Data Collection Methodology of Activity Production Rates for Contract Time Determination

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Abstract

Contract time determination for highway construction projects has never been easy despite considerable research efforts from academia as well as industry. High variations in crew production rates are considered one of the main barriers to accurate contract time determination. This paper presents a methodology for collecting field information on crew production rates which will help to enhance the accuracy of contract time determination for highway bridge construction. Based on a standard data collection tool developed, data on field crew production rates was collected from 14 on going projects in Texas, USA, over the past two years. The production rates based on the data collected were considered by industry practitioners to be more realistic and practical than those available to the current practices. As more data becomes available, key drivers influencing production rates could be identified and provide site personnel with a means to better plan and control production in a project specific context.

Keywords : Data Collection, Crew Production Rate, Time Determination

1. Introduction

Accuracy of construction contract time determination is becoming increasingly important, especially for highway projects. Public inconvenience and safety issues caused by unnecessary and even necessary extended projects are becoming increasingly intolerable to local communities. It is imperative to have a reliable database of crew production rates in order to conduct accurate construction time estimation. Factors driving the production rates are also important for time estimation. Their impacts must be systematically identified and understood by estimators for accurate estimation.

Information including production rates and quantified factors affecting them must be produced from highly accurate site observations in numerous projects. As different projects have different types of constraints and working conditions, a simple value that represents a production rate has little value in preparing accurate time estimation.

There is, however, little reliable uniform information that can be used widely and easily for the highway construction time estimation. Current construction time estimation is, to some extent, based primarily on the construction experts' experiences and best guesses without formal objective analysis (John Christian and Daniel Hachey, 1995).

Few researches have attempted to provide the industry with such reliable information. Many published papers in the field of productivity study focus heavily on project performance evaluation or cost control rather than time estimation. Furthermore, studies that deal with factors base mostly their data on history of completed projects or surveys and so their accuracy is somewhat questionable. The needs for improved information that will lead to accurate highway construction time estimation are evident.

The aim of this paper is to develop a methodology of collecting field information of crew production rates, which will help to advance the accuracy of contract time determination for highway bridge construction[1].

2. Methodology

Standard data collection methodology is carefully developed, as

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depicted in Figure 1. Each of the heading will be discussed, and demonstrated with research results conducted over two years in Texas, USA.

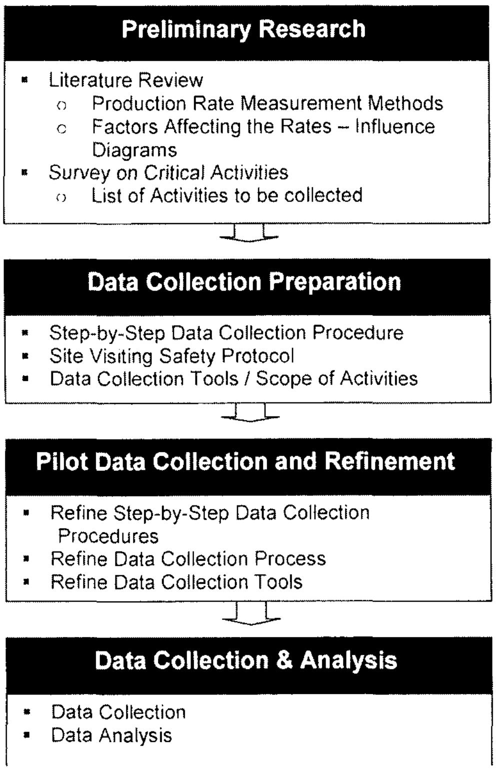

Figure 1. Data Collection Research Methodology

3. Preliminary Research

3.1 Literature Review

A study conducted in 1977 by the Construction Industry Cost Effectiveness (CICE) research project identified the needs for better productivity measurement approaches that can apply more specifically to the work at the task level. The same study also emphasized the importance of productivity measurement in determining trends and levels of productivity and evaluating corrective actions (Thomas et al. 1988).

Since then, many researchers have attempted to improve the project performance by looking at productivity. Diverse motivation theories and productivity evaluation methods in non-construction industries have been introduced in the attempt to improve labor productivity. 'Work Study' (Harris and McCaffer, 1989), 'Performance Factor' (Thomas et al. 1988), 'Foreman Delay Survey' (Tucker 1986; Tucker et al 1980, 1982), 'Work Sampling' (Thomas et al. 1982, 1983; Borcherding et al 1986; Kim Yea-Sang et al.1997) are examples of the efforts in the industry. Although the methodologies for evaluating and improving performance can be used to promote better construction practices in order to improve productivity (John and Daniel 1995), they have limited value to estimating construction time because those methods do not take into consideration completed output quantity necessary to calculate productivity or production rate.

Various models to predict labor performance using certain influencing factors have also been developed to improve project control and project performance. Contractors need to monitor and predict subcontractors' productivity in order to evaluate their manning levels and establish production goals. They are also interested in determining what factors affect productivity significantly (Thomas et al. 1988). Several models with different factors and data analysis methodologies have been proposed in the literature to predict productivity, such as 'Regression Model' (Thomas et al. 1986), 'Factor Model' (Thomas et al. 1990, 1994), 'Simulation Model' (Chao, L. C., and Skibniewski, M. J. 1993), 'Multiple Linear Regression Model' (Simon D. Smith, 1999) and 'Neural Network Mdel' (Jason Portas and Siman AbouRizk 1997, Ming Lu, S. M. AbouRizk, and Ulrich H. Hermann 2000). All those studies on the productivity prediction are more useful for construction time estimation than the studies on the performance evaluation since they provide numeric values of productivity that could be used for time determination.

There are, however, still several limitations that should be noted when applying the models or data for construction time determination. First of all, the majority of productivity measurement system and interpretation of the results focuses greatly on the cost control rather than time estimation. It is little surprising as Thomas[2] stated,

"Most widely publicized productivity measurement systems have emerged from the heavy industrial and power plant construction sectors of the industry, where productivity control has always been treated as a subset of the cost control system"

It must be clearly understood that the productivity figures intended for the cost control may be less appropriate for construction time estimation. The categories being used by CII, Construction Industry Institute, in USA for productivity measurement data collection will serve as a good example. The work-hours spent on direct accounts are summed to

1) In this Paper, project contract type is limited to 'Design-Bid-Build'

2) Thomas, H. R. and Donald F. Kramer, The Manual of Construction Productivity Measurement and Performance Evaluation, Source Document 35, pp 3, Construction Industry Institute, Austin, Texas, USA

compute productivity, including work hours of oilers, safety meetings, and truck drivers. Obviously, the work-hours to be used for the construction time determination should not include those, as long as they are conducted by different crews and simultaneously with direct installation of a work item, as is often the case with highway projects.

'RS Means Heavy Construction Cost Data', published by RS Means in USA and often referred as a source book for crew production rate in heavy construction, is also for primarily project cost and product selection. Adjustment factors provided in the book, namely 'Historical cost indexes', 'City Cost Indexes', 'Location Factors', are only for cost, not for daily output of crew production rates. Therefore, the non adjusted 30-city National average crew production rates developed based on building industry data is little useful for the time determination. Further the data is intended primarily for heavy construction public works, and large site development projects. Generally, the production rates do not apply to small site project (RS Means Cost Data, 2002).

Further limitation of using previous studies or published data for construction time determination is that many of the data used are less reliable because they were collected mostly from historical documentation or survey rather than observations.

3.2 Activity Selection

Preliminary research includes selection of target activities and information to be collected. In the early stage of research, understanding limited resources and research schedule, only activities that are most likely on the critical pass in construction stage are recommended. Survey a few of professionals should be effective enough, in particular for highway project as its construction has relatively simple Work Breakdown Structure (WBS), and easy to agree on what activities are most likely critical.

Based on a list of WBS and TxDOT standard specification, a total of 13 Work Items[3] were initially examined for the study. Survey forms were sent to 17 TxDOT personnel including the research committee members with 14 responding. From theses results, five of the work items were selected for the research, namely Footing, Column, Cap, Beam Erection, and Bridge Deck.

Preliminary research also involves identification of possible factors affecting production rates. In other words, what information should be collected must be studied thoroughly. Potential factors have to be preliminary identified based on intensive literature review and must be included in data collection. Then they are to be revised as preliminary data collection process is conducted based on observations, interviews with site personal and data reconciliation. Influence Diagram is found to be a strong tool to identify those.

4. Data Collection Preparation

Meticulous preparation needs to be made in order to establish a standardized data collection tool that will lead to solid database. As the data is to be collected by observation from multiple projects over a long period, it is essential to develop standardized tool in order to minimize or eliminate possible bias. The preparation includes developing step-by-step data collection procedures, site visiting safety protocols, and data collection tool.

4.1 Site Visiting Process

As data collection involves numerous site visits, data collection procedures need to be well organized for best results. A process of selecting and visiting a project as well as data collection is structured in cooperation with various requirements of organizations involved. Figure 2 illustrates the procedure developed and applied for the research.

When a target area[4] is selected, an area coordinator is contacted to arrange an area meeting for selection of projects. Randomly selected candidate projects from list available in TxDOT web site[5] are also proposed by the researcher in order to have appropriate area engineers in the meeting. The meeting is held typically in the area office and the following agenda is discussed. In particular, the importance of the research is emphasized in order to obtain full support from key personnel during entire data collection.

- Description of the research
- Data collection methodology including process and tool
- Safety protocol
- Proposed projects to be selected
- Selection of projects based on their schedules
- Contact points for the projects
- Brief visiting schedule
- Other issues for the improvement of the research

3) Work Item: "Part of the code of accounts used by TxDOT, Texas Department of Transportation, to describe a physical item of work or work task to be performed. Examples include Beam erection, Cap, Embankment etc." (Texas Standard Specifications, 1993)

4) An 'Area' is the regional sub-division of the Texas state, for the benefit of TxDOT's operation. TxDOT divides the state into 25 Districts and operates. A district consists of several 'Areas'.

5) http://www.dot.state.tx.us/business/cisreports.htm, (accessed in Oct. 2003)

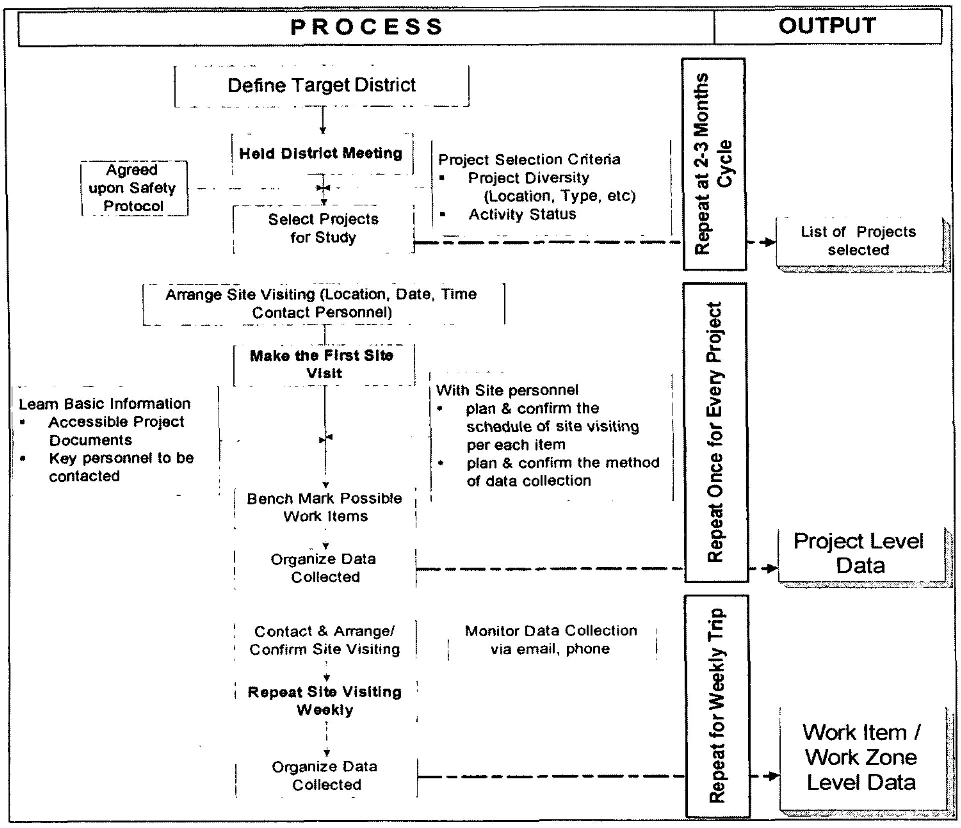

Figure 2. Site Visiting and Data Collection Process

Once target projects are selected, charged area engineers are contacted via email or phone to arrange a meeting with site inspectors and project managers. The presence of the area engineer in the meeting is encouraged. Besides the agenda of the district meeting, the following issues are discussed and collected.

- Project status
- Possible source of data including various project documentation
- Project level data collection
- Schedule over following two to three months
- Possible target work items
- Site organization structure and list of key personnel
- Site tour
- Benchmark targeted work activities

A site tour guided by the chief inspector and/or project manager was found to be crucial for the research. Introduction to superintendents and foremen with a brief explanation of the study by 'someone' in the project makes their attitude much different over the data collection period. During the tour, possible work items are also benchmarked.

Then, weekly site visits are conducted in order to collect production rate information with daily variations obtained from interviews with site personnel, who are mostly foremen. Foremen are likely to remember what happened in a great detail over the previous week. It is the main reason of conducting the site visits weekly. If the period becomes longer than a week, foremen tend to provide little reliable information. During the visit, various documents and plans are also referenced whenever they are available and reliable.

4.2 Safety protocol

Safety protocols for site visits are imperative for the safety of the researcher traveling within construction sites. Besides wearing a hard hat and steel-toed boots, many other aspects are listed and fully understood. In the every first meeting, safety protocol must be reviewed by site engineers to meet their specific aspects.

4.3 Data Collection Tool

Data collection tool has to be developed to guide the entire information collection process. This tool has basically to incorporate all the different factors affecting production rates and allows for new ones to be recorded. A guideline has also to be established to ensure the accuracy, efficiency and consistency of the data collection process. The format must be simple enough to be understood and to be completed. Terminologies to be selected with some degree of subjective judgment are scrupulously explained in the tool. The form of 'Production Rate Tracking; Work Zone and Work Item level (Cap)' used for the research is to be found in the Appendix A1-A3.

The tool is unique in several aspects. First of all it is the first comprehensive guide for measuring crew level production rates in highway construction. Second, its main purpose is to collect data that can realize the accurate construction time estimation. Third, the tool is developed from rigorous discussion with industry and academia, and then evolved as data collection progresses over more than six months. Every detail in the tool is modified and corrected to enhance future data collection.

The tool consists of three sets of production rate tracking forms; Project Level, Work Zone Level, and Work Item level. The Work Item Sheet is a part of Work Item Level tracking form, includes activity specific information to be collected.

'Production Rate Tracking; Project Level' is to collect the list of work items that can be possibly collected from a project as well as general characteristics of the project. The approximate total quantity of each work item is to be filed since it is likely to be an important parameter of production rate. The form needs to be completed only once in the first site meeting.

'Production Rate Tracking; Work Zone and Work Item level' consists of five pages including a 'Work item sheet' [6]. Detailed work zone is to be illustrated with brief yet precise explanation, which can be referenced for better understanding of the rate whenever it is necessary. The characteristics and technical details of the work, such as dimension, shape, and section, are also fully sketched and noted in one page. 'Tracking calendar' page contains crucial information for the analysis of the production rate. Work days and non-work days for the targeted work operation including various factors affected the works should be recorded by using the indicators provided in the sheet. Comments on the operation in a specific day are also to be noted whenever they need to be considered in the future analysis.

'Work Item Sheet' is the page that contains the scope of work item 'Included' and 'Not-Included' for the collection of production rate, which enables consistent observation and data collection. Work item specific information, work item level production rate factor, that is believed to affect the rate is listed in the middle of the sheet. As both scopes of work and work item level factors are different for each of the work items, one sheet for each different work item is developed. The definitions of the scope in the Work item sheet are developed in order to realize the construction time estimation, rather than cost control. If the scope of 'Cap' is taken to illustrate this concept, rebar cutting and bending are not included in the scope, as shown in Appendix A-2.

Although the works are normally thought of as element of the cap activity, they are done simultaneously with actual cap work and expected to be ready for actual erection and installation. In some cost systems used primarily for estimating purposes, all of the efforts or work-hours represented in the 'Not Included' section are charged to the same account. This approach may support efficient and accurate cost estimates. However, for production rate measurement to be used for time estimation, the efforts required for actual installation is the only interested part (Thomas et al. 1988).

6) In this paper, only three pages are presented in the appendix due to limited space. The two pages missed here are one for detailed WZ sketch, detailed dimensions and quantity completed and the other for crew information including equipment.

The units of measure employed must also be simple to use and can be easily and quickly recorded, which will minimize the burden of a data collector. Measurement unit is selected to employ the measurement method of 'Units completed' after rigorous discussions with the research committee as well as literature review.

Table 1 presents the units selected compared with those used commonly in productivity measurement system that are, in most cases, the same as ones in cost control account. The units employed are also easier to be used for contract time estimation in practice, especially at design stage.

Table 1. Units Employed by the Research Compared with CTDS[7]

Work item	Unit of measure in this Research	CTDS Unit of measure (= Cost account unit)
Footing	Ea	CY of Concrete
Column	Ea	CY of Concrete
Cap	Ea	CY of Concrete
Beam erection	Span	CY of Concrete
Bridge deck	Square feet	CY of Concrete

5. Pilot Data Collection and Refinement

Pilot data collection must be conducted before starting extensive site visiting. The purpose of the pilot study is to test the measurement system, and to detail difficulties in the implementation process, and to revise them as needed.

Four projects in San Antonio District were selected and visited over more than two months. One simple project was selected at first based on recommendation from one of the research committee who was also an area engineer in the district. The first site meeting was held on Feb. 28, 2002, with the area engineer, an area designer, inspector and contractor's project manager in addition to the researchers. All of the procedures and safety protocols were reviewed along with the collection tool. Project level information was collected and some work items were benchmarked. Weekly site visits were conducted over a period of about three months where some minor modifications were made on the collection system and forms. The whole process was simultaneously conducted on three other

7) Construction Time Determine System. It is developed in 1990's by TxDOT (Texas Department of Transportation) and provides three point estimates of major work items' production rate. The values were determined as a composite of all the values submitted by several TxDOT employees and others. Survey conducted by the author found that the system was not widely used mainly due to the unrealistic production rates.

projects in the district.

Pilot study results show that the concepts reviewed and developed are sound and minor modifications on the data collection tool were necessary. The site visiting process and the recording data were found to be positive and simple enough.

6. Data Collection

Extensive data collection follows the pilot study. In the initial site visit, possible work items are to be benchmarked after site meeting with key personnel including inspectors and project managers. Then, in most cases, the project is visited weekly to track the work items and benchmark more items. During the site visit, various documents and drawings can be referenced whenever they are available and reliable. Foremen and/or superintendents are to be interviewed face to face in order to find detailed variables that might be happened on the particular operation during the week.

The data of the research were complied from 14 on-going highway projects between February, 2002 and September 2003 for about 30 months. The projects were located across five different counties in Texas State, USA and had a range between about 8 to 261 Million US dollars.

7. Results

The production rate of the Cap activity collected is presented by means of a Boxplot in Figure 3. The Boxplot is useful for presenting variability and skewness of data in a graphical manner, in particular for comparing data groups (Albright et al, 2003). The right and left of the box are at the third and first quartiles. The box itself represents the middle 50% of data or IQR (Inter-quartile Range). The vertical line and dot inside the box indicate the location of median and mean, respectively. The horizontal lines drawn from each side of the box extended to the point that is not further than 1.5 IQRs. Data points farther than 1.5 IQRs but not more than 3 IQRs are shown as individual hollow points and called 'mild outliers'.

The Data revealed that it take 5 crew working days on average to build one cap with standard deviation of 2.5 working days. IQRs are 2.9 from 3.5 to 6.3 days. In TxDOT Design conference held in October in 2003, the results were presented. Many of estimators agreed that the range is realistic and the unit or 'Crew days/EA' used is easier than current practice, in particular, for contract time determination. Further comment was that key factors affecting the rate need to be provided along with the rate range.

The data is also compared with the rates found in CTDS and RS Means cost data. It is to be denoted that the rates are compared in the unit of 'CY/Day' since it is the only unit provided by CTDS and RS Means. Before comparison, following must also be denoted.

1. RS Means and CTDS rates are two-point estimate, minimum and maximum, and so their medians and means are the same.
2. RS Means rate is modified by standard number of crew, five, used in the research. The RS Means rate is based on 16 carpenters. Therefore the rate is divided by 3.2.
3. RS Means rate include formwork, reinforcing steel and finishing. It does not include placing concrete. CTDS only provides the scope of its rate by denoting in the manual that estimators should allow extra time for third-party coordination, curing, stripping, traffic switchover, etc. The scope of this research rate is clearly demonstrated in the Appendix A2.
4. RS Means rate is obtained from Unit Price Section, Division 3, Cast-in-place, Concrete in place, all different sizes of rectangle column (12' *12' to 32' *32'). CTDS rate used is for bent including column and cap.

Obviously the research result, expressed as Observation in Figure 4, shows actual Cap production rate is larger than those provided by both RS Means and CTDS. In other words, TxDOT could give contractors unnecessary time for highway bridge construction.

Although the scope of each data is a little different, the interpretations are still valid because of the following two main reasons.

1) Column production rate, unit of 'M3/Day', is in most cases higher than Cap. Therefore, in fact, the difference of the production rates between Observation and RS Means would be greater than that presented.

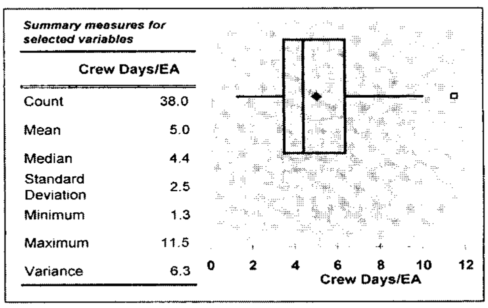

Figure 3. Statistics of 'Cap' Production Rate

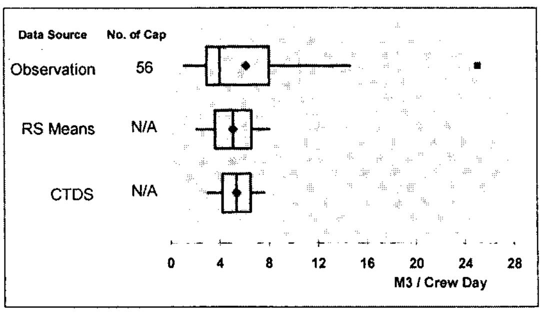

Figure 4. 'Cap' Production Rates Comparison

2) RS Means and CTDS rates are only data available to be compared.

Besides the comparison, the research committee consists of eight TxDOT personal confirmed that the results meet their anticipation. It has been consensus that TxDOT construction time determination of bridge works is unnecessarily longer than what they should be.

8. Conclusions And Recommendations

In this paper, a detailed methodology of collecting field information of crew production rates to be used for highway contract time determination is presented. The methodology has been demonstrated with a research conducted by the authors in Texas, USA. The results from the intensive data collection from 14 on-going projects revealed that the methodology is sound and can provide the rates that are realistic. The alternative unit implemented in the research, Crew days /EA, found to be easier to be referenced, particularly in pre-construction stage, than commonly used unit of CY/Day.

For future study, key factors affecting the rates need to be identified and so estimators can select right rate from the rage of the production rate. The identification of the factors, within a project context, site personal can even accelerate its production rate by applying better planning and scheduling Furthermore, as this research focused on activity production rate, it is necessary to study on lead time between activities as well as their relationships.

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Appendix A1

Production Rate Tracking: Work Zone Level

Work Zone & Work Item Assessed Recorder: ____________

Project ID: ______ Work Item (No.): ________________ District : ____________

Work Zone Description/Sketch:

Description:	Sketch
______________________________ ______________________________	
Typical Workday Start Time: ________	
Typical Workday Stop Time: ________	
Is observed work item on critical path? ☐ Yes ☐ No	
Workers are from: ☐ Union ☐ Non-Union	
How much quantity included in a work item operation cycle: ______________________________ (☐ Not Affected)	▪ *No. of Line indicates the No. of Traffic lines* ▪ *Double line indicates that WZ is not affected by its side of traffic.*

Work Zone Level Variables Evaluation

Variable		Characterization	Comment
1	WZ Accessibility	Difficult Moderate Easy Not Affected	
2	WZ Construction Congestion	Poor Moderate Good Not Affected	
3	Work Zone Site Drainage Effectiveness	Easily-Flooded Moderate Quickly Drains Not Affected	
3.1	Clay Content in Soil	High Moderate Low Not Affected	
3.2	Land Slope	Steep Moderate Flat Not Affected	
3.3	Water Table Depth Below Grade	<4' 4'~10' >10' Not Affected	

Data Analysis Status

Data Point ID: ________________	☐ *Check if data Collection completed* ☐ *Check if data Input completed*
Comment	

Appendix A2

Production Rate Tracking: Work Item Sheet (Cap)

Work Item	Sub-Item	Work Item #	Unit of Measurement
Bent	Cap-CIP	420-3	Crew Days / EA

SCOPE	Included	Not Included
	- False work, if any - Installation of forms and rebar - Inspection of forms and rebar - Handling and placing of concrete	- Site preparation - Preparation of rebar and forms - Rebar fabrication - Curing - All necessary work for the protection of concrete placed under any weather conditions - Removal of forms - Finishing of structure surface - Installation of drainage pipe - Removal of false work

Work Item Level PRODUCTIVITY FACTOR		- **Approximate elevation of structure (*Specify;* ______)** - **Approximate dimension (Specify-L*W*H;______)** - **Use of from liners (Yes, No), (*Note;*______)** - **Complex finish (Yes, No), (*Note;*______)** - **Section of cap (*Draw*; ______)** - **No. of columns per bent (*Specify*; ______)** - **Forms need to be resized for the target? (Yes, No), (*Note;*______)**
NODE	Starting	- False work or form work, whichever starts first.
	Ending	- Concrete placement is completed.
A Crew Definition		- Labor: One Crew for Formwork(4-5), One Crew for Rebar installation(4-5)
		Comment **Verified** ______

- *Node; In a special case, a data collector can judge the Starting and the Ending Node based on his/her professional experience.*

Appendix A3

Production Rate Tracking: Calendar (Work Item Level)

Year:________

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
/ **I** ⋮ **II** / **III** ⋮ **VI**	/	/	/	/	/	/
/	/	/	/	/	/	/
/	/	/	/	/	/	/
/	/	/	/	/	/	/
/	/	/	/	/	/	/

I: Observation #, **II**: X, ○ or ⊖, **III**: Indication , **VI**: Comment No.

Total Working Days: ________________

Indication

T - #: This Observation #	**H**: Holiday or Day Off
W: Weather day (< 2 Hrs of work)	**S**: Work Day With Some Weather Effect
N: UNworkable Soil Condition	**I**: Incomplete Crew
E: Equipment Downtime/not Available	**M**: Material Unavailable
U: Utility Conflicts	**F**: UnForeseen Condition
C: Construction Accident	**A**: Traffic Accident
O: Overtime	**D**: Other Delay (specify in comments)

○ : Normal Working Day ⊖ : ½ Working Day X : Non Working Day

Comments:

1	
2	
3	