Effective Production Rate Estimation and Activity Sequencing Logics Using Daily Work Report Data

by

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PROBLEM STATEMENT

Contract time for state highway projects is the maximum time allowed in the contract for completion of all work contained in the contract documents (FHWA 2002). An accurate forecast of contract time is crucial to contract administration as the predicted duration and associated cost form a basis for budgeting, planning, monitoring and even litigation purposes. Excessive contract time is costly because it extends the construction crew's exposure to traffic, prolongs the inconvenience to the public (unnecessary increase of road user costs), and subjects motorists to less than desirable safety conditions for longer periods of time. Insufficient contract time results in higher bids, overrun of contract time, increased claims, substandard performance, and safety issues. Due to significant importance of contract time determination, Title 23 Code of Federal regulations (CFR) Section 635.121 requires that States should have adequate written procedures for the determination of contract time, and most state DOTs including MDT have a written document describing their procedure to determine a project's contract time.

Accurate and reliable contract time determination is highly dependent upon two major issues; a) production rate estimation of major work items, and b) sequencing of those work items. The MDT manual on contract time determination provides the list of major work items and corresponding production rates (MDT 2008). The production rates were determined from various sources but were mainly based on previous experience and judgement of MDT engineers. The manual further recommends that the production rates must be revised every two years. However, the current production rates are at least eight years old. Additionally, the manual states that factors such as type of construction, bad weather delays, complexity, cost, traffic volumes, length, etc. can also affect production rates. However, the manual does not clearly provide a structured procedure on how to quantify the effects of those factors on production rates. Instead, it simply recommends the use of engineering judgement for production rate adjustment.

MDT currently uses the AASHTOWare – SiteManager that includes daily work reports for more than 700 completed projects. The daily work reports include various project characteristics information, daily quantity of work accomplished for each work item, start and end date of each work item, labor and equipment usage information, weather, etc. This rich data set can be used to estimate realistic production rates of major work items. Also, this digital data set can be used to identify the actual sequence of work items (activities). MDT is transitioning from SiteManager to a web based AASHTOware Project Construction and Materials. The digital data required for production rate estimation in the new web-based system will still be accessible and available.

The proposed project will apply powerful data analytics to the historical daily work reports and develop a) a Montana specific production rate estimation system and b) construction activity sequencing logics for different types of projects. These new tools are expected to significantly improve the accuracy and reliability of contract time determination. This project will not only allow MDT to be equipped with two powerful data driven tools to enhance the current contract time determination procedure but also allow MDT to be one of the leading state DOTs to provide a benchmarking example that other DOTs can follow. The results of this project will be immediately available and used by MDT schedulers, resident engineers and contractors.

BACKGROUND SUMMARY

A production rate is a quantity of production accomplished over a specific period of time and realistic production rates are the key to determining reasonable contract times (Herbsman and Ellis, 1995). The production rates of major construction activities play also an important role in the planning of resources, and tracking project progress as these activities typically fall in the critical path of the project schedule (Woldesenbet et al. 2011). Thus, the accuracy of the estimated production rates is very crucial for effective contract administration. However, most DOTs use a rule of thumb and/or a published list of production rates that were developed years ago. Since highway construction is an outdoor construction operation that involves various types of activities that are heavily affected by a number of operational and environmental conditions, common production rate estimation methods such as expert opinion, engineering judgement, and production rate charts have serious limitations. One of the main limitations is that unique project factors and site conditions are very difficult to be considered quantitatively (FHWA, 2002). Thus, those traditional methods may lead to an erratic production rate estimation, resulting in inaccurate contract time determination.

A production rate estimation and validation study conducted for Oklahoma DOT clearly shows that production rates vary widely depending upon project specific factors (Woldesenbet 2011). For example, Figures 1, 2, and 3 illustrate varying production rates of some of major work items under different project conditions including project location (Figure 1), Route Type (Figure 2), and seasonal effect (Figure 3). These results clearly demonstrate that DOTs need to have an advanced and consistent production rate estimation system in order to improve the accuracy of production rate estimates.

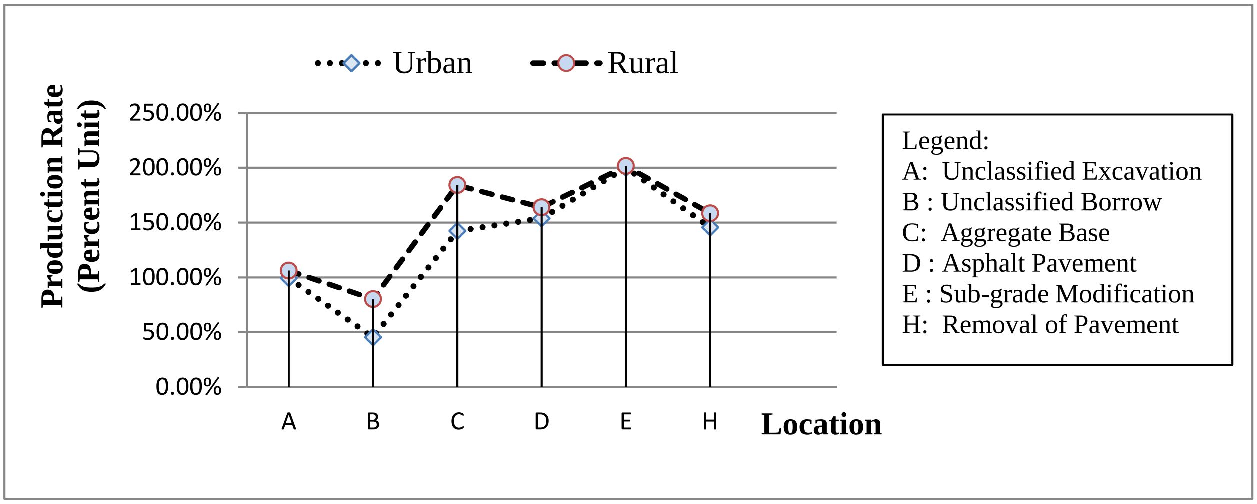

Figure 1 Effect of Location on Production Rate

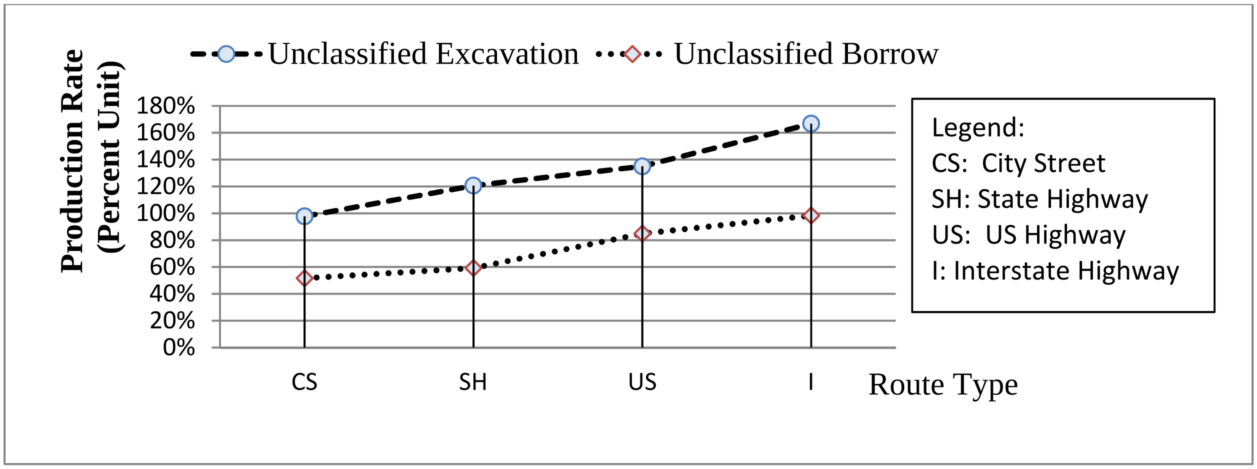

Figure 2 Effect of Route Type on Production Rate

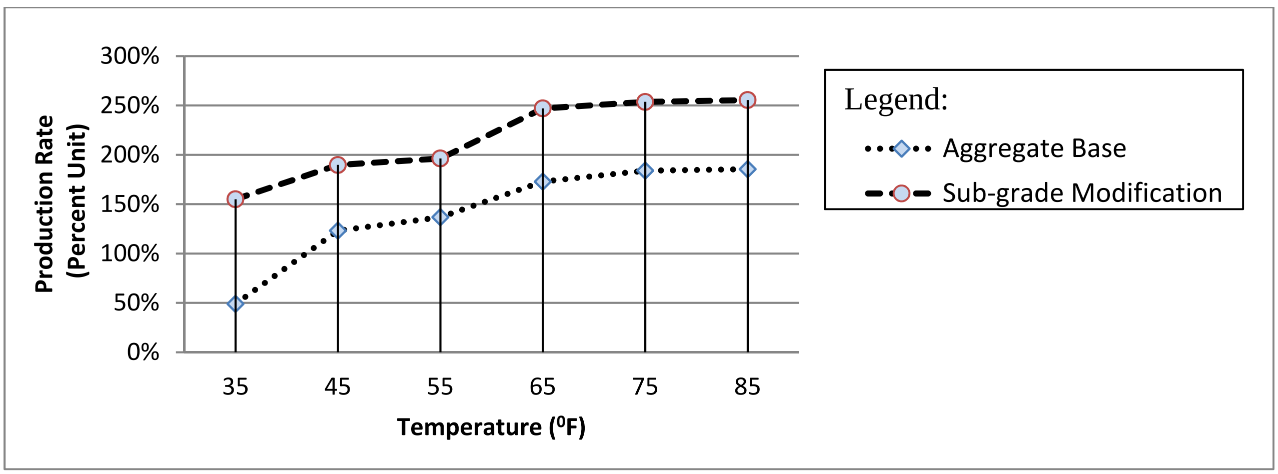

Figure 3 Effect of Temperature on Production Rate

There are several studies that identified significant factors and quantified0 the degree of impact of those factors on production rates. Table 1 shows a high level summary of the factors identified by different research teams. When those factors are appropriately incorporated into the production rate estimation process, the contract time determination process will be more accurate and become meaningful for contract administration.

Also, some state DOTs have invested in modernizing their production rate estimation procedures. For instance, state DOTs such as Texas DOT, Louisiana DOTD, Kentucky transportation cabinet (KYTC) and Oklahoma DOT have developed and utilized computer programs for determining production rates and contract times. Texas DOT developed a MS Excel based construction production rate information system (Chong et al. 2005). The system is based on actual production rates that were collected from site visits. This system is based on 14 different highway project templates and several factors such as geographic location, traffic conditions, and variance in quantity for adjusting the project duration and the contract time. The Louisiana DOTD has developed a computerized program that is similar to the computer system developed by Texas

DOT. They reported that a personal computer based system that used both templates for production rate analysis and a computer software package for development of a bar-chart schedule yielded more consistent and accurate contract times (McCrary et al. 1995). The KYTC has developed a system that uses Microsoft Excel to analyze controlling activities, and estimate their associated production rates, and uses Microsoft Project for generating a schedule for the project (Werkmeister et al. 2000). Six different types of highway project templates are used. The production rates for controlling construction activities were determined from a series of discussions with experts involved in the research project. Oklahoma DOT has also developed a production rate and contract time determination system which can reflect realistic production rates of key controlling activities when project parameters are available (Jeong et al. 2010). A unique feature of the Oklahoma DOT's system is that once production rates for major work items are estimated and quantity information for each work item is entered, the program can automatically generate a MS project based bar chart schedule for the scheduler's review, adjustment, and finalization.

Table 1 Summary of Critical Factors Identified from Prior Studies

Factors	Jiang & Wu (2007)	Chang (2005)	O'Connor & Huh (2005)	Smith (1999)	Chao & Skibniewski (1994)	AbouRizk & Colleagues (2001)	Pan (2005)	Christian & Hachey (1992)	El-Rayes & Moselhi (2001)
a. Location	X	X			X	X			
b. Capacity of Contractors	X								
c. Weather	X			X	X	X	X	X	
d. Traffic Condition		X							X
e. Soil Type		X		X	X	X	X	X	
f. Quantity & Size of Work		X	X						
g. Operating Condition				X	X	X			
h. Material Delivery									X
i. Hauling Constraints									X
j. Construction Methods								X	X
Type of Construction	Pavement Bridge	Pavement Earthwork	Bridge	Earthwork	Earthwork	Pipe Installation	Pavement Earthwork	Pavement Earthwork	Removal

However, many other DOTs including MDT still use a manual method for calculating production rates and contract times. Florida DOT uses a preformatted form that can be completed by hand. An experience engineer fills out the form by identifying major activities and determining production rates of those activities. A bar chart diagram is drawn to calculate the project duration and a conversion factor is used to convert workdays to calendar days in order to obtain the contract time. Indiana DOT also uses a step-by-step process in which a hand-written form is used to establish contract times. MDT has a chart of average production rates for 28 work activities under 9 work categories and has a worksheet to develop a contract time.

FHWA (2002) recommends that in estimating production rates of work items, an accurate database should be established by using normal historical rates of efficient contractors. It further states that the most accurate data can be obtained from site visits and/or review of project records (i.e., field diaries and other construction documents) where the contractor's progress is clearly documented based on work effort, including work crew makeup during a particular time frame.

For most DOTs, data collection from site visits may not be a financially feasible solution because the data should be collected from a significant number of projects across the state and also, the data should be updated every two to three years to meet FHWA's recommendations. An excellent alternative approach is to use a well-organized dataset of completed highway projects, where a project's progress is clearly documented. Daily work reports which are part of AASHTOWare-SiteManager include a variety of project related data. Daily performance at the work item level is recorded by inspectors. The daily work reports contain information about project characteristics, the entire list of work items, daily quantity of work accomplished for each work item, start and end date of each work item, labor and equipment usage information, weather, significant communications with contractors, etc. This digital data set provides very rich and useful data appropriate for production rate estimation. Also, this data set can be used to identify the actual sequence of major activities as it contains information about the start and end dates of each work item.

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BENEFITS AND BUSINESS CASE

The study is expected to significantly improve the MDT's current contract time determination procedures and the progress monitoring of major construction activities during construction. Two major research products from this project are an MS Excel based production rate estimation tool for major construction work activities and construction activity sequence logics for different types of highway projects. These products will a) provide a basis for better planning of resources for highway projects, b) provide data driven and verifiable documentation for a stronger defense in contract time disputes, and c) allow less experienced personnel to gain confidence as they learn how to consistently estimate reasonable production rates and determine contract times. Successful implementation of the project outcomes will allow MDT to avoid unnecessarily lengthy duration of highway projects. So, it would minimize the construction crew's exposure to traffic and reduce the inconvenience to the public (unnecessary increase of road user costs). The research products will also allow MDT to avoid unreasonably short duration for highway projects which typically results in increased exposure of construction crews to safety hazards and substandard performance.

OBJECTIVES

The overall goal of this project is to enhance the MDT's current contract time determination procedures by developing a historical data driven production rate estimation system and construction activity sequence logics using data available in daily work reports (Figure 4).

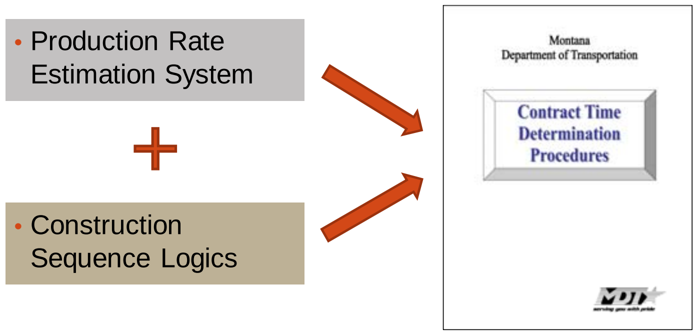

Figure 4. Research Goal

The specific objectives to accomplish this goal are listed below.

- Determine the current state-of-the-practice in estimating production rates and contract time determination, pinpointing MDT's gaps in the current knowledge base and practices.
- Develop a production rate estimation system.
- Develop construction activity sequence logics for different types of projects
- Integrate the two tools into MDT's contract time determination procedures

RESEARCH PLAN

Figure 5 shows the overall research plan and major deliverables from this research project. The research plan is divided into seven different work tasks. The specific descriptions of each task are provided in the following section.

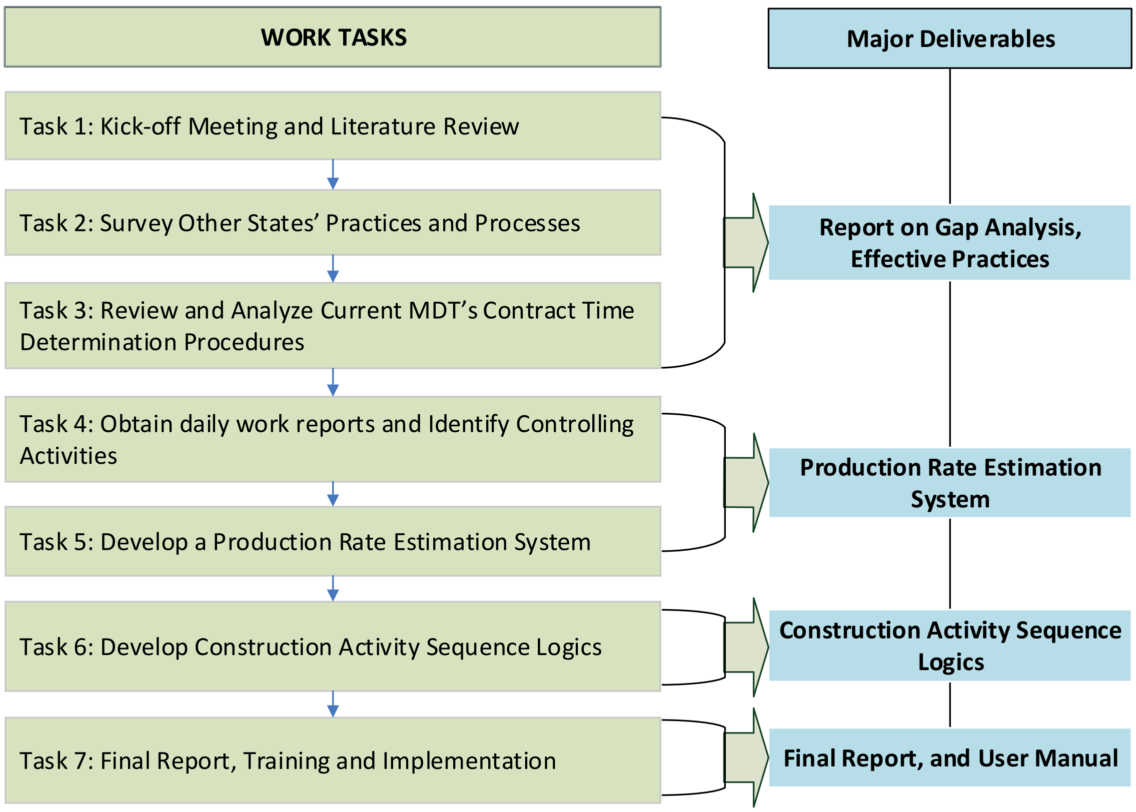

Figure 5 Overall Research Plan

Task 1: Kick-off Meeting, and Literature Review

The research will begin with a kick off meeting between the research team and the MDT technical panel members. This will give a clear understanding of expectations from the MDT as well as tasks to be completed by the research team. The research team will review and effectively synthesize the existing literature including government publications and manuals, conference and journal papers on a) production rate estimation methods and tools, b) sequencing of highway project activities, and c) contract time determination procedures.

Task 2: Survey Other DOTs' Practices

A quick review of some state DOT websites shows that some agencies have an established manual for contract time determination, in which a process of production rate calculation is described. After collecting some information about the procedures employed by different DOTs from literature review in task 1, a web-based questionnaire survey of DOTs will be conducted to identify and document current practices in production rate estimation, project activity logic calculation, and contract time determination. The survey results will be analyzed in a way to be beneficial for the MDT's contract administration services bureau. Effective and advanced methods and tools in terms of production rate estimation and contract time determination will be documented with follow-up interviews with survey participants and additional data collection from them. Those advanced methods and tools might be possibly adopted for this study.

Task 3: Review and Evaluate Current MDT's Production Rate Determination Process

The research team will comprehensively review and evaluate MDT's current practices in estimating production rates of major project activities that are used for contract time determination, and also, methods used for sequencing construction activities. The research team will communicate with the MDT personnel to get relevant documents. A structured interview guideline will be prepared and sent to the MDT personnel before an interview. The findings of Task 3 will be comparatively analyzed with the findings from Tasks 1 and 2 to clearly define the practice gaps for MDT's improvement and approaches to fill the gap. The conclusion of Task 3 will lead to developing the first deliverable of this project- a report on Gap Analysis and Effective Practices. A draft report will be submitted to the technical panel for their review. Any comments from the panel will be fully incorporated into finalizing the report for the panel's approval.

Task 4: Obtain Daily Work Reports and Identify Controlling Activities

In this task, the research team will obtain the entire data set of historical daily work reports of highway projects. The obtained data will be cleaned and organized for production rate analysis. From our preliminary analysis with the data that we have obtained from Lisa Durbin (Bureau Chief, Construction administration services), we were able to identify at least the following factors; weather, quantity of work accomplished per working day, contractor information (Vendor ID), number of workers and total labor hours, total hours for each type of equipment used. This dataset will allow the research team to develop a historical data driven production estimation system. If necessary, the research team will work with the panel to obtain additional project data such as soil data, exact project location data, etc. that may be used to more accurately estimate production rates.

The research team will discuss with the technical panel to identify controlling activities that are likely to be on the critical path of a highway project. Each highway project consists of various construction operations and each operation can be further broken down into a number of activities. Among all the activities required for a project, many of them can proceed concurrently. For example, landscaping and erosion control can be done when pavement construction is being performed. But there are certain activities that are constrained to a given sequence, for example, reinforcement steel and formwork must be in place before concrete is poured. Even for the same type of projects, the critical path and critical activities may change as quantities for project activities and site conditions are different. Those activities that have possibilities to be on the critical path can be called "controlling activities" (Jeong et al. (2009), and Hancher et al. (1992)). Figure 6 shows the concept of controlling activities.

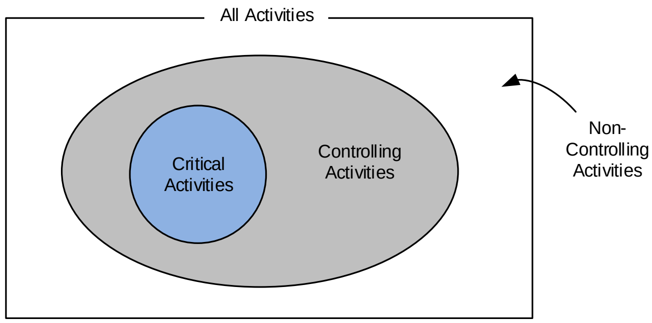

Figure 6. Concept of Controlling Activities (Jeong et al. 2009)

These controlling activities for different types of projects will be identified from discussions with the technical panel. MDT classifies highway project types into 40 categories. This research will focus on controlling activities for work types under construction, resurfacing, and bridges, which are considered to be the most common work types delivered by MDT.

Task 5: Develop a Production Rate Estimation System

Using the historical daily work report data, the research team will develop a production rate estimation model for each controlling activity. For controlling activities that have a significant number of data for statistical analysis, a statistical model will be developed. For other controlling activities, an estimation model based on engineer's judgment from interviews and surveys can be developed. There are several factors that may affect the production rate of a controlling activity. Different controlling activities may have different factors and their degrees of impact will be different. The effects of project location, project type, work quantity, work season, and others will be quantitatively evaluated using the historical data and will be incorporated into the estimation system.

The research team envisions that a Microsoft Excel based software program will be developed for MDT to estimate reasonably accurate production rates. In this program, a user can select a controlling activity under consideration and select possible influential factors, then the program will determine the range of the production rate for the activity (Figure 7). The completion of this task will lead to the second major deliverable of this project, a production rate estimation software program.

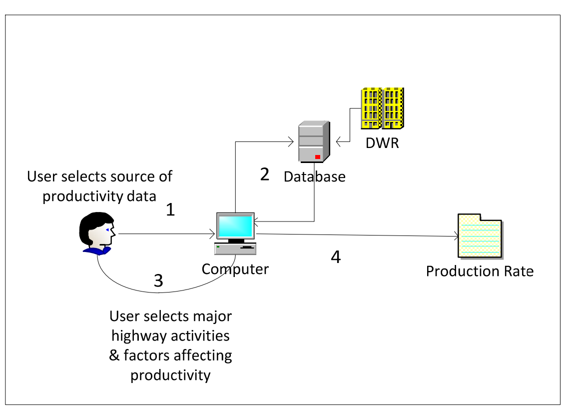

Figure 7 Production Rate Estimation System

Task 6: Develop Construction Activity Sequence Logics

In this task, the historical daily work report data will first be used to develop as-built schedules. Projects of the same work type have high similarities in terms of activity sequencing. For example, a pavement rehabilitation project begins with traffic control activities followed by demolition of existing pavement, and construction of new pavement. Activity start and finish data of previous projects are available in daily work reports. These data will be used to identify the pattern and sequence of controlling activities for each project type. The available data attributes from MDT's daily work report software (AASHTOWare SiteManager) include universal project number (UPN), project type, activity code, mile post and/or coordinates of the activities, the labor and equipment resources used, controlling activity indicator, and the amount of work done. The controlling activities and long duration activities will be the focus of the study while short and less important activities will be removed from the database to facilitate the analysis. The data will be analyzed and transformed programmatically to develop visual as-built schedules. A programming language such as Visual C# can be used to automatically arrange the activity-date data for a particular project. This data will then be exported to a scheduling program such as Primavera and MS Project to develop a visual as-built schedule representing the actual sequences of activities conducted (Figure 8).

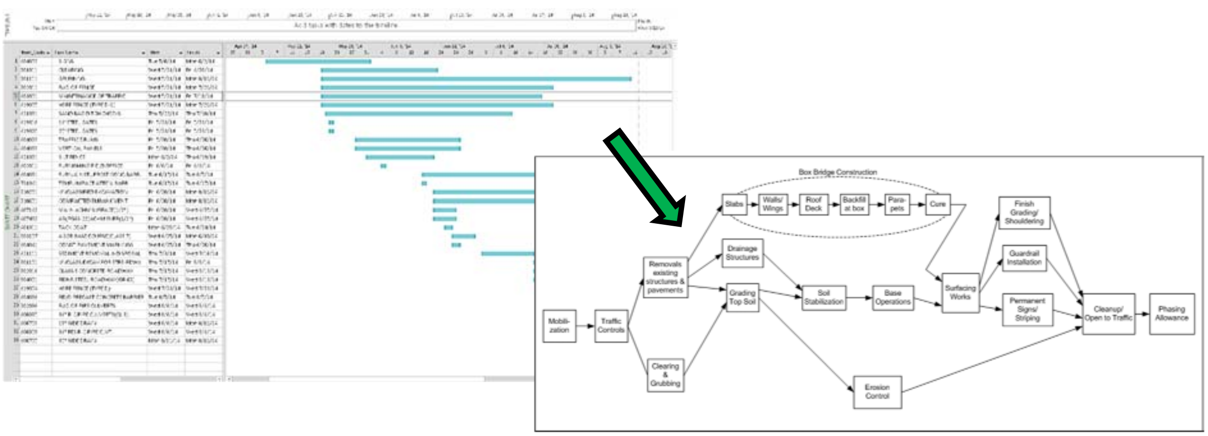

Figure 8 As-built Schedule and Construction Sequence Logics

The activity data will be analyzed further using Sequential Pattern Mining (SPM) algorithms to generate the frequent sequences of the activities. The SPM algorithms deal with data represented as sequences and can identify the hidden sequences which can be used to predict the sequences for additional datasets (Masseglia, Teisseire, and Poncelet 2009). The SPM algorithms have been effectively used for DNA sequencing, medical treatment, web access pattern, and stock market (Masseglia et al. 2009; Li et al. 2005; Wang 2005).

Input will also be sought from experienced MDT schedulers and inspectors to identify common construction sequences. The results from the experience of MDT staff will be used along with the findings from the as-built schedules to develop construction activity sequence logics for different types of projects (Figure 8). The results from this task along with the outputs from task 5 can be integrated to generate a template based scheduling system that will significantly help MDT determine a more defensible contract duration with confidence. The output of this task will be construction activity sequence logic diagrams for different types of projects.

Task 7: Training and Implementation

This is the final task of the study. In this task, a workshop style training session will be provided to the MDT personnel for rapid dissemination of the research findings. A step-by-step process will be described using visual examples to explain how new daily work reports data can be added to the database to update the production rates. A user manual for the production rate estimation system and the construction activity sequence logics will be developed and used for training MDT staff. The final report that encompasses all task results, findings, and products will be prepared for the panel's review and approval.

MDT INVOLVEMENT

The proposed study will require involvement of MDT personnel and resources. The research team will need assistance from MDT personnel who have knowledge in the current practices of production rate estimation and contraction time determination. The research team will also need feedback from the technical panel members on a questionnaire that will be developed for a nationwide survey in Task 2. MDT personnel will also need to review the list of the contacts that will be surveyed for the study. The research team may need to interview highly experienced resident engineers and inspectors who have years of field experience and understand the sequences of construction activities and various constraints that may change the common sequence of activities. In addition, the MDT personnel are expected to be available for meetings regarding research tasks and issues identified during the research. The MDT's historical daily work reports will be required for this study as well.

PRODUCTS

Research products to be developed from this research include:

- Report on gap analysis and effective practices on production rate estimation and contract time determination
- MS Excel based tool to estimate production rates
- Construction activity sequence logics
- Meeting notes
- Quarterly progress reports
- Task reports
- Final presentation
- Final report
- Final report cover image
- Project summary report
- Implementation meeting and report
- Onsite training for MDT staff involved with production rate calculation and contract time determination

All products will be prepared using the latest MDT guidelines and requirements to meet MDT quality standards. The Institute for Transportation (InTrans) at ISU has a full time technical writing and publications staff. All products will be reviewed and edited by the technical writer at Institute of Transportation (Intrans) to ensure professional quality.

IMPLEMENTATION

The Construction administration services bureau will be responsible for implementation of the research results. The implementation plan for the project is as follows:

- On-site workshop style training for MDT staff in Task 7
- Train other potential users of the research products by the construction administration services bureau or by the research team – month 2
- Performance evaluation of the research products by the construction administration services bureau – month 5
- Update the products as required by the construction administration services bureau or by the research team– month 7
- Implement the products state-wide by the construction administration services bureau – Month 8

The implementation of the research products is expected to modernize the process of determining contract times of highway projects. A workshop style training will be provided in Task 7 as part of this project. Any additional training costs are not currently budgeted in this proposal.

SCHEDULE

The technical panel wanted to consider two project execution options before the final funding decision on this project is made; Option A with full execution of all work tasks and Option B with execution of all tasks except Task 6. Thus, two different schedules are developed for the two options. The project is expected to start in January 2017. Major milestones are included in the proposed schedule. Table 2 shows the schedule for Option A with the total duration of 24 months. Table 3 shows the schedule for Option B with the total duration of 20 months.

Table 2: Project Schedule (Option A)

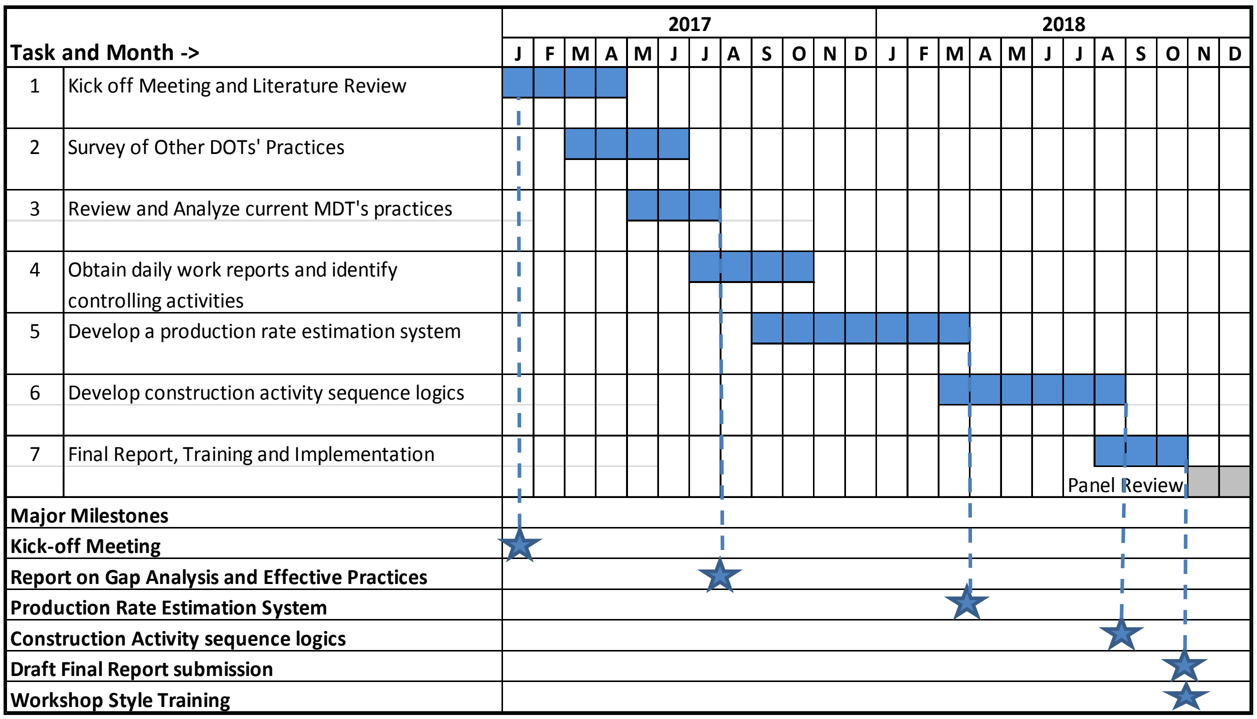

Table 3: Project Schedule (Option B)

Task and Month ->		2017												2018							
		J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
1	Kick off Meeting and Literature Review	■	■	■	■																
2	Survey of Other DOTs' Practices			■	■	■	■														
3	Review and Analyze current MDT's practices					■	■	■													
4	Obtain daily work reports and identify controlling activities							■	■	■	■										
5	Develop a production rate estimation system									■	■	■	■	■	■	■					
7	Final Report, Training and Implementation																■	■	■	Panel Review	Panel Review
Major Milestones																					
Kick-off Meeting		★																			
Report on Gap Analysis and Effective Practices								★													
Production Rate Estimation System																★					
Draft Final Report submission																			★		
Workshop Style Training																			★		

STAFFING

A highly qualified research team has been assembled for this research project. Both PIs have sufficient experience and knowledge in project scheduling, cost estimating, risk management, project delivery process and project management which are a required set of expertise for successful completion of the proposed project. Dr. David Jeong will be the PI for this project overseeing the entire progress of the project. Dr. Doug Gransberg will participate in this project as Co-PI and one PhD level graduate student from ISU's department of Civil, Construction, and Environmental Engineering will be hired throughout the project.

Dr. Jeong has conducted several research projects on the active use of construction data to support data-driven decisions. Most of his previous and current research projects are highly related to project scheduling, production rate estimation, project estimating, cost engineering, highway project management, infrastructure asset management and data analytics for project management. He has published more than 50 technical journal and conference papers in this area for the past 10 years. He also has 6 years of industry experience in bridge construction projects as project engineer and cost engineer. He has won the 2015 Construction Industry Institute (CII) distinguished professor of the year award, 2010 CII outstanding researcher of the year award. He is the recipient of the 2008 Institute of Industrial Engineers (IIE) Transactions Award for Best application paper in Operations Engineering. Several of Dr. Jeong's past funded research projects that are directly related to this work are listed below:

- Co-Principal Investigator, "Preconstruction Services Estimating Guidebook," 2013-2015, NCHRP Project 15-51,
- Principal Investigator, "Data and Information Integration Framework for Highway Project Decision Makings", Oklahoma Transportation Center, 2012-2013
- Principal Investigator, "Procedures and Models for Estimating Preconstruction Engineering Costs of Highway Projects", Oklahoma Transportation Center, 2010-2012
- Principal Investigator, "Development of Improved System for Contract Time Determination (Phase I, II, and III), Oklahoma Department of Transportation and Oklahoma Transportation Center, 2006, 2007, 2008-2010.

Dr. Doug Gransberg holds the Greenwood Endowed Chair in Construction Engineering at the ISU CCEE Department and brings over 20 years of research experience and 20 years of industry experience to the project. He has also served as PI/Co-PI on 58 funded research projects worth a total value of $14.0 million sponsored by National Cooperative Highway Research Program, the National Science Foundation (NSF), the Departments of Transportation in California, Minnesota, North Carolina, Oklahoma, Oregon, Texas, and Washington State, as well as, several privately funded research institutes. Several of Dr. Gransberg's past funded research projects that directly relate to this work are listed below:

- Principal Investigator, "Develop Parametric Cost Estimating System," 2010-2011, San Antonio Water System
- Co-Principal Investigator, "Project Management Strategies for Complex Projects," 2009-2014, SHRP2 Project R-10, Transportation Research Board.
- Principal Investigator, "Preconstruction Services Estimating Guidebook," 2013-2015, NCHRP Project 15-51,

- Co-Principal Investigator, "Quantification of Cost, Benefits and Risk Associated with Alternative Contracting Methods and Accelerated Performance Specifications," Federal Highway Administration, 2013-2015.
- Co-Principal Investigator, "Construction Manager General Contractor Risk Assessment," MnDOT Project 2010-077, 2010-2011

FACILITIES

The scope of work outlined in the Research Plan has very little equipment or facility needs associated with any of the tasks. For this research, the level of support services within the institutions will be more important than physical equipment and facilities, although ISU has exceptional facilities for high quality research.

The ISU research team is affiliated with the Institute for Transportation (InTrans). Resources at InTrans include access to staff specializing in publications work, computer facilities, student resources, and professional staff. InTrans is an ISU research institute administered by the Office of the Provost for Research and Advanced Studies.

The proximity of InTrans to the university campus and the state transportation agency offers tremendous opportunities to share resources and provides an integrated knowledge community environment. Resources at InTrans also allow researchers to maintain websites for information exchange and provide access to e-mail lists, conference programs, and training calendars for federal and state highway administrations. Such access will be critical in both gathering and disseminating information, including feedback on the research products and planning and delivering the research findings.

ISU also supports a world-class library with collections totaling more than 2.2 million volumes and close to 22,000 currently-received journals and serial publications. The Iowa Department of Transportation (Iowa DOT) maintains a synergistic working relationship with the university, providing programmatic support for InTrans, while InTrans conducts significant research and development work for the Iowa DOT. The Iowa DOT also manages an excellent transportation library with many specialty publications and access to TRIS, which InTrans students and staff use regularly.

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