cash flow is one additional and critical diagnostic metric.

### 4.5 Macro Approach: Develop Statistical Models Using Data from Past Projects

The macro approach utilizes statistical models of past payout data to generate a payout curve to predict future payouts. There are different factors that influence the shape of the payout curve, including type (rural widening, rural new location, bridge, interstate); location (mountain, Piedmont, coastal); seasonality (spring, summer, fall, winter); bid amount; and duration. Developing a standardized curve for each type of project requires understanding the characteristics of each project and how they impact payout. For instance, in bridge projects, some agencies compensate contractors for the superstructure only when it is complete. A surge payment thus occurs after the superstructure is delivered; therefore, it is critical to predict when that payment will take place in order to plan ahead for it.

The problem with the macro approach is that the tremendous magnitude of mega projects makes each one different in some significant way. They cannot be compared to each other or used as a model of a future project because of differences in both the magnitude of the variables used to assess them, in the set of variables themselves, and in the small numbers of such projects. Valid comparisons cannot be made for this tremendously small and distinctly unique set of projects.

### 4.6 Micro Approach: Build the Project Payout Curve Based on Anticipated Construction Activities

The micro approach generates the project cost and schedule from the bottom up, allowing for a more customizable payout curve for an individual project. The micro approach model creates a Gantt chart based on activity sequence, productivity, quantity, and cost estimates for each activity, and generates a monthly project payout curve. Especially on large-scale projects, it is essential that contractors create a detailed schedule and perform a detailed cost analysis. This process results in the estimated payout curve provided at the beginning of construction. During the course of construction, many events occur to change the schedule and expenditures. When this occurs, new estimates are generated for any desired time period that take these changes into account. For a mega project, quarterly payout curves developed by the contractor are the most accurate and available source of past and future cost estimates.

Table 1 compares actual and estimated monthly expenditures from May 2014 through May 2015 for project R-2237C. We also compared actual and estimated total expenditures and found percentage differences that are mostly at or less than 4%. However, Table 1 shows significant differences between monthly estimates and actual monthly expenditures. In May 2014, monthly actual costs exceeded estimates by a factor of about 1.6; In June, 2.4; in January 2015, 150, clearly an anomaly. In other cases (August 2014, September 2014, March 2015, and April and May 2015) the factor was between 0.5 and 0.7, meaning that the estimate exceeded the actual cost by a factor of about 2.

### 4.7 Corrective Action During Construction

We reviewed in detail four major highway projects that had significantly exceeded their planned duration at award to assess these four projects with respect to their payout curves. The four projects were: R-2237C – US 321 in Caldwell and Watauga Counties, U-3326A – US 29 in Rockingham County, U-3810 – NC 24 in Onslow County, and R-2519A – US 19 in Yancey County. These were not typical projects and they did not follow the usual course of construction as is to be expected for mega projects. Because delays on these projects significantly affected total construction expenditures in State FY 2017, these projects were evaluated in an attempt to determine whether or not the delays, and their impact on subsequent expenditures, could have been predicted (earlier) on the basis of data that was available during construction at the time the delays began. We will present one of these projects here and summarize all of them.

R-2237C is a major highway project in western NC on US 321. The contract was awarded in November of 2011 at a cost of $66,438,147.43 for a projected duration of 46 months. Utility conflicts began to occur on this project in November 2013 resulting in a total of 226 delay days. The contractor defaulted on March 12, 2014. Additional work at various times on the project resulted in a total of 406 additional work days. These events, and the actual monthly payouts for this project, compared with a forecast of constant payouts over the expected project duration, are shown in Figure 2. The second and third quarters of this project indicated some initial cost payout deviations, effectively identifying the presence of a problem. The utility problems and the default were clearly evident by April of 2014. It took an additional year to April of 2015 for the project to return to an expected payout rate.

Table 1: Comparison of Actual and Estimated Monthly Expenditures for R-2237C

| Month | Actual | Estimated | % Difference |
|---|---|---|---|
| **04/30/2014 Quarterly Update** | | | |
| May-14 | $1,199,292.52 | $742,130.97 | 38.12 |
| Jun-14 | $1,829,991.42 | $749,273.89 | 59.06 |
| Jul-14 | $1,355,169.10 | $811,713.38 | 40.10 |
| **06/15/2014 Quarterly Update** | | | |
| Jun-14 | $1,829,991.42 | $747,920.63 | 59.13 |
| Jul-14 | $1,355,169.10 | $811,713.38 | 40.10 |
| Aug-14 | $1,700,897.33 | $2,310,261.17 | -35.83 |
| Sep-14 | $1,555,884.29 | $2,310,261.17 | -48.49 |
| **09/30/2014 Quarterly Update** | | | |
| Oct-14 | $5,378,896.47 | $3,059,995.14 | 43.11 |
| Nov-14 | $3,173,833.56 | $1,935,624.22 | 39.01 |
| Dec-14 | $1,759,795.18 | $1,248,789.82 | 29.04 |
| **12/31/2014 Quarterly Update** | | | |
| Jan-15 | $956,830.12 | $62,439.49 | 93.47 |
| Feb-15 | $93,924.13 | $62,439.49 | 33.52 |
| Mar-15 | $326,638.53 | $624,394.91 | -91.16 |
| **03/31/2015 Quarterly Update** | | | |
| Apr-15 | $977,327.13 | $1,748,305.75 | -78.89 |
| May-15 | $995,923.46 | $2,060,503.20 | -106.89 |

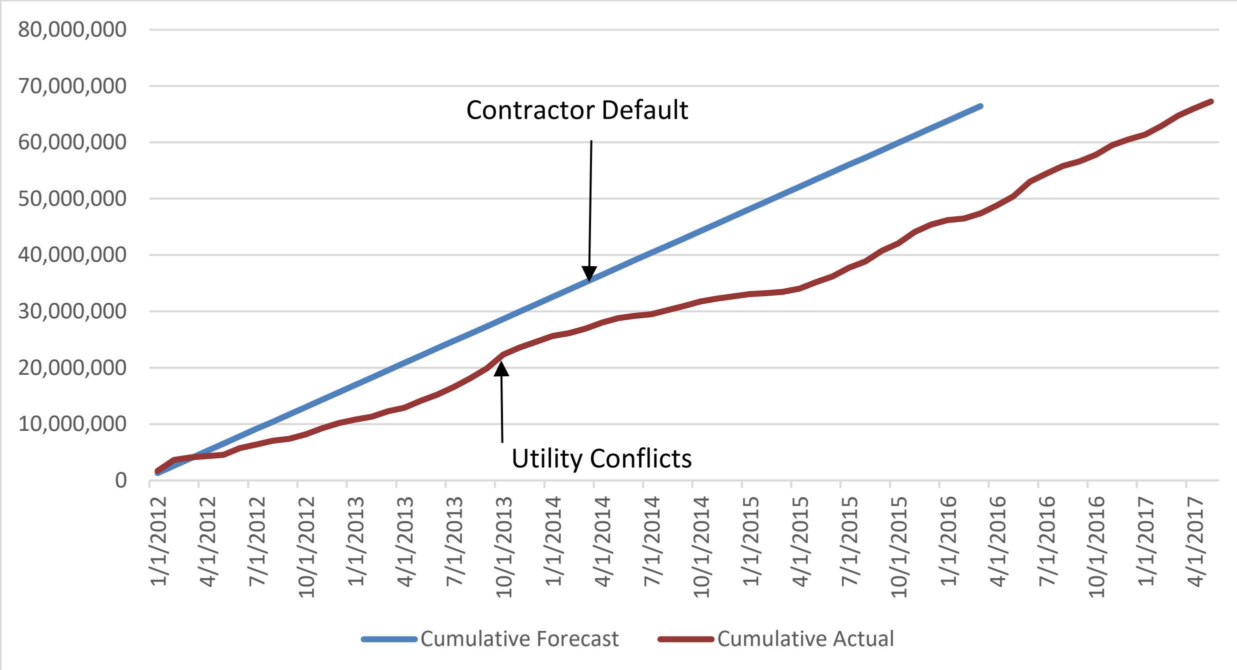


Figure 2: R-2237C Payout Curve.

Table 2 displays a summary of the construction delays for the four case studies and their effect on the duration of these projects. Based on analysis of these construction projects, the following findings emerge:

- Utility conflicts can, and do, account for significant delays in the completion of large highway construction projects and can represent the greatest project uncertainty.
- A uniformly constant payout rate over the expected duration of a project, while not precisely indicative of actual expenditures, does provide a benchmark to determine how well a project is progressing toward completion.
- Regardless of the cause, significant construction problems that can delay the project completion may be reflected in the construction expenditures.
- The ratio of actual expenditures to the expected payouts for a project may provide a reasonable indicator of whether or not a project will be completed on time.
- Detailed communication between the contractor, managers, and forecasters is critical for addressing delays that occur during the lifecycle of a highway project. This communication can and should flow in both directions so that issues which may first appear in payout data can be communicated to project managers and contractors (and vice versa) and remedial actions can be initiated immediately.
- All of these projects had an urban widening component which may indicate a heightened risk of delay for various reasons on this type of project.

Table 2: Construction Data for Four Recently Completed Projects

| Project ID | Project Cost | Let Date | Duration (Days) | Delay Cause | Delay (Days) | Begin Delay |
|---|---|---|---|---|---|---|
| R-2237C | $66,438,148 | 11/15/2011 | 1369 | Utility Conflict | 236 | 11/21/2013 |
| | | | | Contractor Default | | 3/12/2014 |
| | | | | Additional Work | 406 | Various |
| U-3326A | $50,749,005 | 1/17/2012 | 1344 | Utility Conflict | 270 | 5/25/2012 |
| U-3810 | $50,543,692 | 9/18/2012 | 1279 | Utility Conflict | 176 | 3/31/2013 |
| | | | | Additional Work | 87 | Various |
| R-2519A | $41,527,280 | 5/17/2011 | 1466 | Right of Way Issue | 330 | 7/31/2011 |

## 5 SUMMARY AND CONCLUSIONS

This research has made a significant contribution to the development of a set of model design concepts to better estimate project payout curves during construction. Based on a study of payout curve patterns of completed DBB mega projects, the research team evaluated macro and micro model designs for the preconstruction phase and a new and distinctly different model design (uniquely suited to mega projects) for the construction phase.

The macro approach addresses the time prior to the start of construction and proposes to create statistical models using cumulative construction payout data from past projects and adjusted models to estimate payout curves for new projects. Unfortunately, the research team found this approach to be unhelpful. The variability in, and uniqueness of, these mega projects is so diverse that their payout rates are unique, highly variable, and unpredictable.

The micro approach builds a project payout curve based on the anticipated construction activities, the associated unit costs, estimated durations, the construction sequence, and productivity data. This approach was found to be a better predictor than the macro approach. However, it is an approach that provides only the initial project payout estimate. Its value can decrease as the project gets underway, time passes, project characteristics change, and problems arise.

The macro approach was found not to be project specific enough to be a good predictor for the limited number of projects we had available to study. The micro approach was found to be highly detailed, costly to the department, and a duplication of the contractor’s more precise and detailed cost and schedule estimates.

Finally, the Model for the Construction Phase addresses the time between the start and end of construction and recommends the use of the contractor’s estimated construction expenditure forecasts at the beginning of every quarter of a project’s schedule as a basis for payout curve estimation for the construction phase. It regularly tracks progress in a timely manner and uses expenditures to identify potential problems, thus drawing attention to them for possible solutions. It is ideally suited to state transportation agencies that are set up to track money and expenditures but who may not have the resources to track the actual work of projects of this magnitude.

The most important lesson learned in this study is not that the payoff amount for any one month must be highly accurate, but rather, that monthly differences between expected and actual expenditures are indicators of project problems. The earlier these problems are discovered the more time there is to proactively expedite the project and meet the schedule and budget. Payout is thus an excellent tool for transportation departments and contractors to use to do so.

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