A FRAMEWORK FOR AUTOMATING THE DAILY SITE REPORTING AND PROGRESS MONITORING FOR HIGHWAY CONSTRUCTION PROJECTS

by

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Abstract

Construction inspection data allows field personnel to keep record of the work performed, and monitor the project execution in order to provide quality control. Current practices in highway construction projects for collecting, processing, and filing documents associated to a construction job consume a large amount of time and effort. The use of technology provides a solution to make the process more efficient and quicker. As part of this research, a framework for the automation of daily site reporting and progress monitoring for highway construction projects was developed. The framework presents a process where the data is collected in a central database using computers and modern tablets, and then processed to create daily inspection reports and monitoring reports. The automation of this process shortens the time and effort required for an engineer to complete inspection tasks, as well as provides a monitoring tool to support the time and cost control of the project.

Resumen

Los datos de inspección de la construcción le permiten al personal de campo mantener un récord de las actividades realizadas, a la vez que mantienen un monitoreo del desempeño del proyecto. Las prácticas llevadas a cabo en la actualidad en proyectos de construcción de carreteras requieren una enorme cantidad de tiempo y esfuerzo para la recolección, el procesamiento y el archivo de esos datos. El uso de la tecnología para estos menesteres provee una posible solución para hacer de la inspección un proceso más rápido y eficiente. Como parte de esta investigación se desarrolló un marco conceptual para la automatización de los informes diarios de construcción y los informes de progreso para el monitoreo. El modelo presenta un proceso donde los datos son entrados a una base de datos utilizando computadoras y tabletas, y luego estos son procesados para crear los informes. La automatización de este proceso acorta el tiempo y el esfuerzo requerido por el ingeniero para completar las tareas de inspección, a la vez que provee una herramienta de monitoreo para apoyar el control de costos y tiempo en un proyecto.

To my parents

Acknowledgements

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Finally, I would like to thank my parents for their unconditional support and encouragement throughout my studies. Thanks to Pedro Bengochea, who day by day gave me all his love and support in this process. Thanks to my friends, who stand by me in this process with their encouragement and support. I am very grateful to all the wonderful people that surround me everyday and make my life better.

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CHAPTER 1: RESEARCH STATEMENT

1.1 Introduction

Construction is an industry characterized for generating vast amounts of data (Cox et al. 2002; Chen and Kamara, 2011). Data related to the construction process include: quality control and assurance reports, change orders and submittals requests, correspondence, memorandums, Requests for Information (RFIs), field activity logs, resources logs, and inventory logs, among others. In the case of highway construction projects, inspection is one of the processes that generates a great amount of data. Construction inspection data allow the field personnel to monitor project performance with the ultimate goal of providing quality control, a critical aspect for the success of a project.

1.1.1 Construction Inspection

The American Society of Civil Engineers (ASCE), in its manual, *Quality in the Constructed Field* (1985), defines Quality Control (QC) as "*the specific implementation of the Quality Assurance program, including checking and reviewing design and construction related activities*". The QC forms part of the Quality Assurance (QA) program which is the program covering all the activities necessary to provide quality in the work, by meeting the project requirements. Performing effective quality control reduces the possibilities of changes, mistakes, and omissions, which translates to fewer conflicts and disputes between the contractor and the owner. In addition, quality control is also important for compliance with federal and state regulations (Fisk and Reynolds, 2010).

Inspection data recorded daily is vital for the engineer's and the owner's defense in case the project ends up in litigation (Fisk and Rapp, 2004). For this reason, each of the inspectors in a construction project should always maintain a record of everything that happens during the workday, keeping in mind that the recorded data can become evidence in a legal conflict. Examples of recorded inspection data include such things as weather conditions, quantity and location of materials delivered and stored on site, quantity and quality of work performed, project progress status, records of accidents, among others.

1.1.2 Progress monitoring and controlling

Delays are a common denominator in construction projects (Rebolj et al., 2008). Project delays are due to several factors such as unrealistic planning, unforeseen site conditions, and errors or changes in the design, among others (Navon, 2005). To solve these problems two aspects have to be addressed: planning and monitoring. Planning comes before the project activities have started, but even when it is carefully done, unexpected changes can occur. As a result of the unforeseen conditions, field construction cost and time requirements change with little or no warning, and affect the entire project (Sears et al., 2008). In order to maintain a project within the established budget and time schedule, it is critical to employ monitoring and control.

Monitoring and controlling refers to the regular measure of the project progress to ensure that the objectives are being met (Schwalbe, 2010). This process involves collecting, measuring, and analyzing performance information to verify the status of the project and determine improvements that could be made. Progress is the "advance toward a specific end" (Jung and Kang, 2007). The "advance" can be measured in terms of time and cost of the project, by comparing the amount of work completed to the date with the total work of the project.

1.1.3 Technology

Recent advances in information and communication technology (ICT) have brought a wide range of new computer-based tools that can support technical fields such as construction (Froese, 2010). Technology could be used in construction to optimize many processes, including the collection, transfer, and analysis of construction data. Nowadays, the implementation of technology in the construction field is becoming more feasible because of the availability of tools with more capabilities, smaller sizes, and affordable prices. Cleveland (2011) argues that the current state of technology aligns very well with the needs of the construction industry, with advances such as:

- Plentiful, and ascending, server-based computing cycles, memory, and mass storage.
- Affordable and accessible high-bandwidth wireless communications.
- Affordable and easily available portable smart devices (e. g., smartphones, tablets, global positioning systems (GPS), ultra-mobile computers).

- Improved power, mass storage and memory for the portable devices.

These advances made possible the explosion of mobile computing devices in the past few years. Current mobile devices have improved user interfaces that include touchscreens, voice recognition, and global positioning, among others. In addition, the devices have the capacity of creating, displaying, and capturing information in multiple media such as text, audio, photos, images and videos (Cleveland, 2011). Most importantly, all these capacities can be taken into the field with small, portable devices, such as tablets or smartphones, which make this technology suitable for the construction field.

Currently, the experienced workforce is resistant to the implementation of technology in the field, since it represents a big change, and many people are not used to dealing with these types of devices. This resistance to change is a typical culture of the construction industry. However, the use technology is ubiquitous in young generations. Typically, younger people feel comfortable managing all sorts of technology, including portable devices. Therefore, it could be predicted that technology systems in construction could play a more important role in the future, when these young generations join the workforce. For this reason, it seems worthy to continue research in this direction since the future of technology in construction appears to be a successful one.

1.2 Problem Statement

Current practices in highway construction projects for collecting, processing, and filing all documents associated to a construction job raise many concerns. One of the problems is the large amount of time spent by the Engineers and Project Managers in processing construction data, which distracts them from their main task of supervising (Cox et al., 2002; McCullouch, 1993). In addition, the generation of so much paperwork is inconvenient for the management of information, and has a considerable environmental impact. Moreover, the process requires double manipulation of data, which is not only an inefficient use of the time, but also makes the information prone to human errors, and lacking consistency and reliability (El-Omari and Moselhi, 2009). In order to eliminate or mitigate these problems without compromising the quality of the work, it is essential to develop a more efficient system to collect and process inspection data.

The use of technology could help to effectively manage the information and could provide a better solution to make the inspection of highway projects a process much more efficient and faster. By automating the data collection and transfer processes using mobile devices in the construction field, the time required for an engineer to complete reporting tasks will be shortened; therefore the project administrator will have more time to perform other quality control tasks and administrative tasks. An Electronic Document Management (EDM) System could be implemented, which provides easier tracking and storing of the documents.

Moreover, the implementation of technology could enhance the communication process by allowing real-time data flow, which in turn could allow a faster response to the problems in construction. Inefficiency in the communication process may cause downtime, redoing of work, waste and cost overruns, which can eventually lead to project failure (Chen and Kamara, 2011; Cheung et al., 2013). With better communication, project team members can obtain the information in time to avoid and/or correct errors on the site (Leung et al., 2008; Navon, 2005). According to Thamhain and Wileman (1986), effective communication among the different parties involved in the construction is the third most important factor for the success of a project. In addition, Egan (1998) states in his work that the primary mechanism to increase productivity in the construction is to have an efficient information management. Therefore, improving the communication within the different project participants is one of the critical aspects to improve project performance.

The implementation of technology in the inspection reporting process allows the development of new tools for monitoring projects (Jung and Kang, 2007). With the information about each project automatically stored in a database, it is possible to generate other type of reports and information that could be used for progress monitoring, such as S Curves and Requests for Payment. These can be used to analyze the schedule and cost progress of a project on a weekly or monthly basis. This monitoring process helps to verify the project status and identify problems, allowing corrective actions to be taken in order to catch up on time and/or budget (Russell, 1993; Navon and Shpatnitsky, 2005). By taking corrective actions as early as possible, the delivery time of a project could be shortened, and cost savings could be achieved.

1.3 Purpose of the Research

In a previous research effort done by a research team from the University of Puerto Rico, Mayagüez Campus, an application for mobile devices with the purpose of performing inspection in highway construction projects was developed. In this effort, the team automated the inspection process by implementing inspection checklists for the standard specifications of the Puerto Rico Highway and Transportation Authority (PRHTA) in an application for modern mobile computing devices such as tablets (iPads and Android Tablets). This process is similar to the one developed by Moreno (2009), except that Moreno created the program for Windows based Tablet PCs and laptops, using Microsoft Access®. With this technology the inspectors are capable of collecting field data directly in their tablets, which will be stored in a database for the generation of quality compliance reports.

The purpose of this research was to develop a framework that uses the data already collected with the previous application to perform other automated functions. Such functions include the creation of the daily inspection reports and progress reports for monitoring and controlling the project. The framework contains an automated process to create and store the daily inspection reports that the PRHTA currently use. In addition, the framework also contains the logistic to create progress reports that present the original estimate of the work, the work accomplished to the date, and a series of predictions to present the work to be completed. The progress reports also include a report with the work and costs performed during the current month. This report will serve as a tool for the project administrators to check and approve the Requests for Payments submitted by the contractors.

1.4 Research Objectives

In order to achieve the development of the proposed framework for this research, the following objectives were established:

- Perform a detailed study of the inspection practices currently employed by the Puerto Rico Highway and Transportation Authority.
- Identify the elements involved in the inspection process of highway constructions.
- Develop a framework that integrates the data acquired in the inspection process with the reports needed to monitor and control the project, in order to establish a model for the automation of construction inspection.
- Test the validity of the framework through a prototype with information from a real highway construction project.

1.5 Contribution of the Research

The main contribution of this research is the improvement of the administrative aspects related to project progress monitoring and control, and the development of a new model for automating progress reporting and monitoring. This contribution is comprised by:

1. The enhancement of the monitoring process.

   The progress of the projects can be checked on a weekly and monthly basis using the reports generated automatically by the application. The reports will contain the actual work completed to the date and an estimate of the work to complete. Several predictions will be made including the changes approved to the date and the anticipated changes that are not approved to the date, but represent a possible change. With this information at hand, the project administrator will be able to make intelligent decisions based on the predicted outcomes of the project, thus reducing the changes of exceeding project costs and delivery time.

2. The automation of the Monthly Progress Payment Report.

   The framework provides a tool to create the Monthly Progress Payment Reports at the end of each month, or pay period. These reports could be used to corroborate the Progress Payment Reports submitted by the contractor, ensuring that the project is performed with a justified budget according to what is completed on the field each month.

3. The simplification of the project administrator's job.

   The framework simplifies the tasks of reporting for the project administrators by partially automating this process, thus allowing more time for the project administrator to perform other activities. In addition, the model provides monitoring tools that could contribute to a fast response to schedule deviations, and thus to the success of the project.

4. The simplification of the collection and distribution of inspection reports.

By distributing the reports in digital form and using wireless connections, the communication process will be faster and more eco-friendly.

5. The elimination of double manipulation of data, from paper to computer.

   The information will be input directly to the computers, saving time and minimizing the data transferring errors.

6. The organization of data in a modern database management system.

   The data and the reports will be organized in a modern database management system, which will provide an efficient organization and access to any information in the database. This system saves time associated to filing and manually searching for paper forms.

7. The minimization in the use of paper.

   The use of mobile devices will eliminate the need for paper forms, thus helping the environment.

1.6 Scope and Limitations

The scope of the research includes the development of a framework for automating the reporting process of the Puerto Rico Highway and Transportation Authority (PRHTA). The reports included in the framework cover the daily site reporting held by inspectors and project administrators. Other existing reports are not included as part of the conceptual model. The research will set the conceptual basis for the automation, but due to time constraints the programming will not be performed. The programming of this framework into a mobile computing application will be continued in the future by the research team at the University of Puerto Rico-Mayagüez.

1.7 Thesis Outline

This thesis presents a framework developed to automate the daily site reporting and progress monitoring of highway construction projects. The thesis contains six chapters, which should be read in order to understand better the process developed by the author. The first chapter briefly explains the basic concepts behind construction inspection process, the monitoring, and the use of technology. The chapter also states the motivation, objectives, contribution, scope and limitations of the research. A review of the previous work performed in this area follows in Chapter 2. Chapter 3 details the current practices employed by the PRHTA regarding daily site reporting. Chapter 4 presents the methodology for the research and the in depth explanation of the framework for the daily site reporting automation and progress monitoring of the projects. To validate the proposed framework, Chapter 5 presents an example of the model applied to a real construction project. Finally, Chapter 6 presents the conclusions and contributions of the work.

CHAPTER 2: CURRENT STATE OF KNOWLEDGE

In order to optimize a process it is imperative to study it and to investigate previous research efforts done in the area. A literature review was conducted to identify the work previously done by other researchers about the research topic. This review provides the basis for the appropriate development of the research proposed. The theme of automation in construction has been around since the late 1980s, which demonstrates the high interest in the application of technology in the construction field as a way to optimize certain processes. For this reason, a large amount of publications on the general topic were found. The literature reviewed includes academic papers, thesis, dissertations, books, technical specifications and electronic resources. This chapter presents only the publications most relevant to the topics of daily site reporting and quality control automation using mobile computers.

Previous work was accomplished by Moreno (2009) regarding the automation of inspection process for the Puerto Rico Highway and Transportation Authority (PRHTA). Moreno's project report describes a process in which standard inspection forms where created and automated using Microsoft Access®, allowing the field inspectors to monitor the project on site using a Tablet PC or a laptop. The standard inspection forms were created in the form of checklists and followed the specifications in the Manual of Standard Specifications for Road and Bridge Construction of the PRHTA. The specifications in this manual apply to any highway construction, unless otherwise stated in the contract drawings. Figure 1 illustrates an example of the field inspection checklist developed by Moreno. By automating this inspection checklist in Microsoft Access®, the inspectors were allowed to perform the quality control of the activities using a Tablet PC with a checklist at hand. Having a checklist of the most important quality activities provided a higher quality inspection, making sure that the desired activities were met. The automation process intended to address the issues of eliminating double manipulation of data, creating a better organization and filing system, and providing a tool for better quality control.

Checklist for Uniform Inspection of the Items in the Construction Contract

Specification	**No. 150**	**Survey & Stakeout**		
Inspected by:		**Date:** __/__/__		**City or Town:**
Location:		**Legend: 'C' = Complies; 'NC' = Non Complying**		
No.	**Description**	**C**	**NC**	**Comments**
1	The Project Manager made sure that the form "Stake-Out Survey Breakdown" has been approved.			
2	The Inspection Brigade offered the Contractor control points.			
3	The Inspector wrote down the work done in accordance to the breakdown submitted by the Contractor and approved by the Authority.			
4				
5				

Note: An initial inspection at the beginning of the activity must be performed, with consecutive inspections to check the progress of the job. In the column for comments please write 'N/A' if it doesn't apply, 'N/R' if the job hasn't been executed at the moment of the inspection, or 'É/P' if the job is in progress at the moment of the inspection, and write if any action is required.

Distribution:

_____ Contractor with **Action Required** Yes No

_____ Subcontractor with **Action Required** Yes No

_____ Superintendent with **Action Required** Yes No

_____ Design Representative with **Action Required** Yes No

_____ Owner Representative with **Action Required** Yes No

Figure 1: Example of the Field Inspection Checklist Form developed by Moreno (2009)

In the publication, “Application of Small Computers in Construction,” by the Task Committee on Application of Small Computers in Construction of the Construction Division (1985), the authors discuss the first attempts to implement computers in construction and the problems that could be addressed with such implementation. Some of the issues addressed at the time still exist today, such as the lack of communication between different parties, and the problems with document management. Later, McCullouch (1992) conducted research with the goal of creating a “paperless” environment for the Departments of Transportation (DOTs), providing better data organization and flow, which in consequence reduces the time processing data and increases the time managing the project. McCullouch’s investigation revealed that INDOT (Indiana Department of Transportation) engineers spent 4-5 hours daily processing paperwork, which proves that the task was taking a lot of valuable time that could be instead spent in monitoring and controlling the projects. Another problem that the author found was the lack of integration between the different data systems (e.g., bid analysis management system, construction record system, material and test system). With the implementation of the automated system proposed in the research, the following benefits were achieved: decisions based on more complete information, elimination of duplicated information, better construction claims recording system, easier track information, easier trend analysis and forecasting, and reduction in costs. As a result, other valuable data became easily accessible such as more accurate future cost estimates, tracking and processing constructability data, improved project duration estimates, better tracking of project status, and contractor performance records.

Around the same time period, Russell (1993) was performing research on the automation of daily site reporting. His work highlighted the importance of the quick detection of time, cost, scope, and quality deviations from the planned performance, process that can be enhanced by the use of automation in the site. Automation also allows the use of the data from the daily site reporting to automatically update schedule in terms of actual start and finish dates. Additionally, it can provide information to the personnel on site to both help their management tasks and ease their reporting burden. According to Russell, the features that should be included in the application are: specific items to be measured, how to measure them, methods to classify information, development and use of standards, appropriate data structures, relationship amongst data items, exchange of information among functions, and user interface design. After implementing a software system, the author found that benefits were obtained through more credible schedules and faster response to problems.

Cox et al. (2002) describe the construction industry as one characterized by generating large amounts of data. They argue that these data need to be collected, processed, and exchange among the different participants of the project. They also argue that the process of recording and filing the field inspection data is mainly paper-based, which turns into a tedious and time-consuming task. Their research addressed the issue of collecting inspection data at the field by developing an application to automate this process using Pocket PCs. The application gave the inspectors the tool of recording field inspected data in a quality control checklist, which after completion of the inspection task became an Inspection Daily Report (IDR) and could be distributed via e-mail to the desired stakeholders. The creation of this application intended to eliminate double entry of recorded data, reduce the paperwork, generate reports, and provide a faster distribution of the data. These benefits combined translate into a faster project delivery, and thus cost savings.

Chassiakos and Sakellaropoulos (2008) developed a web-based system to facilitate the management of construction information and communication. The system consisted of a centralized database, created in Microsoft Access®, where all the project information was stored and then transferred to the concerning stakeholders. The system was designed to facilitate the communication process at the same time it provides document organization. The database was combined with a set of web pages that allowed users to perform certain actions according to their authorization level. The web pages allowed users to insert new records, make searches in the database, view the results and detail records, and modify and delete existing records. To validate the system, a pilot implementation was conducted focused on the process of daily site reporting.

El-Omari and Moselhi (2009) discuss in their work a system that uses data acquisition technologies to integrate the data collected on the construction site with the progress reporting of projects. For this purpose, different data acquisition technologies were studied, such as bar codes, Radio Frequency Identification (RFID), 3D laser scanning, photogrammetry, multimedia, and pen-based computers. A relational database consisting of 37 entities was used to organize and store the data collected on the site. The integration of the relational database, with the different data acquisition technologies and a planning and scheduling software system forms the cost/schedule control model proposed in this investigation. The model is designed to assist the engineers in the tasks of monitoring and controlling projects with the creation progress reports. These reports help the project team in the decision making process.

Chen and Kamara (2011) explored the use of mobile computing devices in the construction site with respect of the retrieval and transfer of information. The research team developed a conceptual framework showing the links between user and mobile computers, which explores the issue of Human Computer Interaction (HCI). The framework contains an application model and a technical model. The application model identifies six factors (mobile computer, wireless network, mobile application, user, construction information, and construction site), and explores the interactions that affect the implementation of mobile computing. On the other hand, the technical model generalizes the mobile computing technologies, and gives the designers a clear structure for the design of mobile computing systems.

The body of knowledge related to the automation of inspection processes in construction is very comprehensive. For this reason, this chapter presents only the research efforts found that are were more closely related to the research of this thesis. The previous project developed by Moreno in the University of Puerto Rico was described and will be mentioned in Chapter 4, since it is directly related to the work of this thesis. Other papers of automation and using mobile computing devices in the construction site were summarized. The next chapter will expand in the background needed to understand the work of this thesis by providing a description of the current practices held by the PRHTA, entity in which this research is based.

CHAPTER 3: CURRENT PRACTICES OF THE PRHTA

3.1 Overview of the Daily Reporting Process

The current inspection process in the Puerto Rico Highway and Transportation Authority (PRHTA) includes a paper-based reporting system where two kinds of inspection reports are prepared daily: the Daily Activities Report and the Daily Inspection Report. The general concept is to take the data in the field and then manually process it in the office later on. An overview of the process is shown in Figure 2.

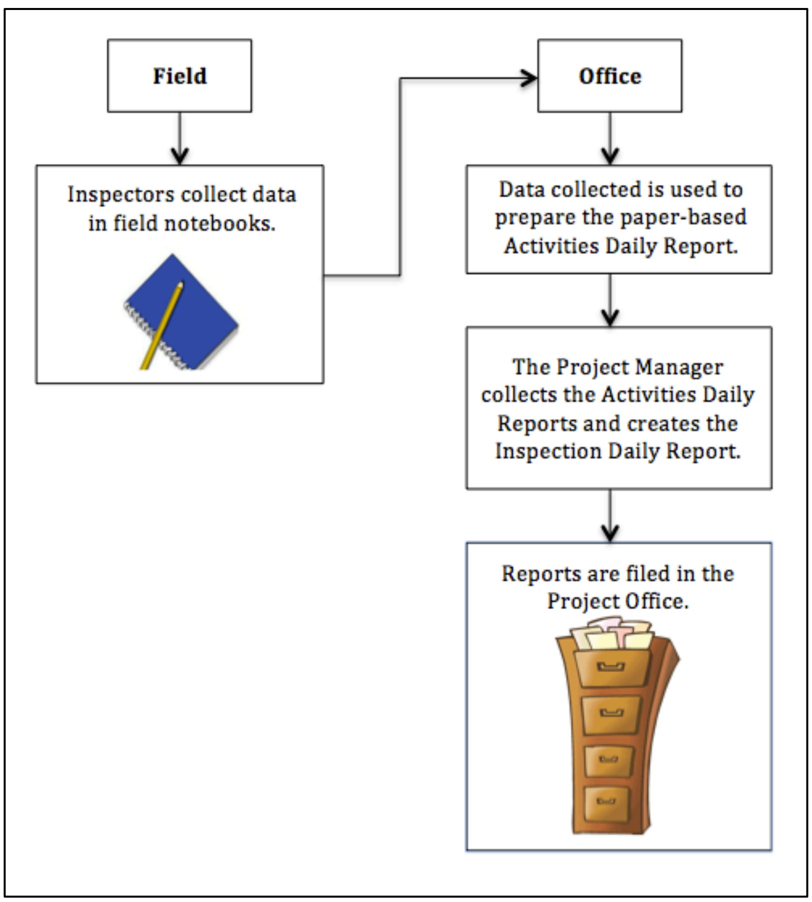


Figure 2: Current Reporting Process in the PRHTA

In this system, field inspectors take notes in personal field notebooks of the work accomplished by the contractor. At the end of the day, the inspectors go to the office and write down the information in the Daily Activities Report. This report is shown in Figures 3a and 3b.

Gobierno de Puerto Rico
Departamento de Transportación y Obras Públicas
AUTORIDAD DE CARRETERAS Y TRANSPORTACIÓN
Área de Construcción
INFORME DIARIO DE ACTIVIDADES

ACT-45
(11/08)

1. NÚM. DE PROYECTO: ________
2. NOMBRE DE PROYECTO: ________
3. MUNICIPIO: ________
4. CONTRATISTA Y/O SUBCONTRATISTA: ________

5. FECHA: ________
6. DIA DE SEMAN L | M | W | J | V | S | D
7. INSPECTOR: ________
8. PÁGINA NO. ___ DE ___ 9. IDA NO. ______

10.CLIMA		AM		PM
11. HORA LLUVIA				

12. HORARIO DE TRABAJO: ______ A ______

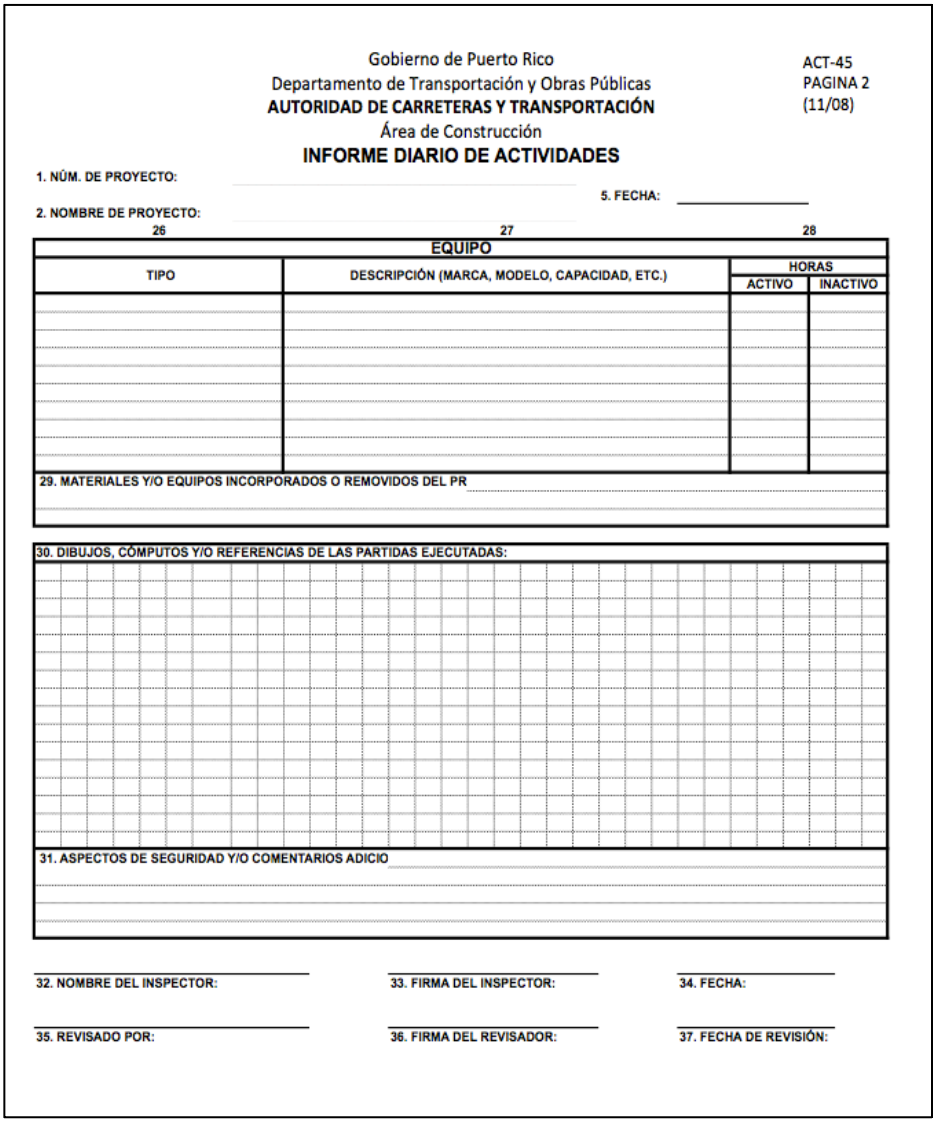
13	14	15	16	17	18	19
TRABAJO EJECUTADO						
PARTIDA	ESPECIFICACIÓN	DESCRIPCIÓN DE PARTIDA	CANTIDAD MEDIDA	UNIDA D	LÍNEA, LADO Y PROGRESIVA	CANT. VERIFICADA Y APROBADA

20. DESCRIPCIÓN DEL TRABAJO Y MATERIAL USADO, INCLUYENDO NÚMERO DE PARTIDA Y LOC/

21. MUESTRAS TOMADAS

22	23	24	25
PERSONAL			
NOMBRE	CLASIFICACIÓN	HORAS TRABAJADAS	OBSERVACIONES

Figure 3a: Daily Activities Report (Page 1 of 2)



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Área de Construcción
INFORME DIARIO DE ACTIVIDADES

ACT-45
PAGINA 2
(11/08)

1. NÚM. DE PROYECTO:

2. NOMBRE DE PROYECTO:

5. FECHA:

26	27	28	
EQUIPO			
TIPO	DESCRIPCIÓN (MARCA, MODELO, CAPACIDAD, ETC.)	HORAS	
		ACTIVO	INACTIVO

29. MATERIALES Y/O EQUIPOS INCORPORADOS O REMOVIDOS DEL PR

30. DIBUJOS, CÓMPUTOS Y/O REFERENCIAS DE LAS PARTIDAS EJECUTADAS:

31. ASPECTOS DE SEGURIDAD Y/O COMENTARIOS ADICIO

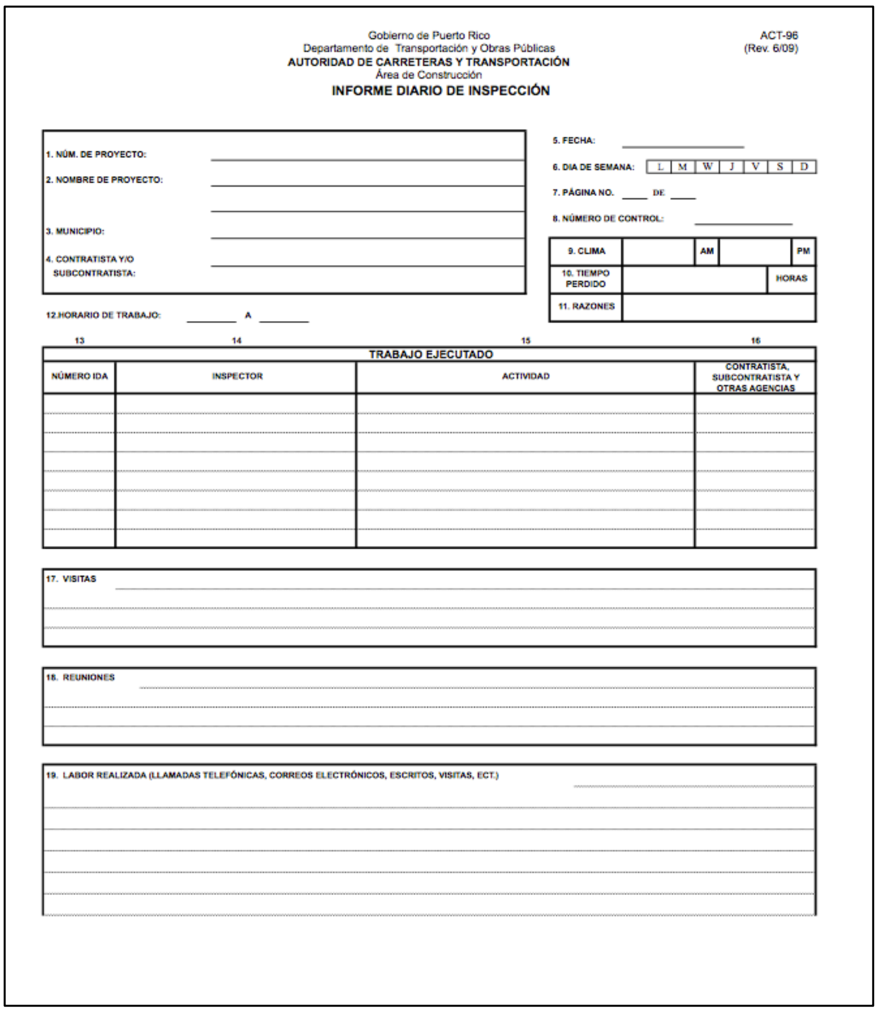
32. NOMBRE DEL INSPECTOR: 33. FIRMA DEL INSPECTOR: 34. FECHA:

35. REVISADO POR: 36. FIRMA DEL REVISADOR: 37. FECHA DE REVISIÓN:

Figure 3b: Daily Activities Report (Page 2 of 2)

In some cases, the information is given to the secretary of the project, who is in charge of preparing the report. This process is inefficient because it requires double manipulation of data, which makes the information prone to human errors, and thus, unreliable. It also makes the process tedious and time consuming for the engineers, taking away from them valuable time that could be spent in their main task of inspecting.

Once each of the inspectors has finished the Daily Activities Reports, they are passed to the project administrator. The project administrator takes the reports, which can be many depending on the amount of inspectors in the project, and summarize the work accomplished in the Daily Inspection Report. The Daily Inspection Report, shown in Figure 4a and Figure , also contains extra information regarding the tasks of the project administrator, such as visits, meetings, and issues discussed with the contractor, among others.



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Área de Construcción
INFORME DIARIO DE INSPECCIÓN

ACT-96
(Rev. 6/09)

1. NÚM. DE PROYECTO:
2. NOMBRE DE PROYECTO:
3. MUNICIPIO:
4. CONTRATISTA Y/O SUBCONTRATISTA:

5. FECHA:
6. DIA DE SEMANA: L M W J V S D
7. PÁGINA NO. ___ DE ___
8. NÚMERO DE CONTROL:

9. CLIMA		AM		PM
10. TIEMPO PERDIDO			HORAS	
11. RAZONES				

12.HORARIO DE TRABAJO: ______ A ______

TRABAJO EJECUTADO

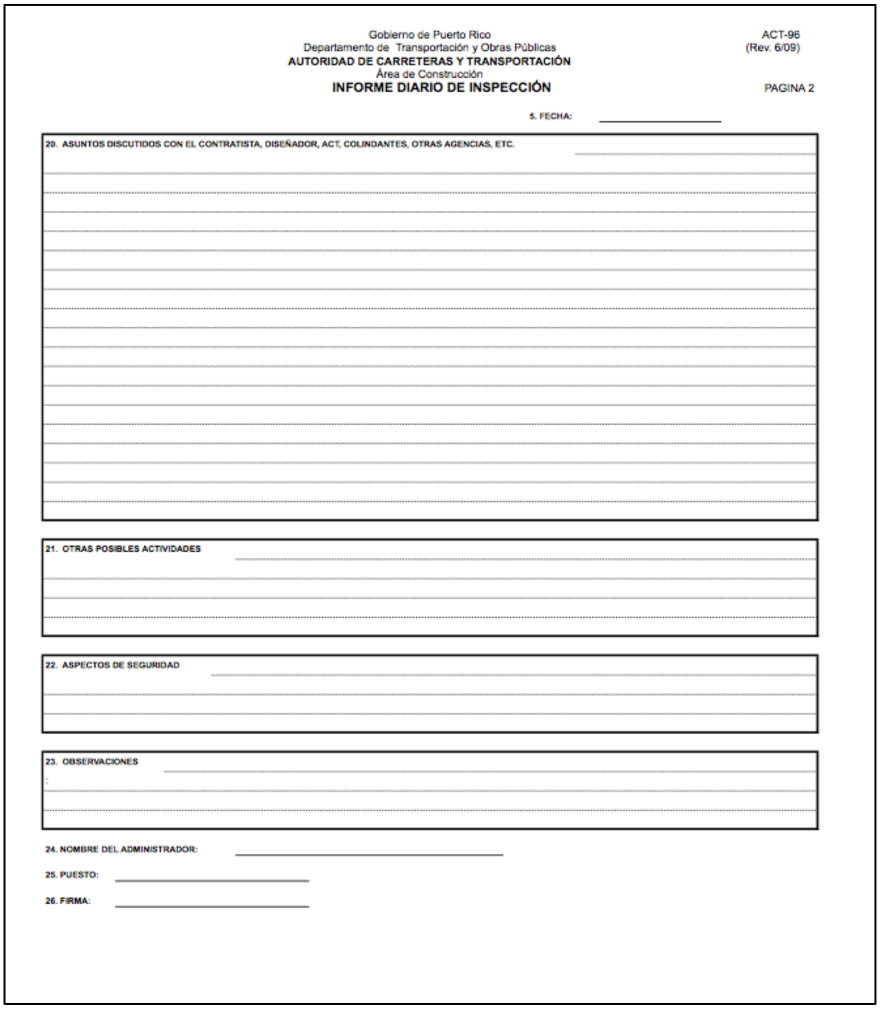
13 NÚMERO IDA	14 INSPECTOR	15 ACTIVIDAD	16 CONTRATISTA, SUBCONTRATISTA Y OTRAS AGENCIAS

17. VISITAS

18. REUNIONES

19. LABOR REALIZADA (LLAMADAS TELEFÓNICAS, CORREOS ELECTRÓNICOS, ESCRITOS, VISITAS, ECT.)

Figure 4a: Daily Inspection Report (Page 1 of 2)



Gobierno de Puerto Rico
Departamento de Transportación y Obras Públicas
AUTORIDAD DE CARRETERAS Y TRANSPORTACIÓN
Área de Construcción
INFORME DIARIO DE INSPECCIÓN

ACT-96
(Rev. 6/09)

PAGINA 2

5. FECHA: ____________

20. ASUNTOS DISCUTIDOS CON EL CONTRATISTA, DISEÑADOR, ACT, COLINDANTES, OTRAS AGENCIAS, ETC.

21. OTRAS POSIBLES ACTIVIDADES

22. ASPECTOS DE SEGURIDAD

23. OBSERVACIONES

24. NOMBRE DEL ADMINISTRADOR: ____________

25. PUESTO: ____________

26. FIRMA: ____________

Figure 4b: Daily Inspection Report (Page 2 of 2)

After the information is recorded in these two types of documents, it is stored in a filing cabinet system for later reference if necessary. This type of manual, paper-based document management system is ineffective, since it can be time-consuming to make searches through the documents and the risk of losing documents is higher. In addition, recording the data in paper eliminates the potential of using the information to make data analysis and other kinds of reports.

3.2 Daily Activities Report

This section lists all the information required to complete the Daily Activities Report. The information was divided in topics for convenience in managing the information and presenting it to the reader. The data necessary to complete the report are the following:

- Basic Project Information
    - Project ID
    - Project Name
    - City or Town
    - Contractor and/or Subcontractor
- Basic Daily Information
    - Date
    - Day of the week
    - Inspector
    - Weather
    - Working hours
- Work Completed
    - Item Number
    - Specification
    - Description
    - Quantity Measured
    - Units

  - Location (Station)
  - Quantity Approved
- Description of the work and materials used
- Samples Taken
- Workforce
  - Name
  - Classification
  - Hours Worked
  - Observations
- Equipment
  - Type
  - Brand, Model, Capacity, etc.
  - Hours, Active and Inactive
- Materials and/or equipment incorporated or removed from the project
- Drawings, computations and/or references of the activities executed
- Security aspects and/or additional commentaries

3.3 Daily Inspection Report

This section lists all the information required to complete the Daily Inspection Report, which is prepared by the project administrator. The information was divided in the same topics of the previous section for convenience in managing the information and presenting it to the reader. The data necessary to complete the report are the following:

- Basic Project Information
  - Project ID
  - Project Name
  - City or Town
  - Contractor and/or Subcontractor
- Basic Daily Information
  - Date
  - Day of the week
  - Control Number
  - Weather
  - Working hours
  - Time lost and reasons
- Work Executed
  - Report ID (Daily Activities Report)
  - Inspector
  - Activity
  - Contractor, Subcontractor, and Other Agencies
- Visits
- Meetings
- Tasks Performed (Phone calls, e-mails, notes, etc.)
- Issues discussed with the Contractor, Designer, PRHTA, and other Agencies
- Other possible activities
- Security aspects

- Observations

It is important to present the data contained in the two reports because some of this data will be filled automatically with the implementation of the framework described in the next chapter. With the automation of the framework developed, the two reports will be generated partially filled with the basic project information, basic daily information, and work completed data. The inspectors and the project administrator's task will be to verify that the data is correct and to complete the remaining fields in the report. The process is better described in the next chapter, where the methodology of the research and complete framework is explained in more detail.

CHAPTER 4: METHODOLOGY

4.1 Transportation Automated Inspection Process (T.A.I.P.)

The integration of technology in the field of construction presents an opportunity to improve the processes of data collection and analysis. A previous research effort by a team at the University of Puerto Rico, Mayagüez Campus, recently developed an application for mobile devices with the purpose of performing quality checks in highway constructions. The application is known as T.A.I.P., acronym for Transportation Automated Inspection Process. Similar research was performed previously by Moreno (2009). In her work, she automated the quality check process using Microsoft Access®, as discussed in Chapter 2 of this thesis. With T.A.I.P., the quality check process was automated using modern mobile computing equipment such as iPads and Android Tablets. The inspection forms created for the application contain checklists of the specifications in the *Manual of Standard Specification for Road and Bridge Construction* of the PRHTA. This technology allows inspectors to collect field data directly in their tablets, and store these data in a database for the generation of quality compliance reports. An example of the inspection form available in the application is shown in Figure 6.

As stated in Chapter 1, the aim of this research was to develop a framework for the daily site reporting and progress monitoring of highway construction projects, utilizing the practices of the PRHTA. The investigation presented by this thesis uses a combination of the data already collected using T.A.I.P. with new data acquired to perform other functions. Such functions include the creation of the two daily reports that the PRHTA requires to their inspectors and project administrators: the Daily Activities Report and the Daily Inspection Report. In addition, progress-monitoring reports, for the control of costs and time, were developed and integrated to the model of automation. The integration of these new functionalities to the T.A.I.P. application is presented in this chapter.

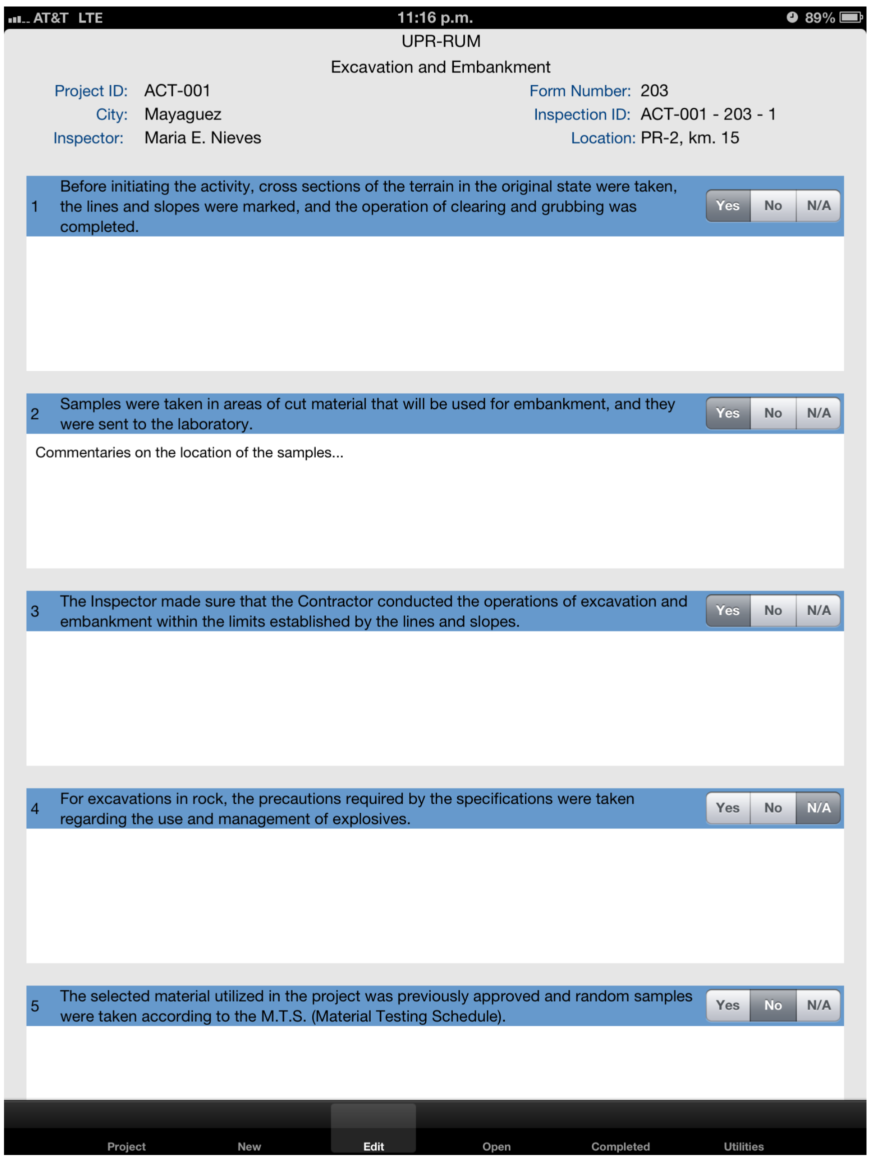


Figure 5: Inspection form in the T.A.I.P. application for iPad

4.2 Research Strategy

In order to accomplish the objectives of the research, an overall research strategy was established and divided into four main steps. The steps guided the process from the literature review to the final development of the model and the case study. This strategy is shown in Table 1.

Table 1: General research methodology

Research Step	Research Objective	Research Question	Research Method
Step 1	Investigate the concepts and elements involved in the inspection process of highway constructions.	What elements are necessary in the inspection process? What are the existing mechanisms for inspection?	Literature Review
Step 2	Perform a detailed study of the inspection practices currently employed by the Puerto Rico Highway and Transportation Authority.	What are the current practices employed by the PRHTA? What kinds of reports are performed? How can the process be enhanced?	Interviews
Step 3	Develop a framework that integrates the data acquired in the inspection process with the reports needed to monitor and control the project, in order to establish a model for the automation of construction inspection.	What are the relationships between the different elements involved in the inspection process? What are the relationships between the collected data and the monitoring data? How can mobile computing be used to enhance the inspection process?	Modeling
Step 4	Demonstrate the validity of the framework through an Example.	How can the framework be applied to real construction Situations?	Case Study or prototype

In Step 1, a literature review was conducted among a variety of resources. The most relevant findings of the review were documented in Chapter 2 of this thesis. Step 2 involved investigating and studying the current practices in the PRHTA. The results of this step are presented in Chapter 3. This part of the investigation was accomplished by interviewing several experienced engineers from the PRHTA, and collecting documents from finished construction projects. An analysis of the information acquired in this step was done, including the study in depth of all the documentation collected and identifying the potential areas of improvement. In Step 3, the process to automate and optimize the current situation was developed. The framework developed at this stage is the main deliverable of this research. This framework will allow the extension of the T.A.I.P. application, to include new functionalities by using the information in the server to generate the necessary reports for the monitoring and control of the construction job. Finally, an example application of the framework was conducted in Step 4. The application consists of a sample scenario demonstrating how the application would work on a real construction project.

4.3 Framework for Automating Inspection Processes

Figure 6 depicts a flowchart that describes the overall automation process for the daily site reporting and progress monitoring. The model can be divided into four main parts, which are: the Field Daily Reporting, the Office Daily Reporting, the Weekly Progress Reports, and the Monthly Progress Reports. The four parts revolve around a central database, where all the information from the construction inspection team is stored and managed.

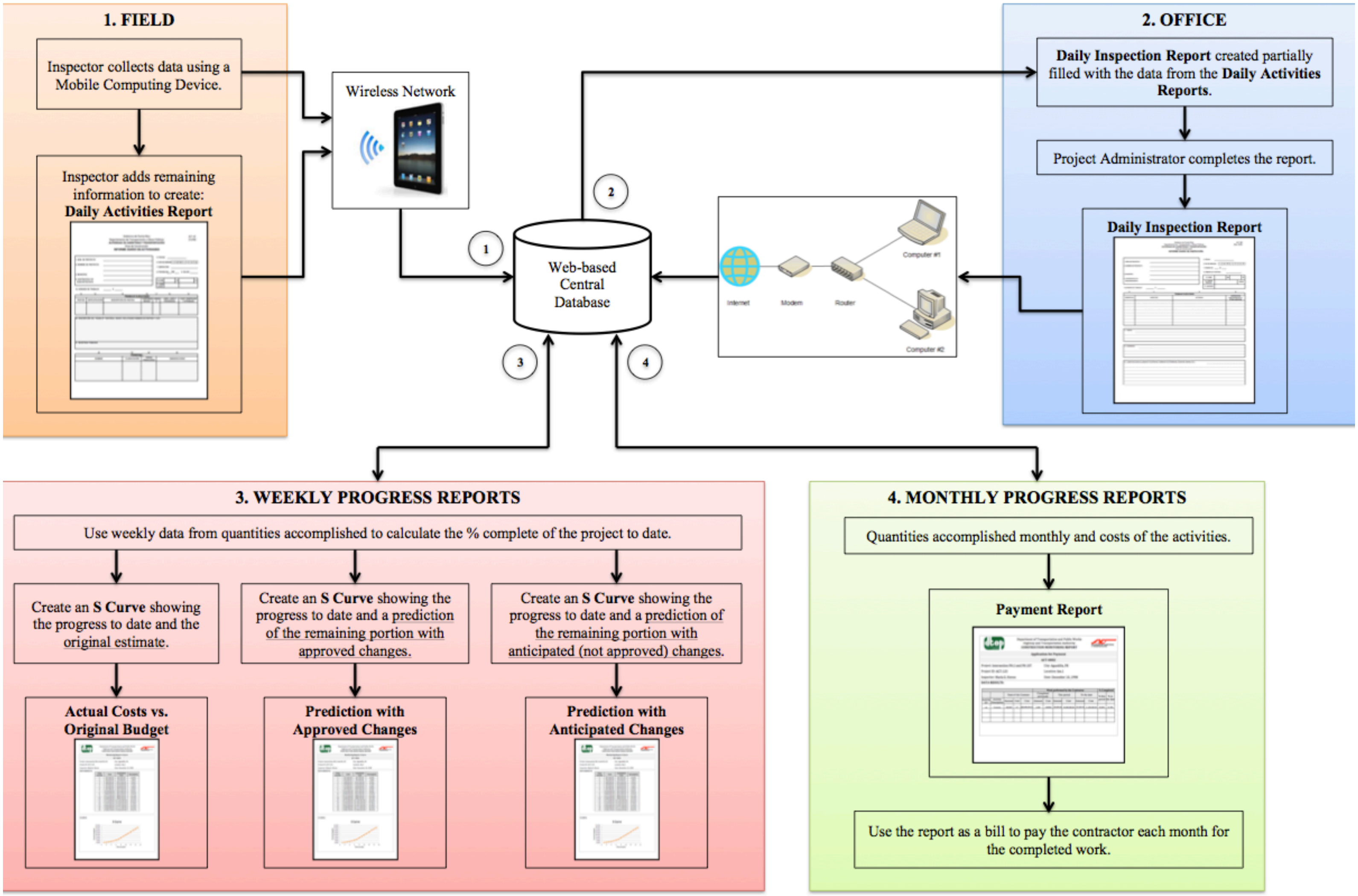


Figure 6: Description of the automation process

The flowchart depicts the process from the moment the inspector collects the data to the creation of the reports. The first process is the collection of the data on the field using a mobile computing device. The data is collected in the T.A.I.P. application, and is later stored in the database. The field inspector will have the option of completing the Daily Activities Report directly in the application. Once the report is finished, it will be stored in the database for the creation of other reports, and for later reference. The second process is the creation of the Daily Inspection Reports. Since this report summarizes some of the information collected in the Daily Activities Reports, the server will identify the information needed for the Daily Inspection Report and will generate this report partially filled with the data available. The project administrator will complete the remaining fields in the report and will upload it to the database for later reference. The database will serve as a tool to store and organize the data, and provides the convenience of making searches more efficiently. All the reports will be accessed from the web page created for the application, and will appear in an organized manner according to the project, the type of report and the date.

The third and fourth process creates the progress monitoring reports. The third process consists using the data collected to calculate the quantities completed during a certain period, the cost during the period, the cost to date, and finally the cost to complete the project. With that information, S-Curves can be generated on a weekly basis to monitor the progress of the project. In addition, the data collected during a pay period will be accumulated to generate a Progress Payment Report. The following section examines the components involved in the process of automation herein proposed.

4.3.1 Components of the Developed Model

The developed model is divided into three main parts: the input data, the database, and the outputs. The system architecture is shown in Figure 7. The input data has two components, one in the field and one in the office. The data collected in the field is the one accomplished using mobile devices. At this stage, the inspector collects the daily basic information, the work executed, additional information regarding workforce and equipment, and digital images of the work performed. The daily basic information contains data about the date, weather, and working hours, among others. The work executed contains information about the items performed or installed, the quantities, and the units. The data under each of these divisions is listed in Chapter 3.

In addition, other data is collected in the office. Such data include the cost proposal, a cost-loaded schedule, and information about changes, among others. This information is uploaded to the database at the beginning of the project or as the changes occur. Before the start of the project, the project administrator is required to upload the project basic information, the cost proposal, and a cost-loaded schedule. The project basic information contains data such as the name of the project, the project ID, and location, among others as listed in Chapter 3. The cost proposal contains the data of the unit prices for each item and the project total cost, data necessary to make the calculations of the progress reports. The cost-loaded schedule is necessary to estimate the original progress of the project. This information facilitates the comparison of the actual progress of the work with the original estimated outcome. The other kind of data input in the office is the project changes. These changes can be in the form of change orders or extra work orders, and are necessary to update the total cost of the project and make predictions about the outcome of the project.

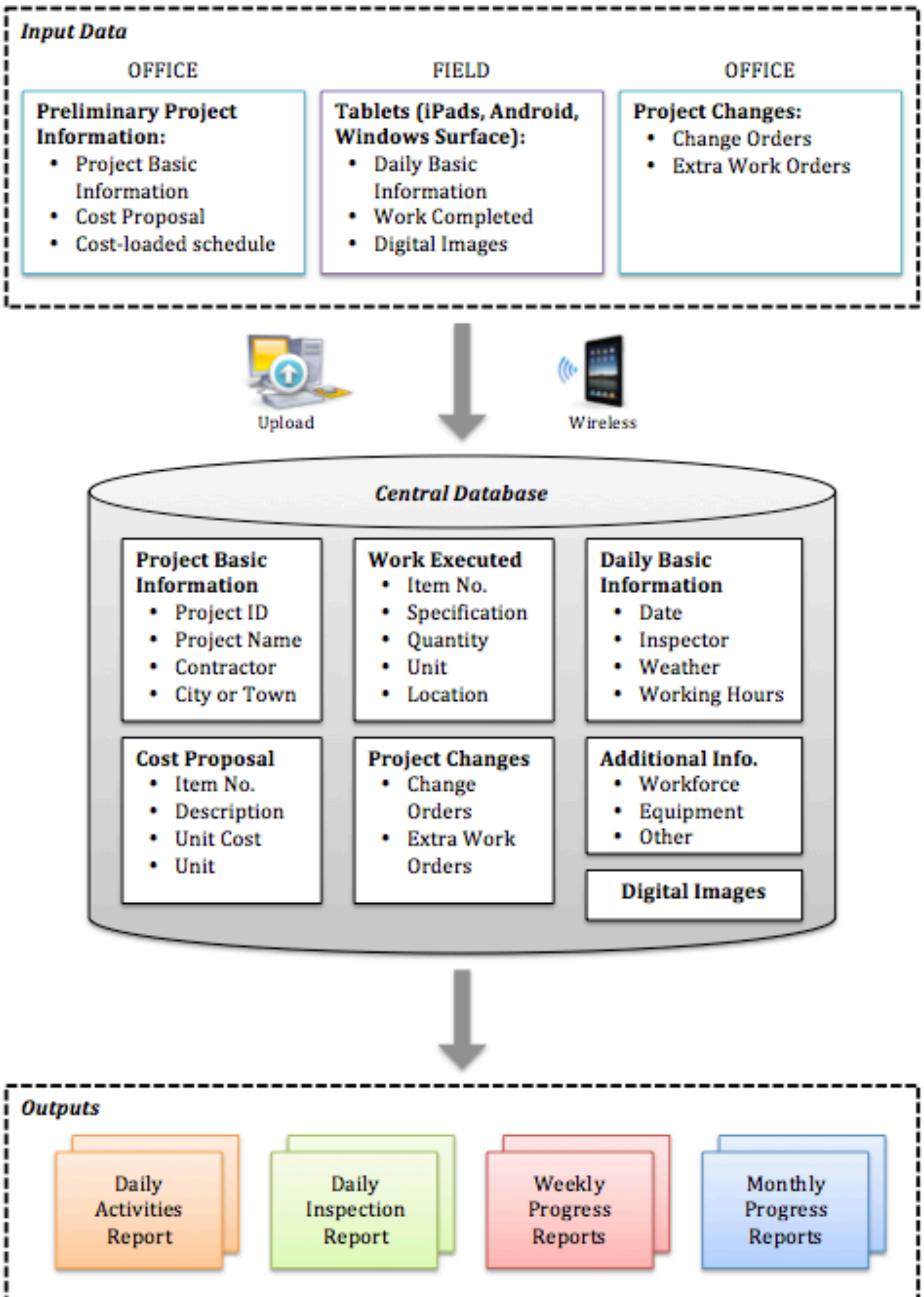


Figure 7: Proposed System Architecture

The second element of the model is the central database. The database organizes and stores all the data input to the model. This data is used to make daily reports and to perform the calculations that measure the progress of the work. The information is presented to the user in four reports, which become the outputs of the model. The Daily Activities Report and the Daily Inspection Report are basically the automation of the two reports already performed daily by the inspectors and project administrators of the PRHTA. In addition, weekly progress reports are generated to show the progress of the project in the form of S-Curves, which allow the comparison of the estimated progress with the actual progress, as well as the development of predictions for the remaining part of the project. Furthermore, monthly progress reports are payment reports created for each pay period. The following sections describe in more depth each of the components of the model.

4.3.2 Field Reporting

The field reporting consists of keeping record of the events that happen during a workday in the construction jobsite. As presented in Chapter 3, the PRHTA requires their inspectors to complete the Daily Activities Report at the end of every workday. The process of manually completing the reports can become tedious, time consuming and prone to errors, since it requires double manipulation of the data. For this reason, the first step of the framework is the automation of the Daily Activities Report. In this automated process, the inspector will collect data at the field using a mobile computing device, such as an iPad or Android Tablet, and the report will be generated by the application. The data collected using the mobile device application will be stored in the central database for later use in other reports. This process is depicted in Figure 8.

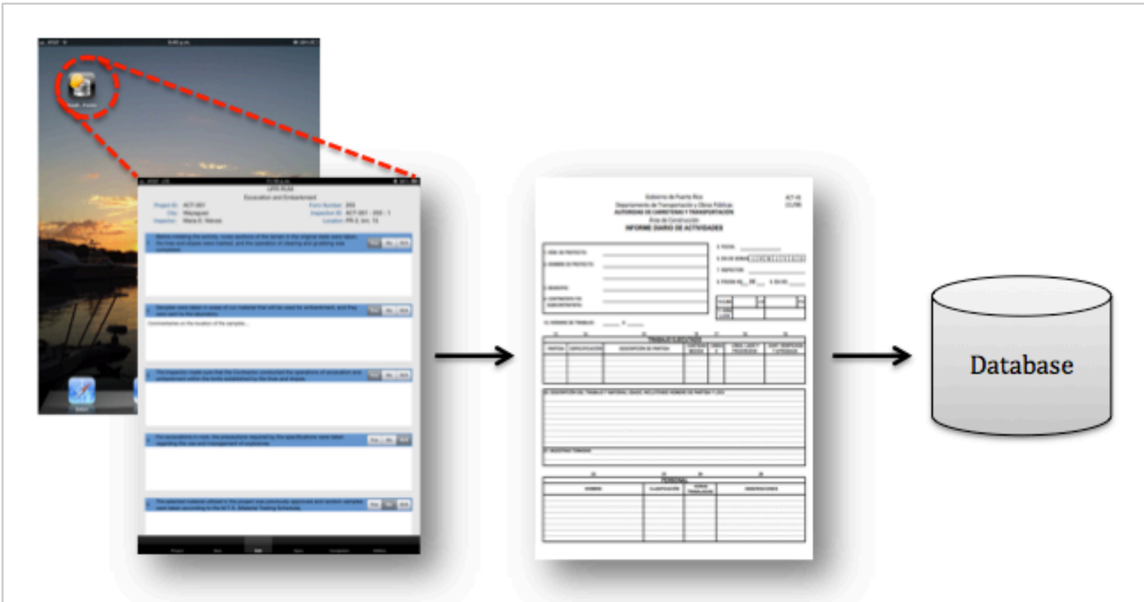


Figure 8: Field Reporting Process

The reports are generated with a combination of information already stored in the database, and new information taken daily. The basic project information is entered to the application only once, the first time the project is inspected. The screen to enter this information in the T.A.I.P. application is shown in Figure 9. In the subsequent occasions, the inspector selects the project from a list, and the project basic information will be automatically filled in the inspection form. The project basic information is: Project ID, Project Name, City or Town, and Contractor.

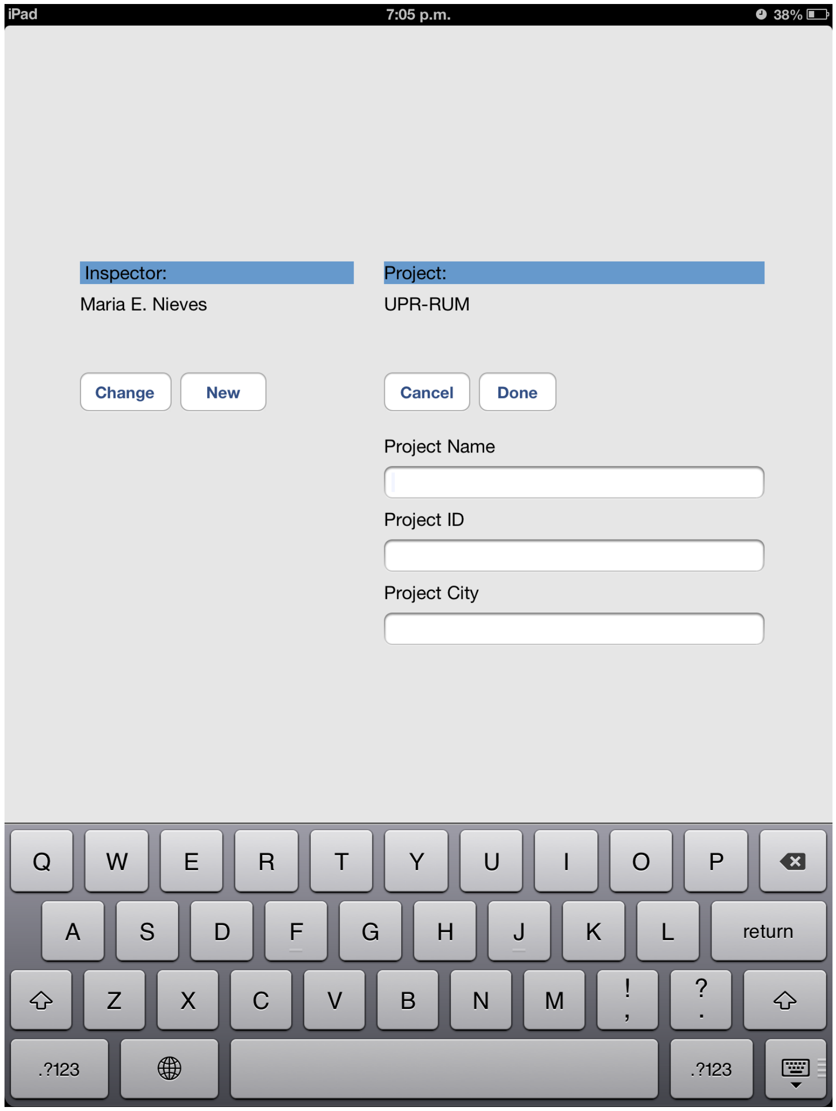


Figure 9: Enter basic project information in the T.A.I.P. application for iPad

In addition, the form needs to be fed with basic daily information, including the date, day of the week, name of the inspector, working hours, and weather. The date, day of the week, and name of the inspector, are automatically filled in the inspection form. The working hours and the weather data are items added manually by the inspector on a daily basis. The next step is to record the work executed in the field during the day.

The Daily Activities Report requires the inspector to document the quantities of the items performed during the day. This data is used to keep track of the project progress, and to compute the payment of the contractor at the end of the month. The information required to keep track of the work executed is a function of the following variables:

$$DR_A = (I, S, D, Q, U, L, V) \tag{1}$$

Where:

I: Item

S: Specification

D: Description

Q: Quantity Measured or Installed/In Place

U: Unit

L: Location

V: Quantity Approved

For each activity performed, the inspector records the item, the specification number, the activity description, quantity measured, unit, and location. The recording of this data is done in the same inspection forms of the T.A.I.P. application. The current form in the application lacks some of the fields to obtain all the necessary data. For this reason, additional fields will be added to the inspection form during the automation process. Figure 10 depicts the current form in the application for iPad, with the fields that need to be added to collect the complete information. The added fields are shown in the three boxes (orange, green and red).

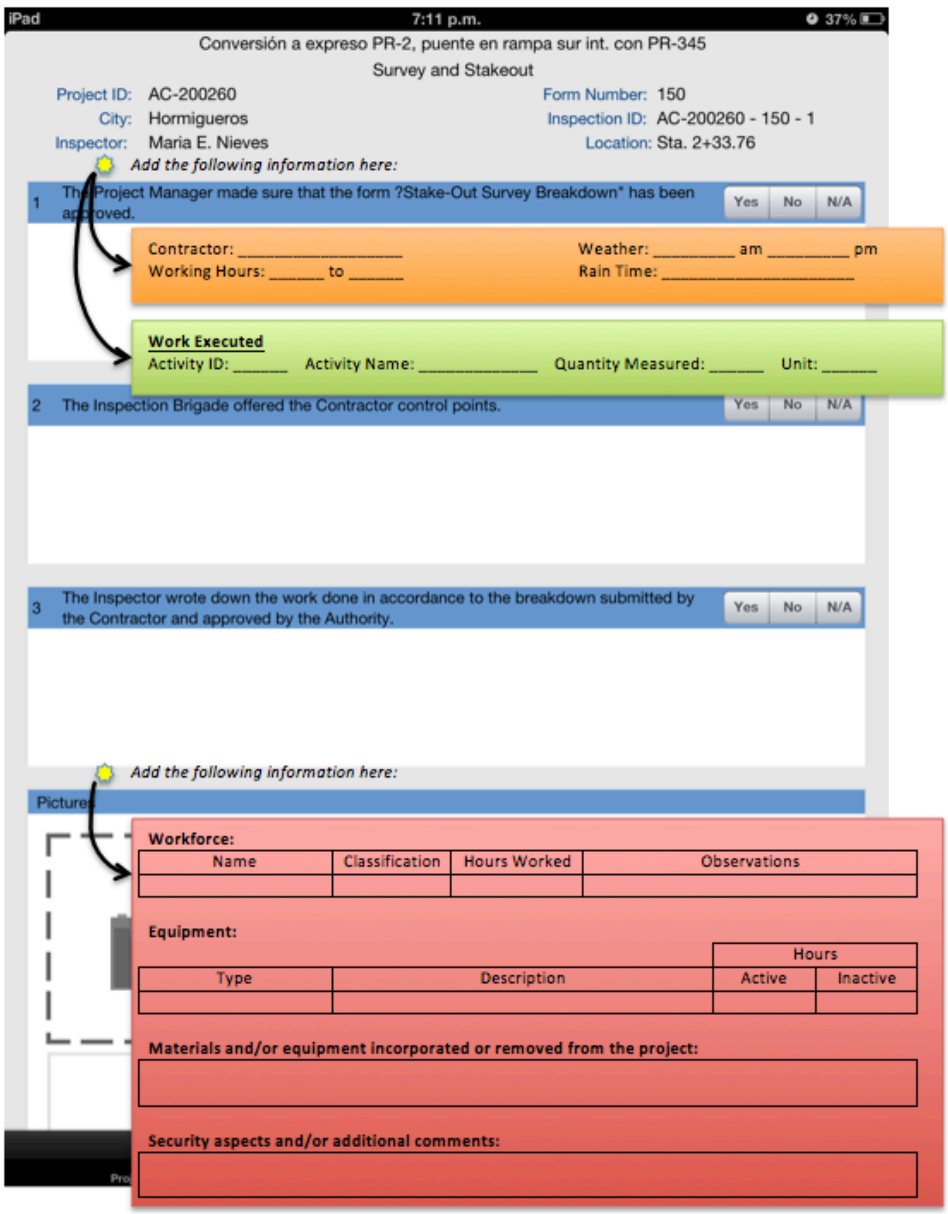


Figure 10: Inspection form filled in the T.A.I.P. application for iPad

The orange box represents the basic daily information that needs to be added to the current inspection form, while the green box show the work executed information that also need to be added. The basic information to be added is the name of the contractor, working hours, weather, and rain time. The name of the contractor will actually be entered in the first page of the application, where the other basic project information is entered. For this purpose the field of contractor needs to be added to the first screen, as shown in Figure 11. The inspector will enter the name of the contractor at the time he or she enters the rest of the project basic information. This information will appear automatically in the inspection form. The remaining daily basic information will be manually entered in the application on a daily basis.

In addition to the Contractor's name, a new set of fields is also included in the opening window. These fields stand for the oracle number, the federal number, and the contract number, which need to be added the first time a new project is entered into the database. The numbers are stored in the database for later use in the Monthly Progress Payment Reports, since these data is important to perform the project payments.

The green box shows the fields that have to be added to the inspection form in order to collect the necessary information for the work executed. This information is: activity ID or Item, the Activity Name or Description, the quantity measured or installed, and the units in which the item is measured. With this information in the inspection form, the inspector will be able to make the quality check of the activity at the same time he or she is collecting the data necessary for others reports, thus saving a considerable amount of valuable time.

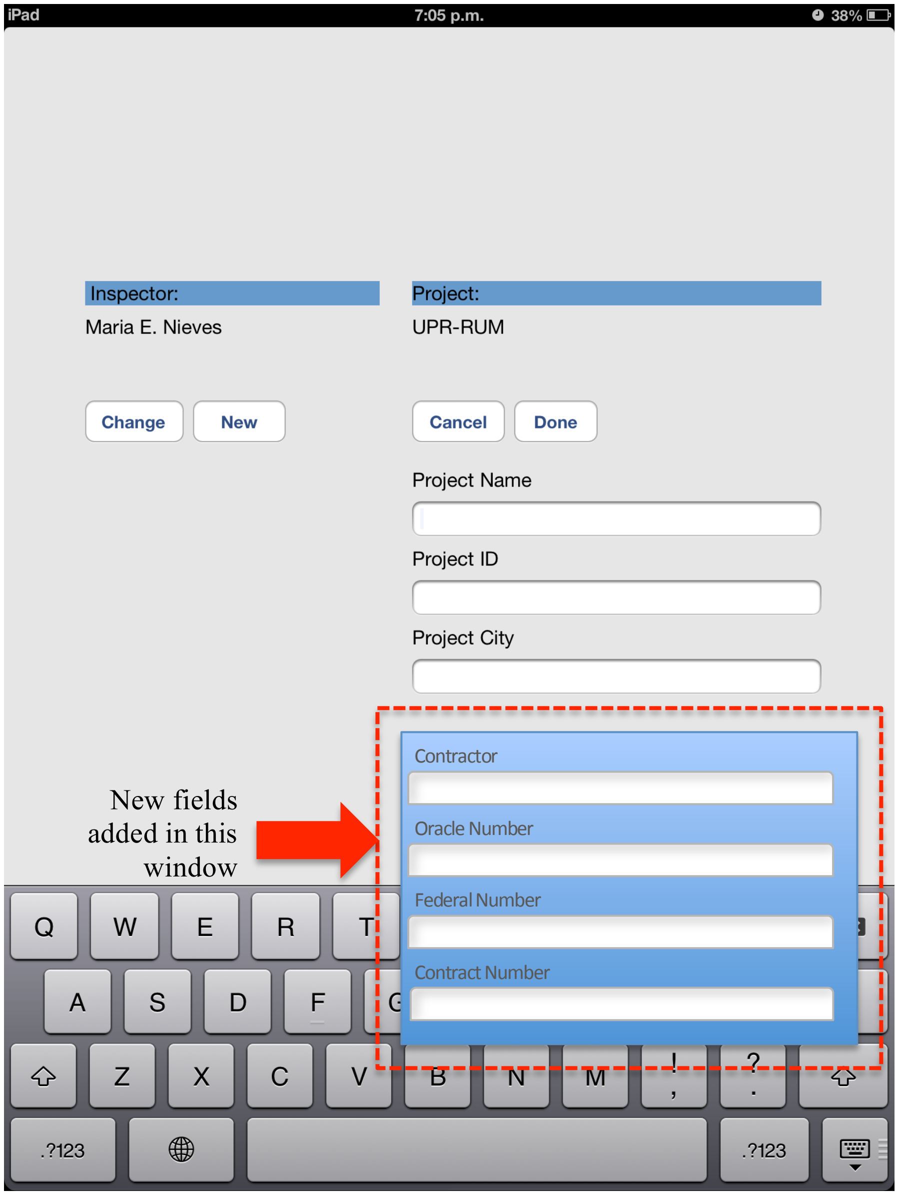


Figure 11: Updated basic project information screen in T.A.I.P.

Finally, the red box, shown in Figure 12, contains fields to collect the additional data in the Daily Inspection Report. This part collects the data regarding labor and equipment. The labor is referred to as workforce, and requires the name of the field personnel, the classification, working hours, and additional observations if necessary. The classification will be provided in a drop-down menu, and will contain the following typical classifications:

- Carpenter
- Cement Mason/Concrete Finisher
- Electrician
- Ironworker
- Laborers- unskilled
- Laborers- pipelayers
- Line construction- linemen
- Line construction- telephone linemen: ground and pole
- Pipefitter
- Plumber
- Power equipment operators
- Truck driver
- Welders
- Other

Equipment is the other main field required in the daily records. To record the equipment data, the form requires the type of equipment available at the field, the description of the equipment, including brand, model and capacity, among others, and the hours active and inactive. The form also includes a space to document the materials and/or equipment incorporated or removed from the project, and a space for security aspects or any other additional comment regarding the daily activities.

Workforce:

Name	Classification	Hours Worked	Observations

Equipment:

Type	Description	Hours	
		Active	Inactive

Materials and/or equipment incorporated or removed from the project:

Security aspects and/or additional comments:

Figure 12: Labor and Equipment Data Collection

After completing the inspection task, the inspector chooses to sign and generate the report. When the report is finalized, it is then uploaded to the database where it is stored for later reference. In some cases, one inspector may have inspected more than one activity the same day, or the same project may contain multiple inspectors; therefore, multiple Daily Inspection Reports will be created for the same project on the same day.

4.3.3 Office Reporting

After the field reporting process is finished, the next step is the office reporting, which consists in the creation of the Daily Inspection Report. As was mentioned in Chapter 3, the Daily Inspection Report is a document created by the project administrator with a summary of the work accomplished each day in the project. The summary of the work accomplished uses the data from the Daily Activities Reports of all the inspectors in the project. In addition, the project administrator includes other data regarding the activities performed during the day in the report.

With the automation of the daily reporting, the task of completing the Daily Inspection Report is simplified. The model gathers the data from all the Daily Activities Reports completed during a day, which could be various depending on the amount of inspectors in the project. The data from the work executed in each of the Daily Activities Reports is then summarized in one Daily Inspection Report. These data are extracted from the database to make the Daily Inspection Report. The Inspection Report is created partially filled with the basic project information, basic daily information, and work executed, similar to the case of the Daily Activities Report. Afterwards, it is responsibility of the project administrator to complete the report with the information of the administrative tasks accomplished during the day. Once the report is finished, it is uploaded to the database for storing. The process described is illustrated in Figure 13.

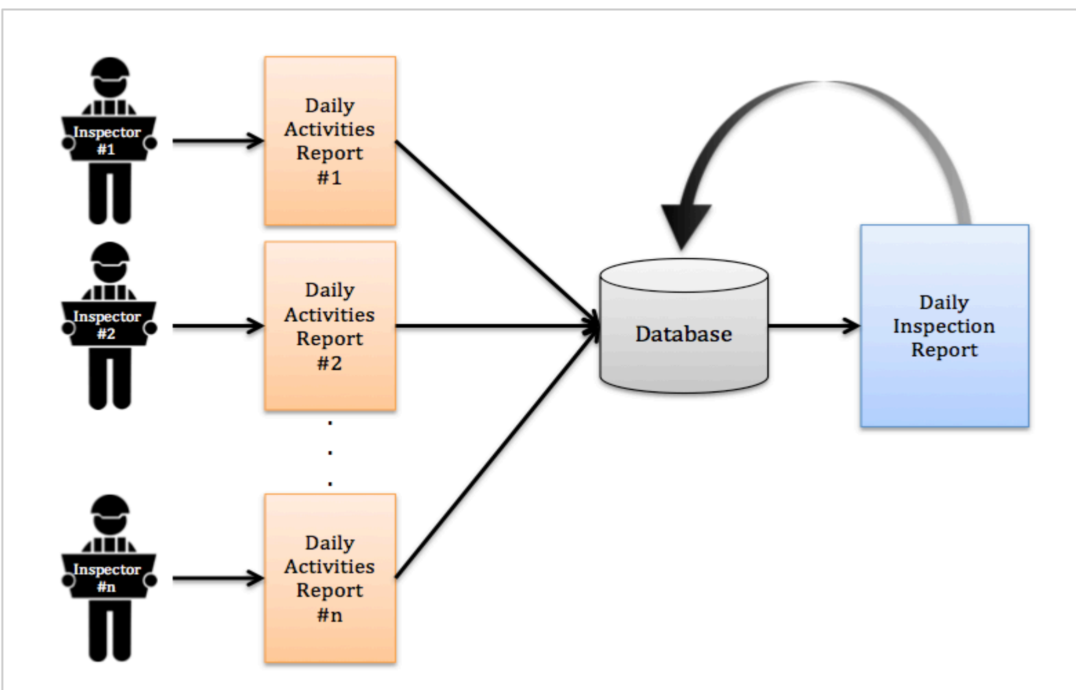


Figure 13: Daily Inspection Reporting Process

With the framework proposed in this thesis, the Daily Inspection Report will be semi-automated, by preparing the report partially filled with the basic project and daily information, and the data of the work executed collected by all the inspectors in the project during the workday. The basic project information is the Project ID, Project Name, City or Town, and Contractor. This information is input to the database before the project starts. Furthermore, the basic daily information contains the date, day of the week, inspector, weather, and working hours. This information is input by the inspectors each day. In addition, the data summarized in the Daily Inspection Report (DR_I) contain basic information about the work executed and inspected during a day. The data contained in the report is a function of the following variables:

$$DR_I = (R, E, D, C) \tag{2}$$

Where:

R: Record ID (Daily Activities Report Identification Number)

D: Activity Description

E: Engineer or Field Inspector

C: Contractor, Subcontractor or other Agency

At the end of the day, the project administrator accesses the report from a computer or tablet and the report is generated. The project administrator then, verifies the data from the field inspectors, and adds information regarding activities as manager during the day. Such activities include meetings, visits, and tasks performed, among others, as discussed in Chapter 3.

Figure 14 depicts the current Daily Inspection Report from the PRHTA with the data that has an automatic input in the report when generated. The blue fields represent the basic project and daily information stored in the database. The yellow fields represent the data from the work executed during the workday, which are extracted from the various Daily Activities Reports submitted by the field inspectors during the day. At the end of the day, the report is generated with the data in the yellow and blue fields. The project administrator should verify the data, complete the remaining portion of the report, and submit it to the database for storing and later reference.

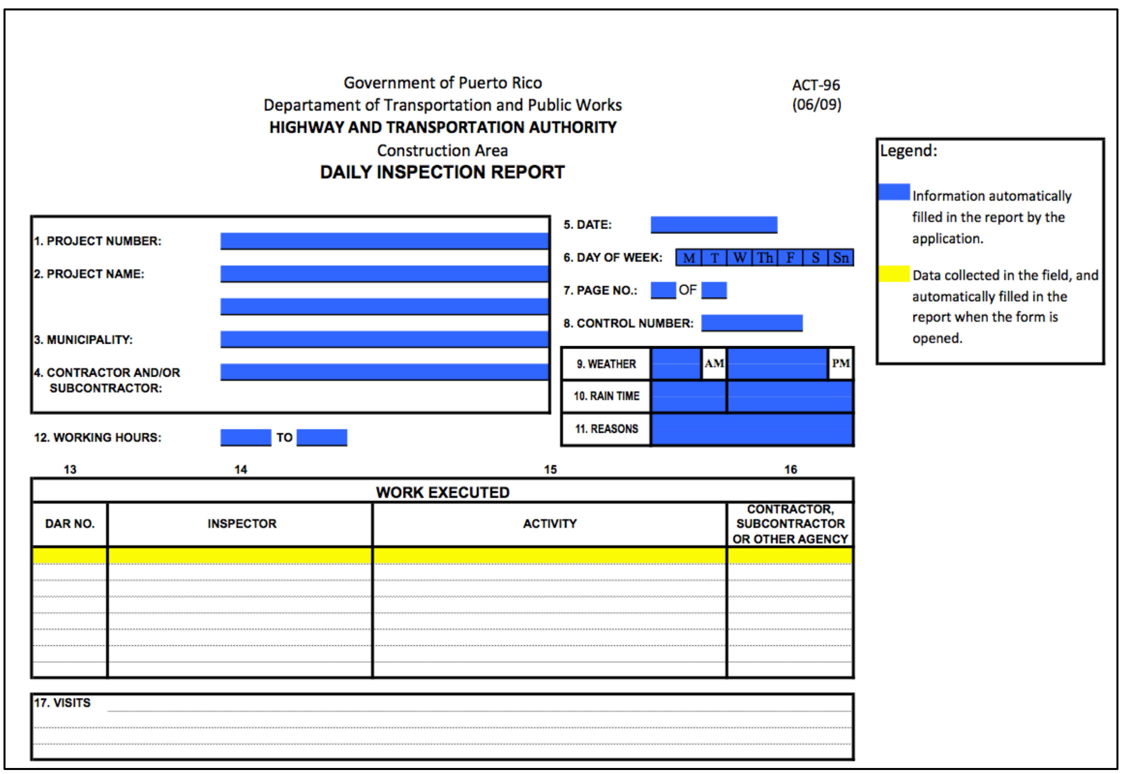


Figure 14: Example of the Daily Inspection Report with the data automatically input in the report

4.3.4 Overview of the Progress Monitoring Process

Project cost control is a critical aspect for delivering the project within the specified budget and timeframe. The key to a successful job for both, the owner and the contractor is staying within the budgeted cost and knowing when and where the costs are deviating from the planned values (Sears et. al., 2010). One of the principal aspects when controlling the costs is to periodically compare the actual costs with the budgeted or estimated costs. With this comparison, the contractor could know when the costs are surpassing the budget and when corrective actions are needed. Unfortunately, very often when the project managers notice significant discrepancies it is already too late to take remedial actions (Chiao Lin et al., 2012). As a solution to this problem, predictions of the possible project outcomes can be generated. Periodical predictions of the estimated cost to finish could be made in order to have a total estimate cost for the project that could be compared to the budgeted estimated cost at the beginning. With these predictions, project managers could take preventive actions prior to any delay or cost-increasing event that could lead to budget surpassing, rather than taking corrective actions after a cost-increasing event has occurred.

The other two processes presented in the flowchart of the framework for automation are the weekly and monthly reports. These two types of reports are designed to help the project administrator to keep good monitoring and control of the project. The weekly reports consist of progress S-Curves, where the original estimate, the actual costs, and predictions for the remaining part of the project are presented. Furthermore, the monthly reports consist of an accumulation of the completed work for the activities during a month's period and their costs. With this information, a report for the Progress Payment Report is created at the end of each month. The Progress Payment Report is the application for payment submitted monthly by the contractor for his work. These two kinds of reports are generated using a combination of the variables stored in the database with the daily reports, and additional information that needs to be input to the database. The variables needed to generate Progress Payment Report and S-Curves are: Item, Amount Measured or Installed, Unit and Costs. The cost of the activities is automatically acquired from the cost estimate submitted by the contractor for the particular project. The estimate submitted by the contractor is transformed into a field budget that is used to monitor field performance.

4.3.5 Weekly Progress Monitoring

To monitor the progress of a project two types of data are needed: the actual costs incurred in the project and the estimated cost to complete the project. With this data, and using the Cost-to-Cost method, a progress measure known as Percent Complete can be calculated. The Percent Complete, shown in Equation 3, uses the data collected of the actual costs incurred to the date and compare it to the estimated cost to complete the project, including changes, which results in an effective progress measure that is widely used in the construction industry. This means that the percent complete of the activities, and the percent complete of the project will be assessed by comparing the actual cost to date for the activities and for the project divided by the estimated cost of the activity or project.

$$Percent\ Complete = \frac{Actual\ Cost\ Incurred\ to\ Date}{Estimated\ Total\ Cost\ to\ Complete} x100\% \quad (3)$$

With the values for percent complete in every period, a graphical representation known as the S-curve can be generated. The S-curve represents the progress of the project by plotting the cumulative value against the project duration. The S-shape of the curve represent the way that construction projects commonly behave; slow in the beginning and ending periods, and faster in the middle, where most of the construction is taking place. This is a tool commonly used by owners and contractors for the project planning and control (Chao and Chien, 2010). An example of the S-curve is shown in Figure 15. A typical measure used for the cumulative value is the percent complete, cost based. The project duration is typically measured in terms of months or weeks, depending on the length of the project. The information typically used to generate the S-curve is shown in Table 2, and includes the cost incurred in the period, the cost to date, total estimated cost, and the percent complete.

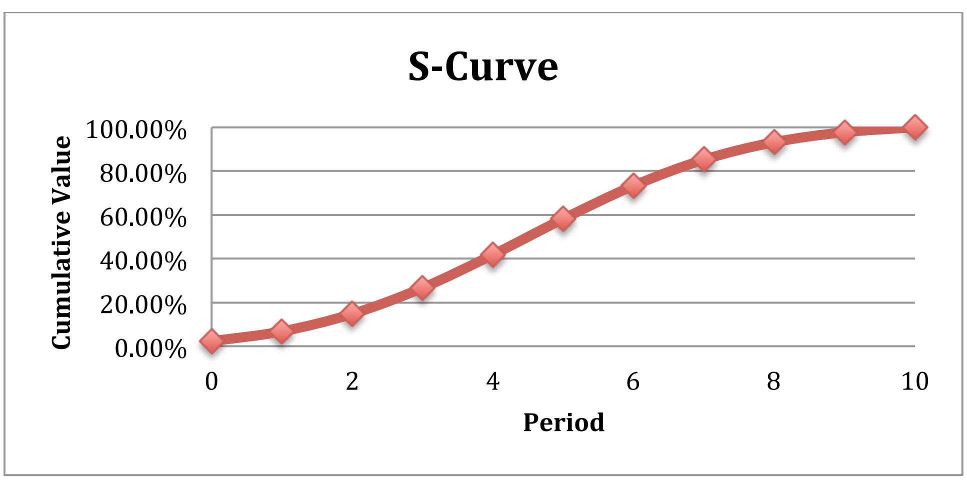


Figure 15: Example of an S-curve

Table 2: Data needed to generate an S Curve

Period	Cost this period	Cost to date	Total Estimated Cost	Percent Complete
Period 1	$ -	$ -	$ -	% -
Period 2	$ -	$ -	$ -	% -
Period 3	$ -	$ -	$ -	% -
.	.	.	.	.
.	.	.	.	.

Before the project starts, an S-curve is generated with the original estimated costs. The owner and the contractor use the estimated S-curve to forecast the cash flow and make the corresponding financial arrangements prior to the start of the project. In order to generate the curve, it is necessary to have a cost-loaded schedule of the project. This schedule represents when the contractor plans to perform the activities and the associated estimated cost for all activities, thus providing information of the estimated cost each period. With this information, the cost to date of each period can be calculated and later divided by the total estimated cost of the project to obtain the percent complete of the project. With this information, the original S-curve can be generated.

As the project progresses, the S-curve needs to be updated frequently with the data collected in the field, since the actual progress may deviate significantly from the original estimate. The project progress could be assessed at a certain time by comparing the actual percent complete with the estimated percent complete. This is achieved in the Actual Cost vs. Original Budget progress report. In Figure 16, a curve with the original budget and a curve with the actual progress to date at a particular data date are presented.

In this case, the discrepancy between the original budget curve and the actual costs can be appreciated, showing that the actual progress in the project is less than the original estimate. It could be inferred that the project is delayed at the current date when the actual work to date is compared to the planned work at the data date.

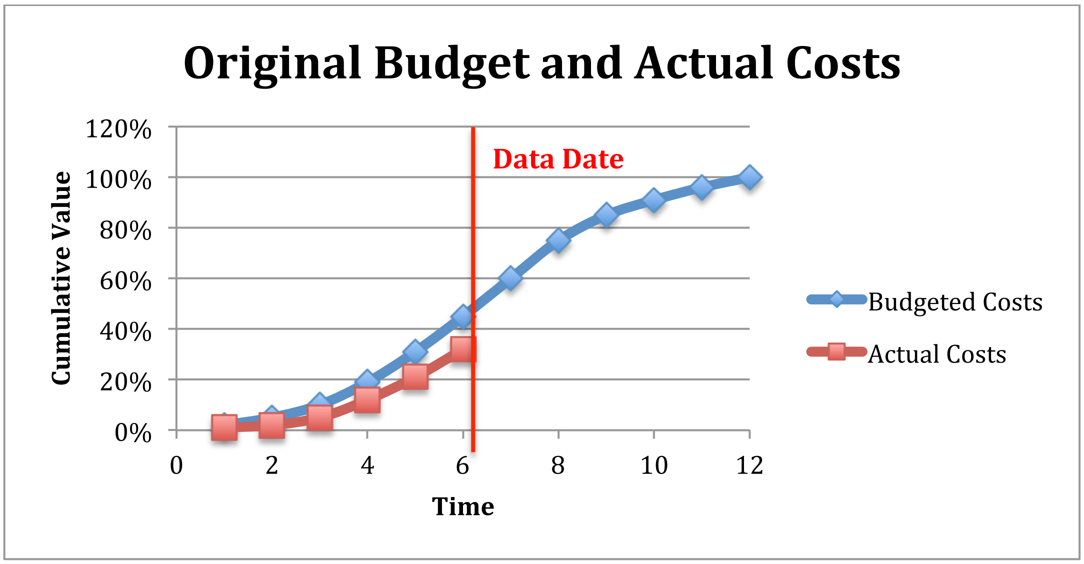


Figure 16: S-curve of the Original Budget vs. Actual Costs

It is important that the inspector records the correct amount of work being performed in the activities, since these quantities will be used to generate the S-curve in the progress report. Therefore, in order to have a good assessment of the progress of the project, accurate data is needed. If the inspection process is being performed in a correct way, the amounts recorded by the inspector should match or be very close to the amounts in the contractor's records. If the data being stored is not accurate, problems and discrepancies could emerge between the inspector and the contractor, which could lead to project claims and disputes.

4.3.6 Changes in the construction project

It is important to recognize that, due to the high uncertainty in the planning and design process of a project and due to the dynamic nature of construction, changes are very common in construction projects. Construction changes refer to work state, processes, or methods that deviate from the original construction plan (Park, 2012). Any additions, deletions or modifications to the scope of the project are considered changes (Hwang and Low, 2012). Changes can derive from different sources, various causes, can occur at any stage of the project, and can have considerable impacts on the overall performance of the project (Karim and Adeli, 1999; Motawa et al., 2007).

To control the impact of the changes it is critical to perform a good monitoring of the project. Figure 17 depicts the overall process of monitoring and controlling changes in a project. As the work progresses, inspectors collect data of the work performed and complete the daily inspection reports. Afterwards the data is processed to create monitoring reports, from where unexpected situations, or changes, can be detected. The change can be in the form of Change Order, Extra Work Order, or Time Extension. The Change Order is a directive to change the amount of an existing contract item. This occurs when the actual amount of work is different from the estimated, in which case the difference needs to be added or subtracted to match the actual work performed. Moreover, an Extra Work Order is a directive to add an item that was not originally included in the contract. This occurs when items that were not considered in the estimate are found to be necessary during the progress of the project, so a new item id and cost has to be assigned to the activity. Finally the time extension is a directive that awards more time to the contractor to complete the project. Time extensions are given when a delay in the project is expected due to situations beyond the contractor's control, such as additional tasks assigned or situations of force majeure.

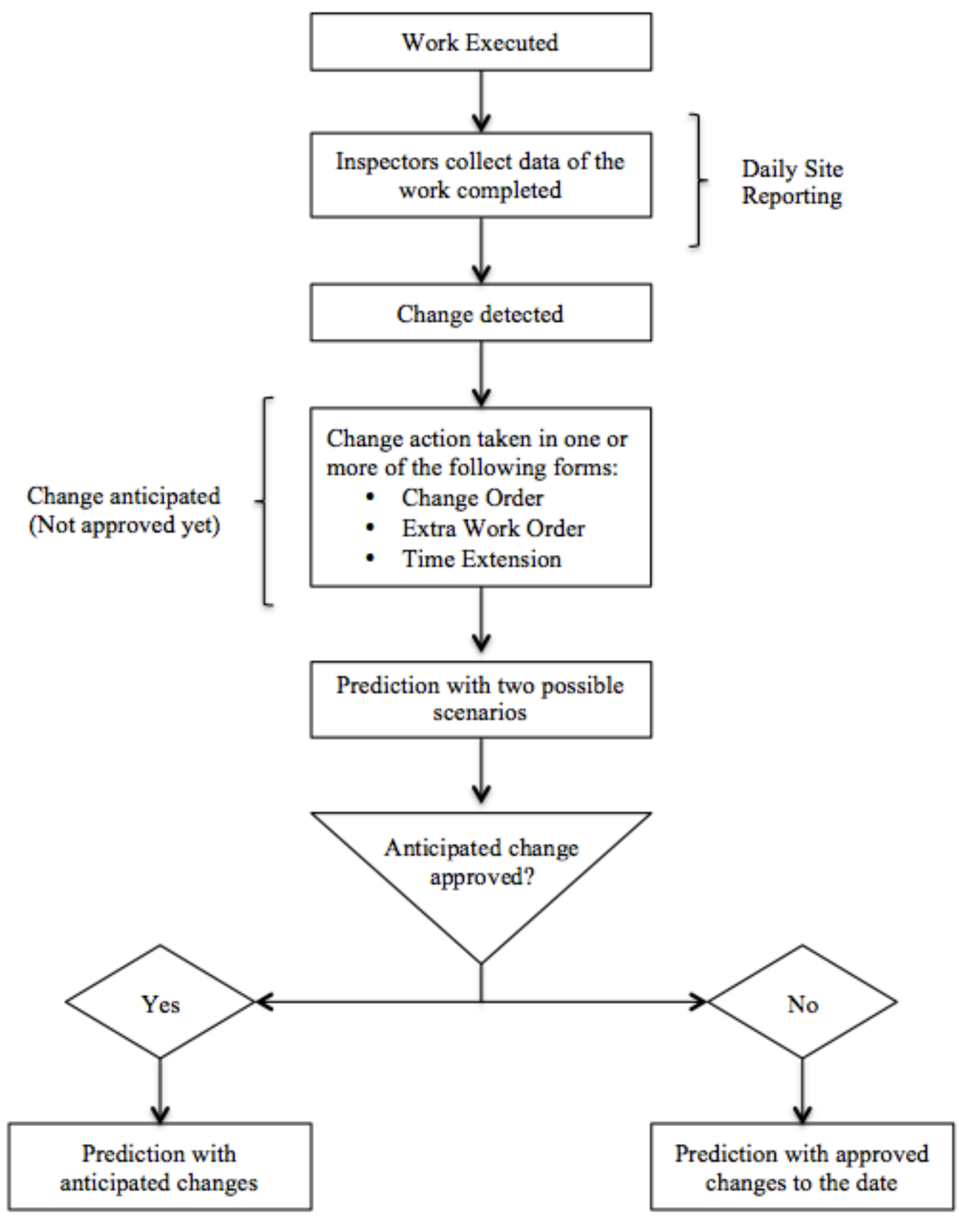


Figure 17: Process for detecting, monitoring and controlling changes

With the monitoring process, the changes are detected and control actions can be taken to address the needs of the change occurring. Actions may imply rising or lowering costs, schedule acceleration or compression, or providing more time to complete the project. For this reason, the next step is to predict the impact that the changes could have on the remaining portion of the project. At this point the change is anticipated, but not approved yet by the major officials of the PRHTA. Even though the outcome of the decision is still unknown at this stage, the project manager could start analyzing the two possible scenarios in order to provide a fast response to the decision. The two predicted scenarios are: the supervisors approved the changes, or the supervisors did not approved the changes, in which case the project remains with the changes approved previously to the date. These predictions could help the project managers take the appropriate actions to minimize the negative effects of the changes (Motawa et al., 2007).

An effective progress monitoring and controlling of any project requires the changes and predictions to be included in the analysis. When generating the S-curves it is critical to understand the importance of including any change in the calculation of percent complete. Since the percent complete is calculated with the total estimated cost of the project, any change in the project cost affects the total estimated cost, and thus the percent complete. So any changes such as change orders and extra work need to be included in the computations to measure the project progress. In addition, predictions of the progress for the remaining portion of the project could be generated to analyze the impact of the changes in the overall project progress.

In order to determine progress at the time of the analysis, percent complete, cost to date, and the total estimated cost are used. The cost to date is equal to the cost incurred in the project to the actual date. The total estimated cost is the original estimated project cost plus the cost changes to the date, including change orders and extra work orders. The formula to compute the total estimated cost at a certain time is shown in Equation 4.

$$Total\ Estimated\ Cost = Original\ Contract\ Cost + Changes \qquad (4)$$

The total estimated cost need to be recalculated in each period to make sure that all the changes up to the date are being accounted for. Changes that are anticipated in the project, but are not approved yet by the PRHTA, could be included in this calculation to make a prediction of the project progress with the anticipated changes. Once an accurate total estimated cost is computed, the percent complete is calculated, and the S-curve subsequently generated.

Approved and anticipated changes should be included in the estimated cost to complete. Approved changes are those already submitted and officially approved by the PRHTA. Anticipated changes are those detected, but not officially approved. It includes changes in any stage of the approval process, from the moment the change is detected, to later when the change order or extra work order is submitted but not yet approved, until the change order is formally approved by the officials in the PRHTA. If the change is justified it is usually approved, based on the feasibility of incorporating the change to the project. Once the change is approved it passes from anticipated to approved change.

4.3.7 Weekly Progress Reporting and Prediction Model

The framework developed in this thesis includes the generation of three weekly progress reports:

- Actual Costs versus Original Budget
- Prediction with Approved Changes
- Prediction with Anticipated Changes

The model for producing the three progress reports needs input from several sources. Prior to the project start, the cost proposal and a cost-loaded schedule need to be input into the database. As the work progresses on the jobsite the data from the daily reports is input by the inspectors and stored in the database. This information is crucial for the generation of the actual costs curve. In addition, the data regarding changes, if any, are needed. These data come from change orders and extra work orders, and should be input as soon as the changes are anticipated. Once all this information is gathered the reports can be generated. This process is depicted in Figure 18.

The Actual Costs versus Original Budget Report includes the values of the original estimated budget and the values of the costs to date. The graphical representation was shown in Figure15. The values for the actual costs curve are obtained from the data recorded daily by the project inspectors. The inspectors record in the application the number of the item inspected, the date, the quantity measured, and the units in which the item was measured. After the data is uploaded to the database, it is matched to the cost proposal to obtain the unit price and calculate the cost of the item measured during the day. With this information the cost in the period and the cost to date can be calculated. Table 3 details the information and calculations necessary to generate the actual costs S-curve.

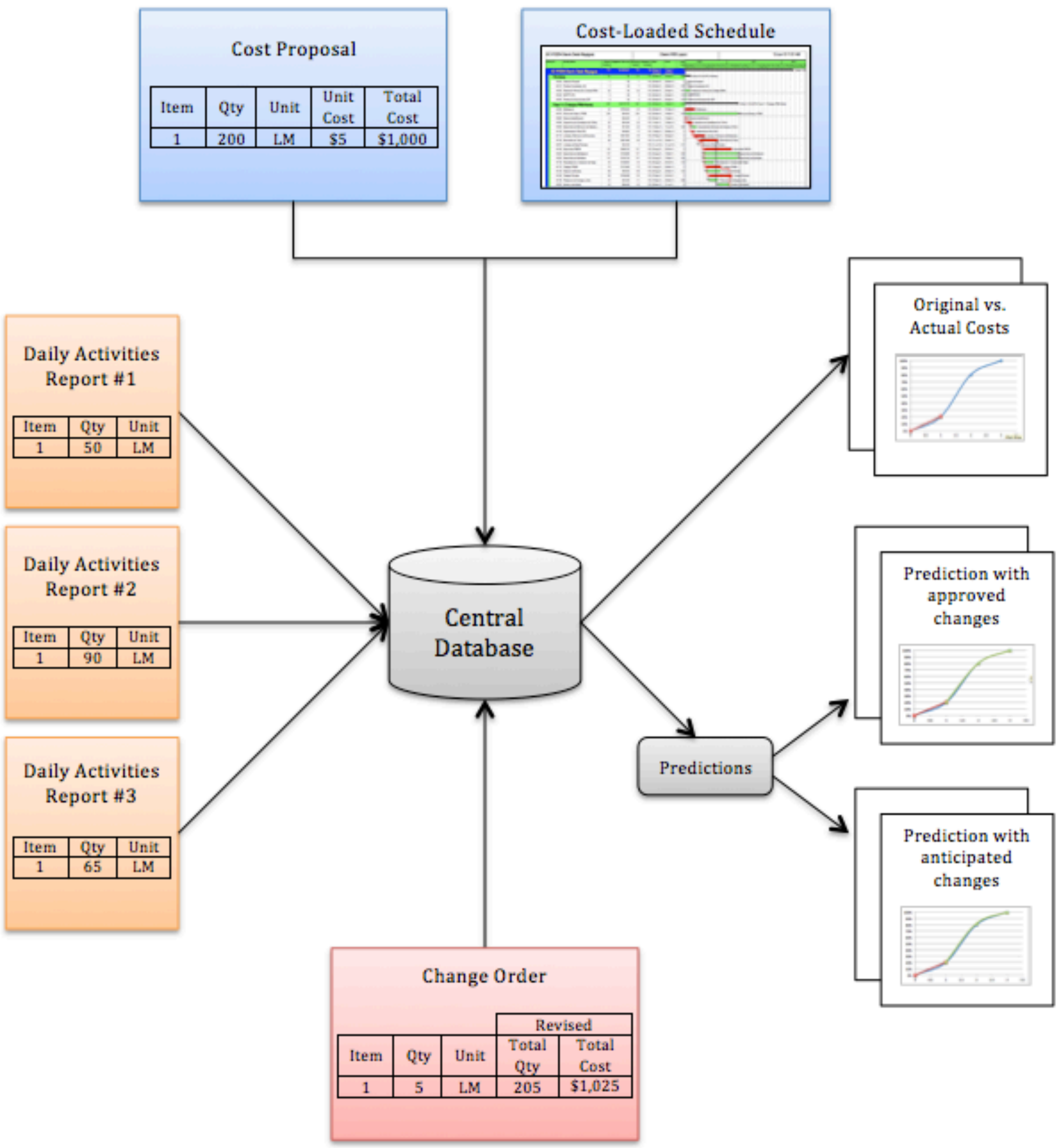


Figure 18: Progress reporting process

After making the analysis in Table 3, the system can update the S-curve with the actual progress of the project. The S-curve can be updated in any desired period of time, in this case, weekly. An example of the calculations to generate the curve is shown in Table 4. After making these calculations, the curve is generated using the data from the date and the percent complete. The dates can be accumulated in a period of one week, for example in this case, from 01/01/13 to 01/07/13 the item 1 reached 40% complete. The S-curve is plotted with the date or time period in the x-axis, and the % complete in the y-axis.

Table 3: Calculations for the Actual Costs S-Curve

Item No.	**Date**	**Qty.**	**Unit**	**Unit Price**	**Cost this period**	**Cost to date**	**Total Est. Cost**	**% Complete**
Recorded in the tablet application and uploaded to the database				Extracted from the cost proposal by matching the item number	Calculated: *Cost this period = Quantity Measured* Unit Price*	Calculated: *Cost to date = Previous period Cost to date + Cost this period*	Calculated: *Total Estimated Cost= Cost to date+ Estimated Cost to complete including Change Orders and Extra Work*	Calculated: *%Complete = Cost to date/ Total Estimated Cost*

Table 4: Example of the calculations to generate the S-curve

Item No.	**Date**	**Qty.**	**Unit**	**Unit Price**	**Cost this period**	**Cost to date**	**Total Est. Cost**	**% Complete**
1	01/01/13	10	LM	$1	$10	$10	$100	10%
1	01/06/13	10	LM	$1	$10	$20	$100	20%
1	01/07/13	20	LM	$1	$20	$40	$100	40%

After plotting the actual progress curve, a forecast of the future progress can be calculated. The Prediction with Approved Changes Report consists of a prediction of the future progress of the project after adding the changes already approved to the date to the calculation of the total estimated cost. Hence, the resulting report includes the actual progress to date plus the predicted progress to complete the project, including the approved changes to the date. The original budgeted costs curve is included in all reports to compare the actual project performance to the original estimate, thus checking if the project is going according to the plan. The curves generated for this report are shown in Figure 19.

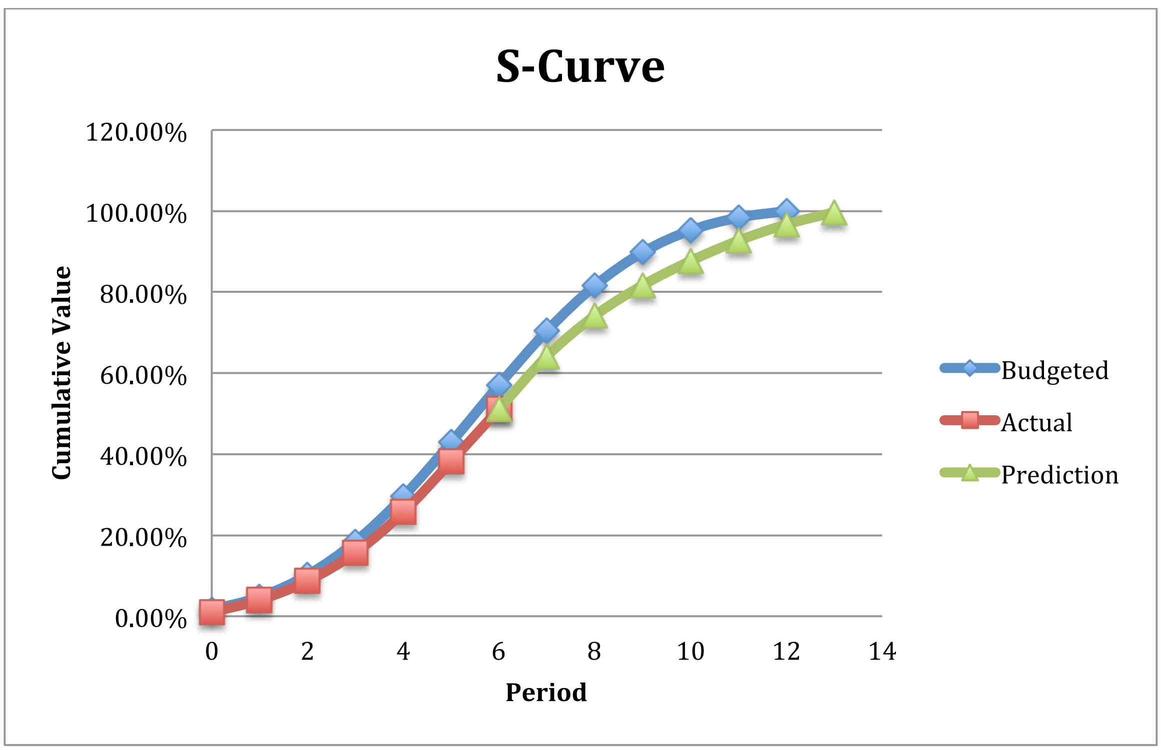


Figure 19: Prediction with approved changes S-Curve

Moreover, the Prediction with Anticipated Changes Report consists of predicting the future progress of the project by adding the changes anticipated to the calculation of the estimated cost to complete. Therefore, the resulting report includes the actual progress to date plus the predicted progress to complete, including the approved and the anticipated changes to the date. The original budgeted costs curve is also included to compare the original estimate to the actual progress. The result is a set of curves similar to the ones shown in Figure 19. This information allows the project administrator to consider anticipated changes as early as possible to take the necessary corrective actions. It also allows the PRHTA officials to be informed about possible changes in cost and completion dates associated with the changes anticipated.

The prediction of the future progress is accomplished by distributing the remaining costs to complete the project in the remaining time expected to finish the job. Several approaches could be used to predict the outcome of the project. Further research needs to be done to determine the best method to make this prediction.

4.3.8 Monthly Progress Payment Reports

In addition to the weekly progress reports, monthly progress reports are generated at the fourth step of the framework. These reports contain the data from the activities accomplished during an entire month period, and the cost of each activity, to generate what is known as the Progress Payment Reports. In the typical construction practice, the Progress Payment Report is generated by the contractor and approved by the inspector or project administrator. PRHTA practices vary from the common practice, in the fact that the project administrator is one in charge of generating the Progress Payment Report. The highway construction contractor still maintains a record of the activities accomplished, and at the end of the month, or the established pay period, the contractor and the project administrator have a meeting to compare the data and come up with the final Progress Payment Report.

In the framework developed, the Progress Payment Report will be automatically generated by the system using the data input by the inspectors in the daily reports. Additional data is needed from the cost proposal to obtain the unit prices of each item, and the total estimated amounts of each item. Also, data regarding changes are necessary to update the total estimated cost of the project and calculate an accurate percent complete of the project. The data are accumulated and reported at the end of the pay period. The general process is depicted in Figure 20.

The monthly Progress Payment Report contains data showing the contract amount, the work performed by the contractor in the period, and the percent completed of the project, among others. In this report, the amount of work completed each period is recorded and the costs of each activity are calculated, based on the cost of each item in the contract. Afterwards, the amount completed in each period is added to the amount previously completed to obtain the cost to date. In addition, the percent complete of the period is calculated by dividing the cost of the period by the total cost to complete the project. The percent complete to the date is calculated as shown previously in Equation 3, where the cost to date is divided by the total cost to complete the project. Table 5 shows all the data needed to complete the Progress Payment Report and the calculations required for some of the parameters. Once all the data in the table is collected and computed the Progress Payment Report can be created by the system, under the request of the project administrator.

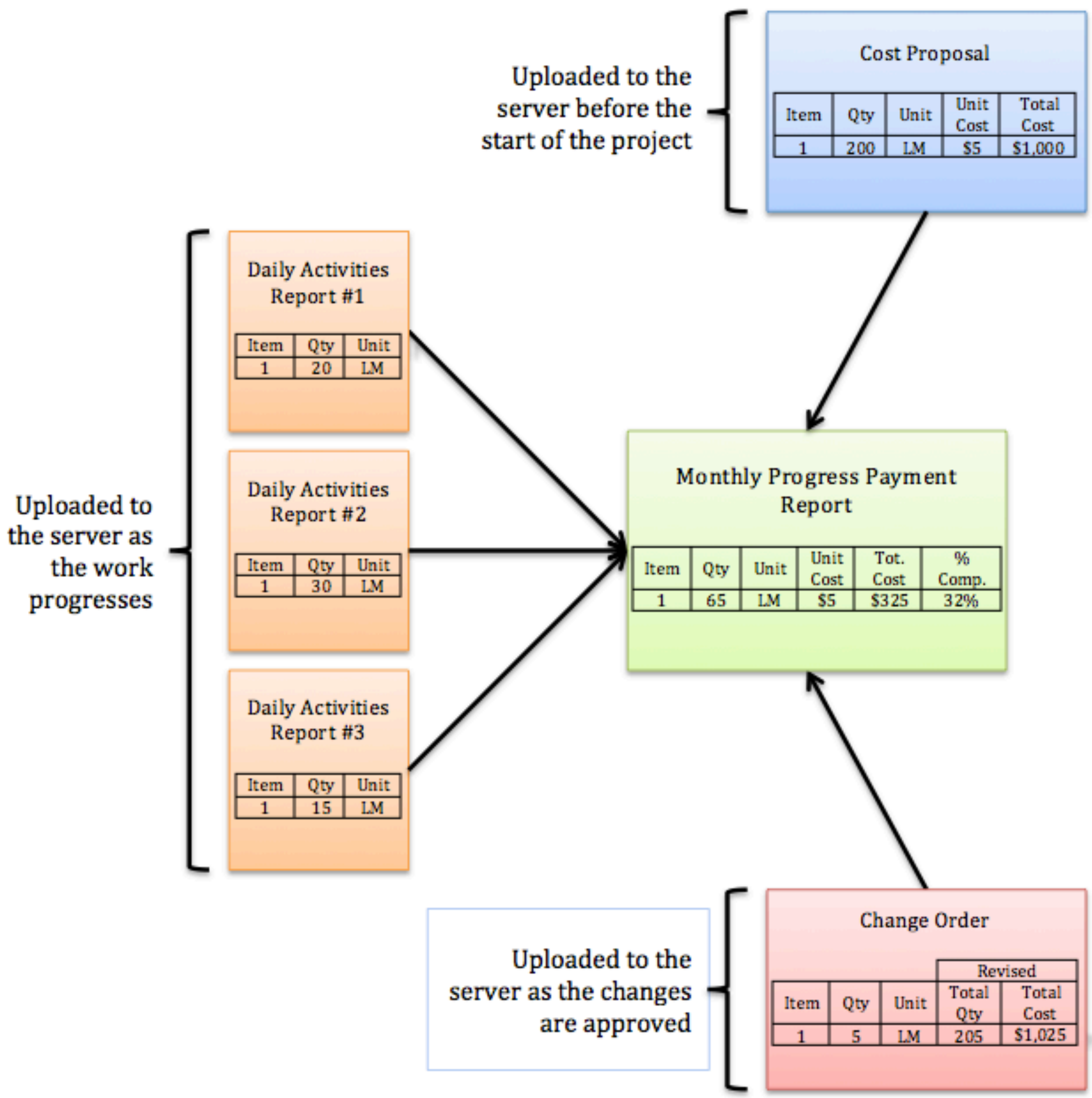


Figure 20: Monthly Progress Payment Report Process

Table 5: Calculations for the Monthly Progress Payment Report

1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
tem No.	**Spec.**	**Description**	**Unit**	**Quantity Measured**	**Unit Price**	**Cost this period**	**Cost to date**	**Total Estimated Cost**	**% Complet**
ecorded in the pplication and ploaded to the database		Matched in the database with the Item Number	Recorded in the tablet application and uploaded to the database		Extracted from the cost proposal by matching the item number	Calculated: *Cost this period = Quantity (5) * Unit Cost (6)*	Calculated: *Cost to date = Previous Cost to date + Cost this period (7)*	Calculated: *Total Estimated Cost = Cost to date + Estimated Cost to complete including Change Orders and Extra Work*	Calculated: *%Complete = Cost to date (8) * Total Estimated Co (9)*

4.4 Distribution of the reports

As previously shown, with the automation of the inspection process the data collected will be stored in a central database. The location of the server hosting the database could be in a physical site such as the central offices of the agency, or in a virtual cloud computing system. This allows the information to be accessed or viewed by more people related to the project. The information could be easily read or retrieved, from any computer or mobile device by connecting to the server. The server could have different levels of access and safety according to the hierarchy of the people involved in the project. When given the login information to a new user, different authority levels could be given in accordance to the hierarchy of the user in the project. This allows the information to be viewed, but not necessarily edited, by all the people involved in the project, providing transparency to the process. In addition, the fact that the Contractor has the information from the inspection available, could promote a better communication between the parties, thus saving time and money from the project.

The proposed framework is capable of generating four kinds of reports necessary to keep record of the project and provide an effective monitoring of the project progress. The system generates these reports with the data input on a daily basis by the project administrators and the field inspectors. The data is input from different sources: a mobile computing application, computer uploads, and the user interaction with the system. The processes described in this chapter are studied in more detail in Chapter 5 with the illustration of an example.

CHAPTER 5: EXAMPLE APPLICATION OF THE FRAMEWORK

5.1 Description of the Project

This chapter presents an example application of the proposed framework by presenting an application of the model in a real highway construction project. For this purpose, real data from a recent PRHTA project was acquired. The project selected for the study is the West Detour of Mayagüez, Phase 3, from the intersection between the PR-2 and the PR-64 to the entrance of the Community El Maní. The project consists on the improvements of the existing road, adding a lane, a signalized intersection, illumination, and pavement markings, among others. Pictures of the project are shown in Figure 21 and Figure 22.

The notice to proceed stated that the project was to begin by March 26, 2010, and had to finish by March 14, 2012. This target was not accomplished, and instead of lasting the twenty-five months planned, the project reached substantial completion by August 13, 2012, after thirty months of work. The administrative work is still in progress. In terms of costs, the original contract amount was $10,875,000.00, which was not accomplished as well. The revised contract amount of the project was $12,036,242.50, which means that the project surpassed its budget by $1,161,242.50. Several change orders and extra work orders occurred during the project, which are illustrated in the example presented in this chapter.

Figure 21: West Detour Mayagüez Project (Picture 1)

Figure 22: West Detour Mayagüez (Picture 2)

From the thirty months that the project lasted, Month #12 was picked to show the entire process of daily reporting and progress monitoring proposed by the framework developed. This month was chosen for convenience because it contains changes approved and changes anticipated, thus in the example the different cases in the progress monitoring reports can be presented. Reports for the rest of the months in the project were also created, and can be found for reference in the Appendix.

The example presented in this chapter contains real data acquired from the baseline cost-loaded schedule, the Monthly Progress Payment Reports, the Change Orders, and Extra Work Orders. The contractor of the project, Tamrío, Inc, provided these data. In addition, the times of the changes anticipated were assumed by the author, since there is no way to know this information after the project is finished, unless the anticipation was recorded, but that was not the case for this project.

5.2 Daily Reporting

The first step for the daily site reporting is to collect the data in the field using a mobile device (iPad, Android or Surface Tablet). This process is depicted in Figure 23. The inspector opens the T.A.I.P. application and chooses the project from a list, or creates a new project by entering the project basic information directly in the tablet. Then the application will direct the user to a list of specifications. These specifications are the ones found in the PRHTA Manual for Standard Specifications. Next, the user chooses from the list, the specification that will be inspected, and the inspection form will appear.

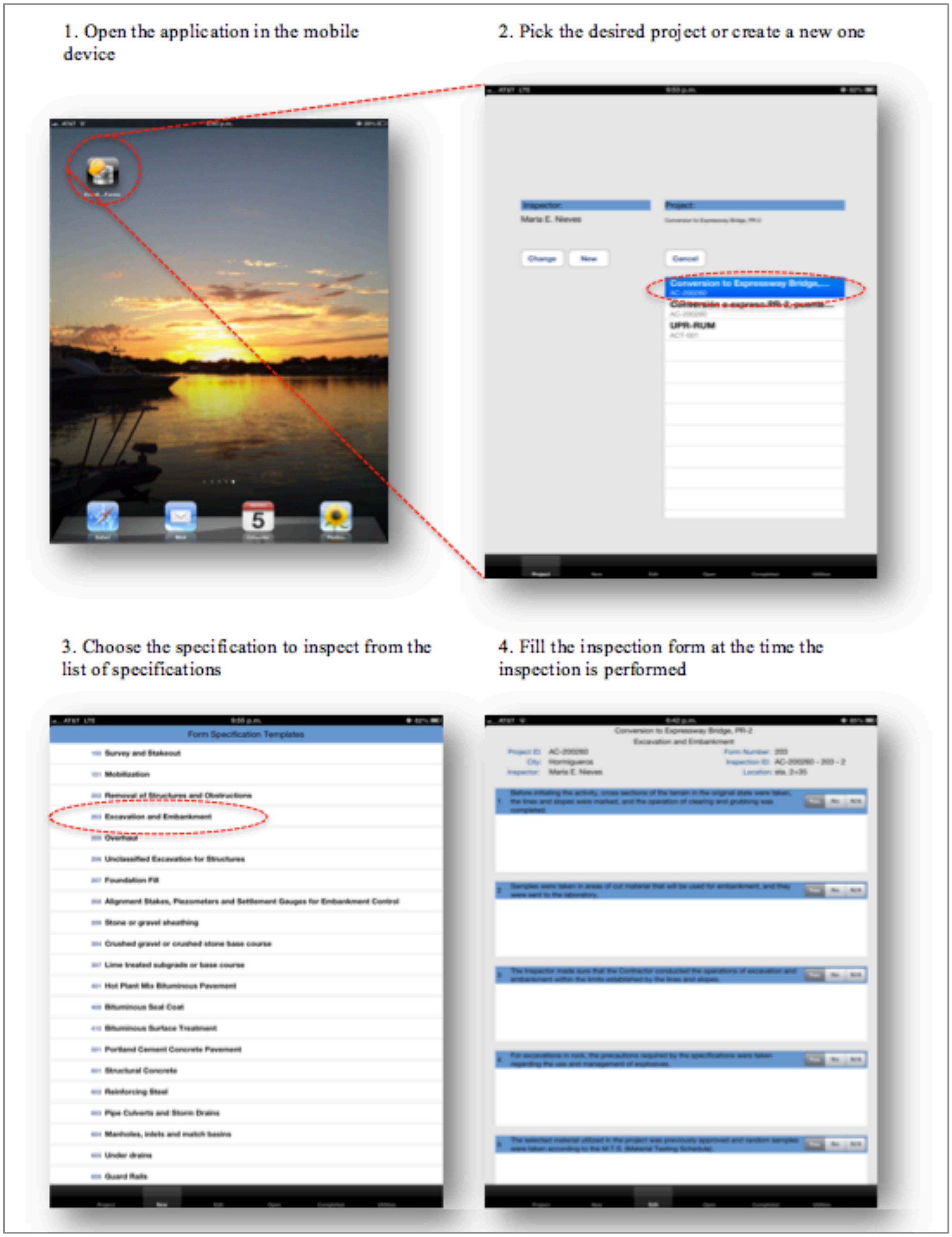


Figure 23: Example of the T.A.I.P. application

The inspection form is filled as the inspected activity is performed. This form collects the basic project and daily information, and the quantities measured, at the same time it provides a checklist of the aspects that should be inspected in order to ensure the quality of the inspection. An example of a completed inspection form is shown in Figure 24.

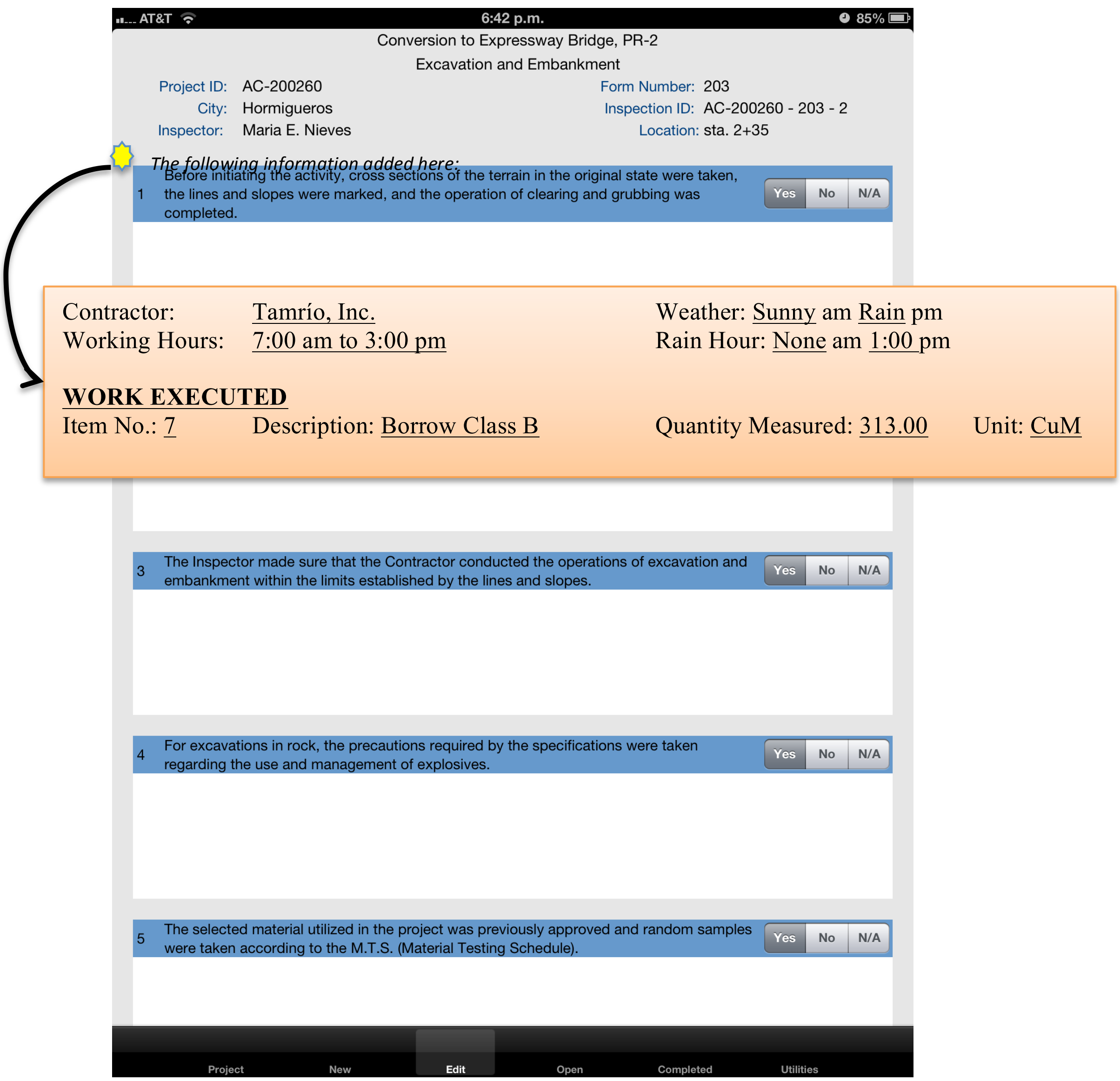


Figure 24: Example of the inspection form recorded in the field

After the data is recorded in the mobile device, it is uploaded to the database using a wireless connection. The data is organized and stored for the creation of other reports. The first report created is the Daily Activities Report. Figure 25 shows an example of the data stored in the database, and the Daily Activities Report as an output of the process. This report is generated at the end of the day with the fields in yellow already completed. The inspector then verifies the information and completes the report by adding the information that corresponds to the remaining portion of the report. The completed reported is shown in Figure 26a and Figure 26b.

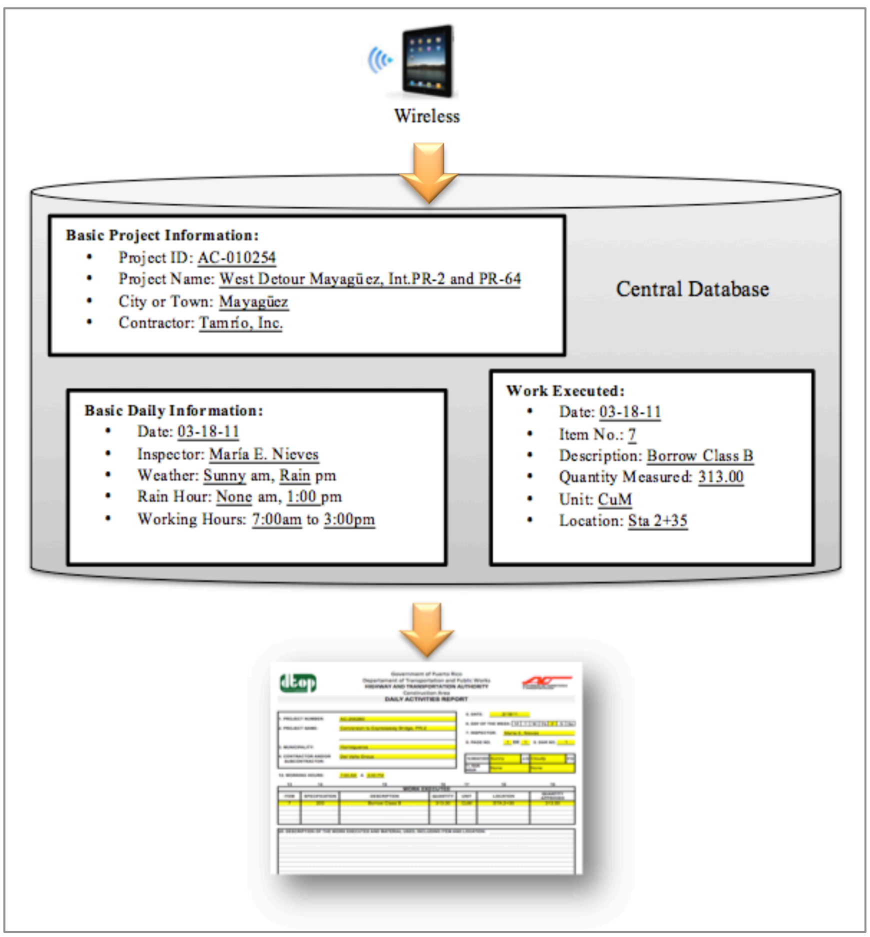


Figure 25: Data stored in the database for the Daily Activities Report

Government of Puerto Rico
Departament of Transportation and Public Works
HIGHWAY AND TRANSPORTATION AUTHORITY
Construction Area

AUTORIDAD DE CARRETERAS Y TRANSPORTACIÓN

DAILY ACTIVITIES REPORT

1. PROJECT NUMBER: AC-010254
2. PROJECT NAME: West Detour Mayagüez, Phase 3
PR-2 Int. PR-64
3. MUNICIPALITY: Mayagüez
4. CONTRACTOR AND/OR SUBCONTRACTOR: Tamrío, Inc.

5. DATE: 3/18/11
6. DAY OF THE WEEK: M | T | W | Th | [redacted] | S | Sn
7. INSPECTOR: María E. Nieves
8. PAGE NO. 1 **OF** 1 **9. DAR NO.** 1

10.WEATHER	Sunny	AM	Rain	PM
11. RAIN HOUR	None		1:00 PM	

12. WORKING HOURS: 7:00 AM **TO** 3:00 PM

WORK EXECUTED

13 ITEM	14 SPECIFICATION	15 DESCRIPTION	16 QUANTITY	17 UNIT	18 LOCATION	19 QUANTITY APPROVED
7	203	Borrow Class B	313.00	CuM	STA 2+35	313.00

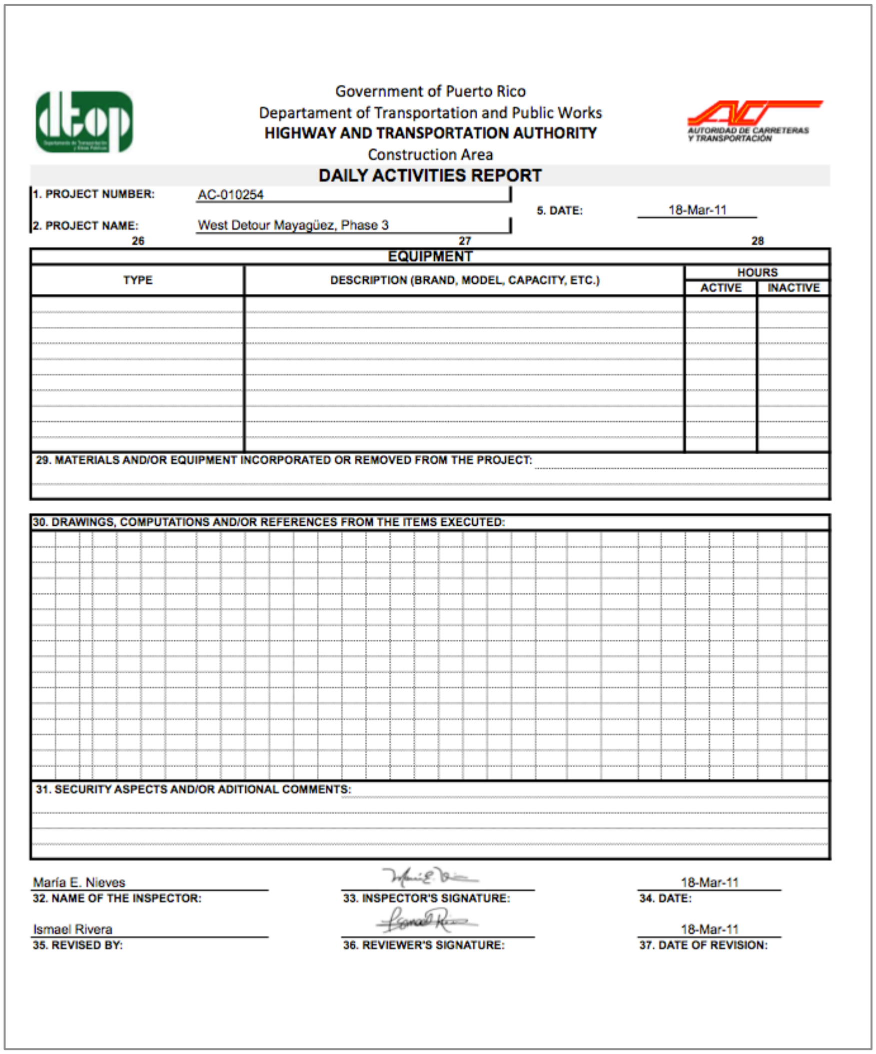
20. DESCRIPTION OF THE WORK EXECUTED AND MATERIAL USED, INCLUDING ITEM AND LOCATION:

21. SAMPLES TAKEN: None

WORKFORCE

22 NAME	23 CLASSIFICATION	24 HOURS WORKED	25 OBSERVATIONS
Juan Pérez	worker	8	
Luis García	worker	8	

Figure 26a: Example of the Daily Activities Report (Page 1 of 2)



Government of Puerto Rico
Departament of Transportation and Public Works
HIGHWAY AND TRANSPORTATION AUTHORITY
Construction Area

DAILY ACTIVITIES REPORT

1. PROJECT NUMBER: AC-010254
2. PROJECT NAME: West Detour Mayagüez, Phase 3
5. DATE: 18-Mar-11

26 27 28

EQUIPMENT

TYPE	DESCRIPTION (BRAND, MODEL, CAPACITY, ETC.)	HOURS	
		ACTIVE	INACTIVE

29. MATERIALS AND/OR EQUIPMENT INCORPORATED OR REMOVED FROM THE PROJECT:

30. DRAWINGS, COMPUTATIONS AND/OR REFERENCES FROM THE ITEMS EXECUTED:

31. SECURITY ASPECTS AND/OR ADITIONAL COMMENTS:

María E. Nieves
32. NAME OF THE INSPECTOR:
33. INSPECTOR'S SIGNATURE:
18-Mar-11
34. DATE:

Ismael Rivera
35. REVISED BY:
36. REVIEWER'S SIGNATURE:
18-Mar-11
37. DATE OF REVISION:

Figure 26b: Example of the Daily Activities Report (Page 2 of 2)

After all the inspectors have completed their respective inspections tasks and have uploaded the data from the mobile devices to the database, the Daily Inspection Report is created. The process is similar to create this report is similar to the process of creating the Daily Activities Report. The information input to the report is also similar, with a difference in the data from the work executed. In the case of the Daily Inspection Report, the data of the work executed input to the report is the only the description of the item, the inspector who performed the inspection, the contractor, and the number of the Daily Activities Report that contain the information about the activity. Figure 27a and Figure 27b depict the Daily Inspection Report generated.

Government of Puerto Rico
Departament of Transportation and Public Works
HIGHWAY AND TRANSPORTATION AUTHORITY
Construction Area
DAILY INSPECTION REPORT

1. PROJECT NUMBER: AC-010254
2. PROJECT NAME: West Detour Mayagüez, Phase 3
PR-2 Int. PR-64
3. MUNICIPALITY: Mayagüez
4. CONTRACTOR AND/OR SUBCONTRACTOR: Tamrío, Inc.

5. DATE: 18-Mar-11
6. DAY OF THE WEE M | T | W | Th | ■ | S | Sn
7. PAGE NO. 1 **DE** 1
8. CONTROL NUMBER: 215-12

9.WEATHER	Sunny	AM	Rain	PM
10.TIME LOST	3		HOURS	
11. REASONS	Rain			

12. WORKING HOURS: 7:00 AM **A** 3:00 PM

WORK EXECUTED

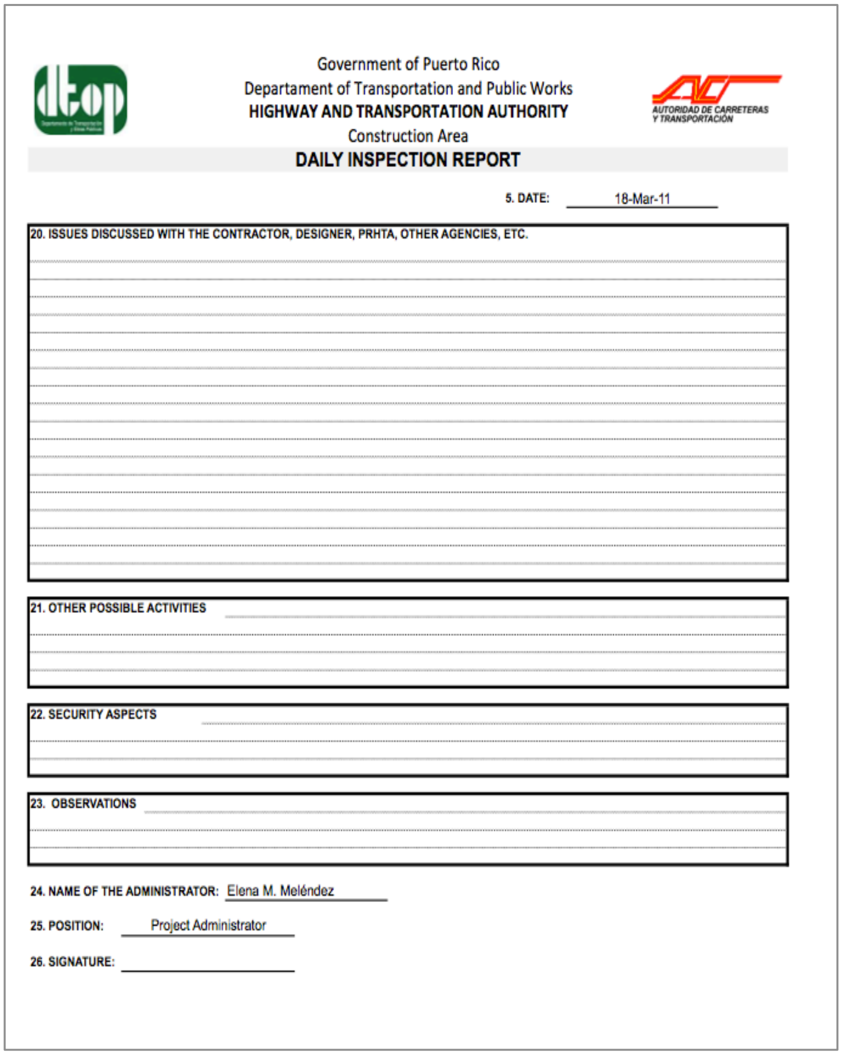
13 DAR NO.	14 INSPECTOR	15 ACTIVITY	16 CONTRACTOR, SUBCONTRACTOR OR OTHER AGENCY
1	María E. Nieves	Borrow Class B	Tamrío, Inc.
2	David Quintana	Clearing and Grubbing	Tamrío, Inc.
3	Wilfredo López	Subbase Course	Tamrío, Inc.

17. VISITS Visit from the Project Supervisor, Luis Santiago, at 2:00pm.

18. MEETINGS Meeting with the Contractor to discuss the last details of the Change Order that is going to be submitted today.

19. TASKS PERFORMED (PHONE CALLS, E-MAILS, LETTERS, ETC.)
Worked in the preparation of a Change Order Request.

Figure 27a: Example of the Daily Inspection Report (Page 1 of 2)



Government of Puerto Rico
Departament of Transportation and Public Works
HIGHWAY AND TRANSPORTATION AUTHORITY
Construction Area
DAILY INSPECTION REPORT

AUTORIDAD DE CARRETERAS Y TRANSPORTACIÓN

5. DATE: 18-Mar-11

20. ISSUES DISCUSSED WITH THE CONTRACTOR, DESIGNER, PRHTA, OTHER AGENCIES, ETC.

21. OTHER POSSIBLE ACTIVITIES

22. SECURITY ASPECTS

23. OBSERVATIONS

24. NAME OF THE ADMINISTRATOR: Elena M. Meléndez

25. POSITION: Project Administrator

26. SIGNATURE:

Figure 28b: Example of the Daily Inspection Report (Page 2 of 2)

Similar to the process of the Daily Activities Report, the Daily Inspection Report is created only partially filled with the information from the basic project information, basic daily information, and work executed. The rest of the report has to be later completed by the project administrator at the end of the workday. After the daily reports are completed they are uploaded back to the database for storing, and later reference in case of claims and disputes, when documentation is extremely important.

5.3 Progress Monitoring Reports

The first step for creating the progress monitoring reports is to plot the original estimated S-curve. This curve is created with the information provided in the cost-loaded schedule of the project. The data corresponding to the original estimate for this project is shown in Table 6. The plot of the cumulative cost against the period results in the original budgeted curve of the project, which is shown in Figure 28.

Table 6: Data for the original estimated budget of the project

Period (Months)	Cost this period	Cumulative Cost	% Complete this period	Cumulated % Complete
1	$48,420	$48,420	0.45%	0.45%
2	$400,683	$449,103	3.68%	4.13%
3	$447,503	$896,606	4.11%	8.24%
4	$106,999	$1,003,605	0.98%	9.23%
5	$314,760	$1,318,365	2.89%	12.12%
6	$406,072	$1,724,437	3.73%	15.86%
7	$568,769	$2,293,206	5.23%	21.09%
8	$553,975	$2,847,181	5.09%	26.18%
9	$467,294	$3,314,475	4.30%	30.48%
10	$267,595	$3,582,070	2.46%	32.94%
11	$239,903	$3,821,973	2.21%	35.14%
12	$1,526,359	$5,348,332	14.04%	49.18%
13	$531,571	$5,879,903	4.89%	54.07%
14	$377,255	$6,257,158	3.47%	57.54%
15	$469,276	$6,726,434	4.32%	61.85%
16	$233,911	$6,960,345	2.15%	64.00%
17	$499,317	$7,459,662	4.59%	68.59%
18	$269,470	$7,729,132	2.48%	71.07%
19	$502,146	$8,231,278	4.62%	75.69%
20	$288,074	$8,519,352	2.65%	78.34%
21	$431,258	$8,950,610	3.97%	82.30%
22	$368,211	$9,318,821	3.39%	85.69%
23	$1,350,392	$10,669,213	12.42%	98.11%
24	$171,257	$10,840,470	1.57%	99.68%
25	$34,530	$10,875,000	0.32%	100.00%

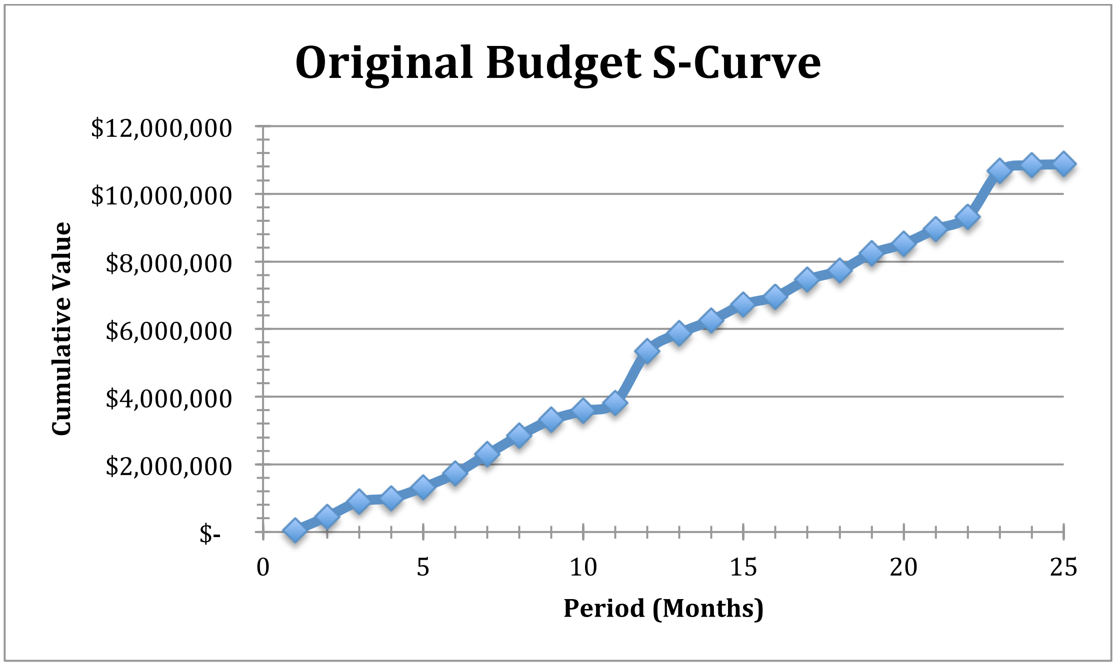


Figure 28: Original Budget S-Curve for the West Detour Mayagüez Project

After the original estimated progress curve is plotted, the actual progress curve is calculated. The actual progress curve uses the data from the costs incurred during each period to calculate the percent complete to the date. This data was obtained from the Monthly Progress Payment Reports of the project. The total estimated cost of the project is recalculated in each of the periods to make sure that the approved changes are been accounted for. Table 7 shows the data used to calculate the percent complete and plot the actual progress curve until Month #12, which is the actual time for the purpose of this example. Notice that in Month #12 the total estimated costs changed to $11,856,774.43 due to the approved change orders and extra work orders to the date. The two curves created with the data of original and actual costs are shown Figure 29.

Table 7: Data for actual progress of the project

Month	Cost this period	Cost to date	Total estimated costs	% Complete this period	% Complete to date
1	$142,226.00	$142,226.00	$10,875,000.00	1.31%	1.31%
2	$481,336.09	$623,562.09	$10,986,930.50	4.38%	5.68%
3	$359,160.19	$982,722.28	$11,001,670.10	3.26%	8.93%
4	$260,597.00	$1,243,319.28	$11,001,670.10	2.37%	11.30%
5	$559,241.49	$1,802,560.77	$11,028,500.10	5.07%	16.34%
6	$375,382.85	$2,177,943.62	$11,038,740.10	3.40%	19.73%
7	$348,619.17	$2,526,562.79	$11,038,740.10	3.16%	22.89%
8	$341,286.81	$2,867,849.60	$11,528,560.93	2.96%	24.88%
9	$370,130.85	$3,237,980.45	$11,687,205.93	3.17%	27.71%
10	$176,280.70	$3,414,261.15	$11,687,205.93	1.51%	29.21%
11	$1,241,916.22	$4,656,177.37	$11,687,205.93	10.63%	39.84%
12	$848,647.92	$5,504,825.29	$11,856,774.43	7.16%	46.43%

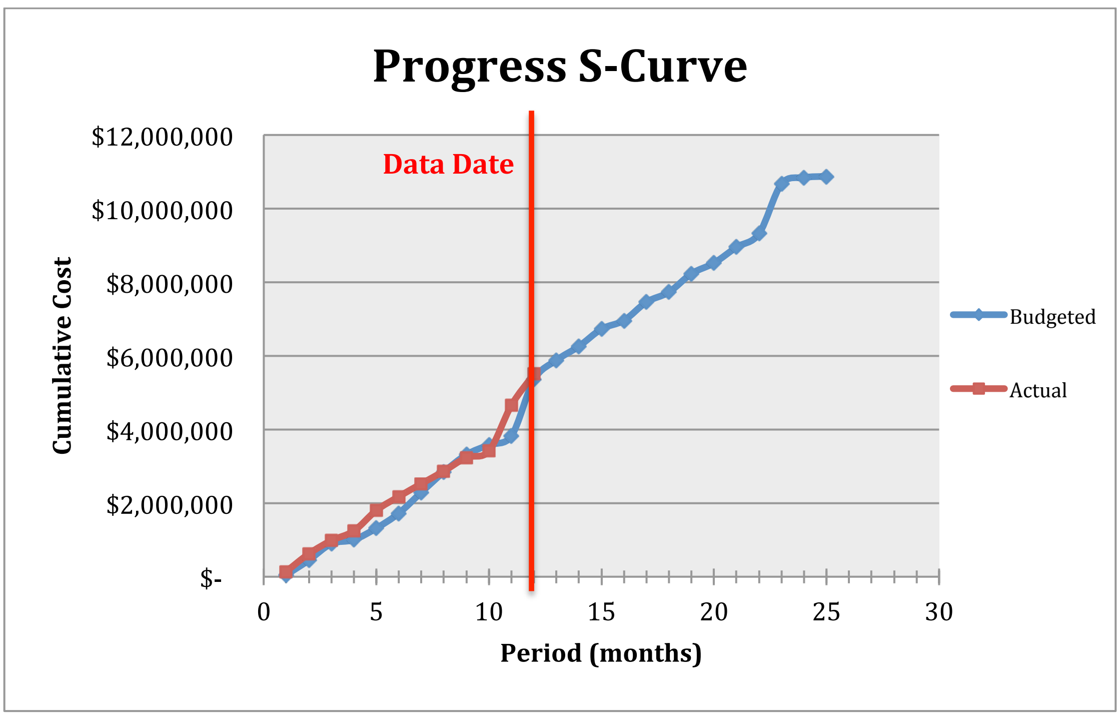


Figure 29: Example of the S-curves showing the actual progress versus the original estimate

The difference between the original estimated progress and the actual progress is noticed in the previous figure. The actual progress of the project started similar to the original estimate, but after Month #3 the curve started deviating probably due to the low productivity during the following months. Afterwards in month 8, the actual curve meets again the budgeted curve. This behavior is repeated on month #12, which is the one under study. At this stage, two predictions could be calculated.

The first forecast made by the proposed model is the prediction with approved changes. A simplified method was used to make this prediction, by updating the baseline schedule with the changes approved to the date and observing the deviation from the original plan. All changes, extra work, and time extensions approved to the date of study have to be incorporated in the cost-loaded schedule, using Primavera Project Management, in order to obtain a more accurate prediction of the outcome of the project.

In the example presented in this chapter, changes had already been approved to the date of study, which is Month #12. By this month, the contract amount had ascended to $11,768,680. The activities corresponding to the change orders and extra work orders where added to the cost-loaded schedule performed in Primavera P6 with their matching expenses and time extensions. After the approved changes to the date are added to the schedule of the project, the baseline schedule is updated to obtain the new S-curve that aligns with the changes in the contract. The original S-curve is kept in the set of curves to compare the original plan to the updated plan of construction. The prediction is made taking into account the changes. Figure 30 depicts the resulting set of curves after the calculations were made for month #12 of the West Detour Mayagüez project.

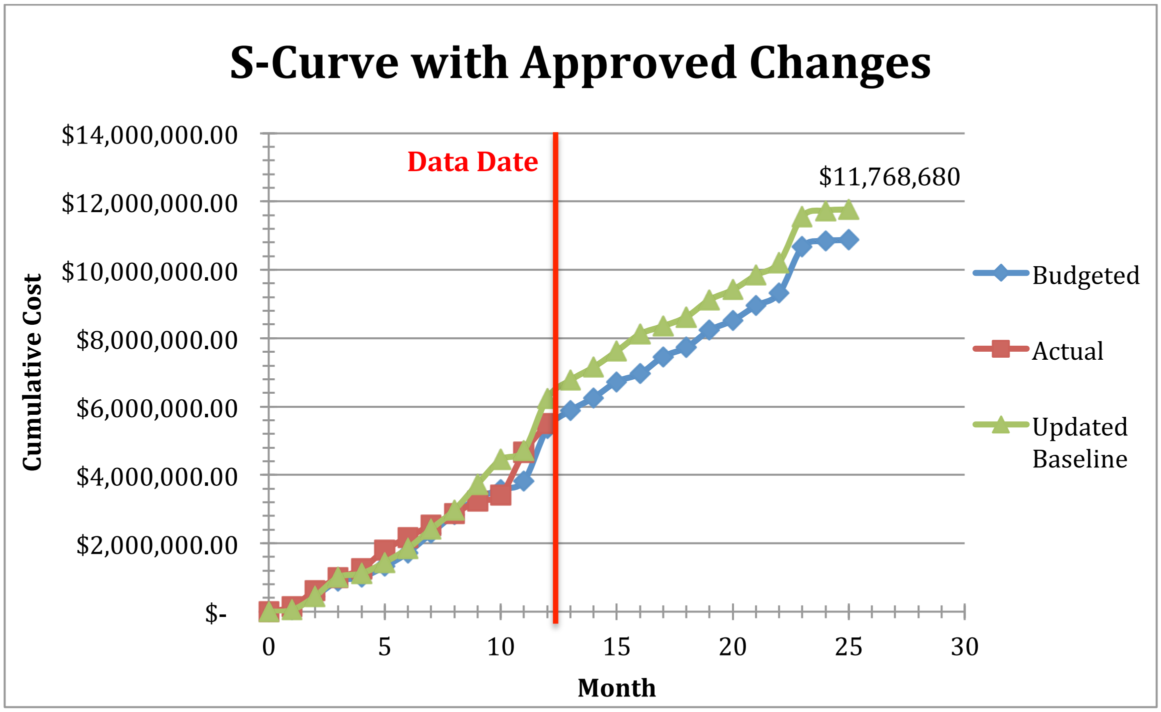


Figure 30: S-Curve with approved changes, month #12

In order to consider changes as soon as they are anticipated an additional curve can be plotted. This curve is addressed in this model as the *prediction with anticipated changes*. The curve consists of the updated cost-loaded schedule including all changes that have been identified, but not necessarily approved yet at the date. The approval process for a change order or extra work order can take months, and thus this prediction helps the project administrator to consider the effect of the changes before they are officially part of the contract. To make this prediction, all the changes need to be added to the cost-loaded schedule, including the changes approved and the changes in process of approval. The process of updating the schedule is performed in Primavera P6, and the resulting curve is shown in Figure 31.

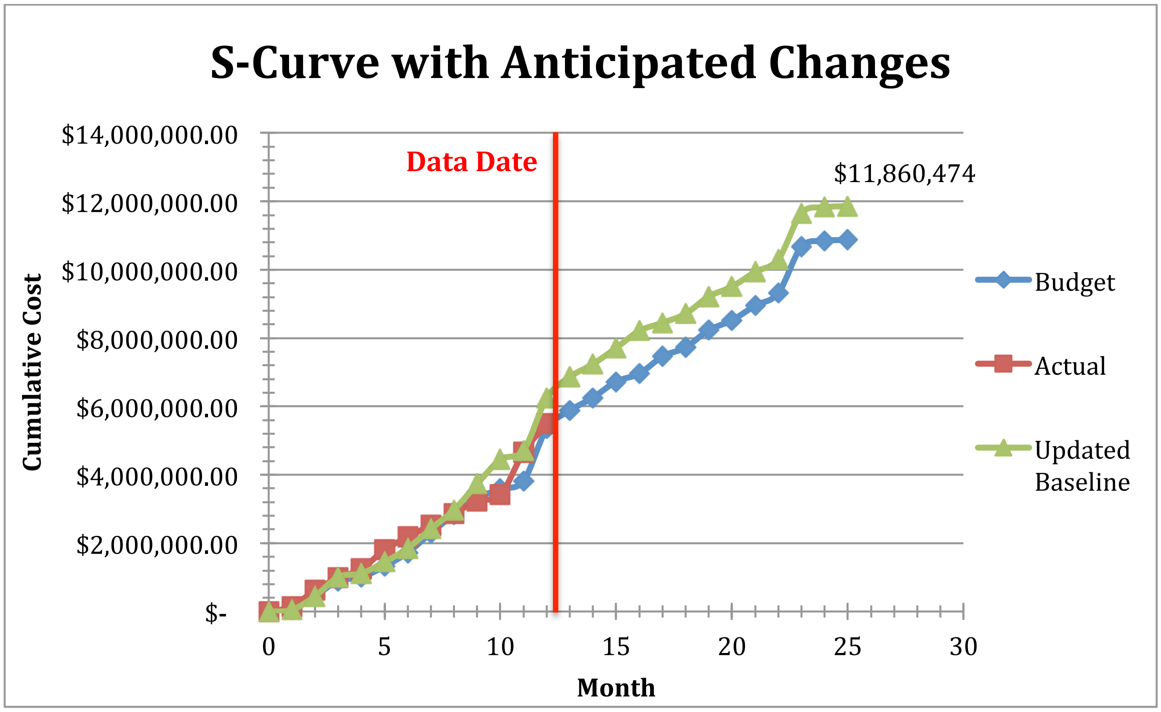


Figure 31: S-Curve with anticipated changes, month #12

The process for generating the curves with the anticipated changes is the same as the previous shown, but including any changes that have been foreseen to the date. After generating the three curves previously discussed, a report of the curves is generated. The report is shown in Figure 32a, 32b and 32c. The report contains the data from the original project estimate, the data from the actual progress to the date, and the three curves generated.

Government of Puerto Rico
Department of Transportation and Public Works
Highway and Transportation Authority

CONSTRUCTION PROGRESS REPORT

ACT-0024

Project: West Detour Mayagüez, Phase 3
Project ID: AC-010254
City: Mayagüez, PR
Contractor: Tamrío, Inc.

Date: 30-Mar-11
Contract Beginning Date: 26-Mar-10
Contract Completion Date: 14-Mar-12
Revised Completion Date: 14-Mar-12
Contract Amount: $10,875,000.00
Revised Contract Amount: $11,856,774.43

ORIGINAL ESTIMATE:

Month	Cost this period	Cost to date	% Complete this period	% Complete to date
1	$48,420	$48,420	0.45%	0.45%
2	$400,683	$449,103	3.68%	4.13%
3	$447,503	$896,606	4.11%	8.24%
4	$106,999	$1,003,605	0.98%	9.23%
5	$314,760	$1,318,365	2.89%	12.12%
6	$406,072	$1,724,437	3.73%	15.86%
7	$568,769	$2,293,206	5.23%	21.09%
8	$553,975	$2,847,181	5.09%	26.18%
9	$467,294	$3,314,475	4.30%	30.48%
10	$267,595	$3,582,070	2.46%	32.94%
11	$239,903	$3,821,973	2.21%	35.14%
12	$1,526,359	$5,348,332	14.04%	49.18%
13	$531,571	$5,879,903	4.89%	54.07%
14	$377,255	$6,257,158	3.47%	57.54%
15	$469,276	$6,726,434	4.32%	61.85%
16	$233,911	$6,960,345	2.15%	64.00%
17	$499,317	$7,459,662	4.59%	68.59%
18	$269,470	$7,729,132	2.48%	71.07%
19	$502,146	$8,231,278	4.62%	75.69%
20	$288,074	$8,519,352	2.65%	78.34%
21	$431,258	$8,950,610	3.97%	82.30%
22	$368,211	$9,318,821	3.39%	85.69%
23	$1,350,392	$10,669,213	12.42%	98.11%
24	$171,257	$10,840,470	1.57%	99.68%
25	$34,530	$10,875,000	0.32%	100.00%

Figure 32a: Example of the Construction Progress Report (Page 1 of 3)

ACTUAL PROGRESS:

Month	Cost this period	Cost to date	Total estimated cost	% Complete this period	% Complete to date
1	$142,226.00	$142,226.00	$10,875,000.00	1.31%	1.31%
2	$481,336.09	$623,562.09	$10,986,930.50	4.38%	5.68%
3	$359,160.19	$982,722.28	$11,001,670.10	3.26%	8.93%
4	$260,597.00	$1,243,319.28	$11,001,670.10	2.37%	11.30%
5	$559,241.49	$1,802,560.77	$11,028,500.10	5.07%	16.34%
6	$375,382.85	$2,177,943.62	$11,038,740.10	3.40%	19.73%
7	$348,619.17	$2,526,562.79	$11,038,740.10	3.16%	22.89%
8	$341,286.81	$2,867,849.60	$11,528,560.93	2.96%	24.88%
9	$370,130.85	$3,237,980.45	$11,687,205.93	3.17%	27.71%
10	$176,280.70	$3,414,261.15	$11,687,205.93	1.51%	29.21%
11	$1,241,916.22	$4,656,177.37	$11,687,205.93	10.63%	39.84%
12	$848,647.92	$5,504,825.29	$11,856,774.43	7.16%	46.43%

ACTUAL COSTS VS. ORIGINAL BUDGET:

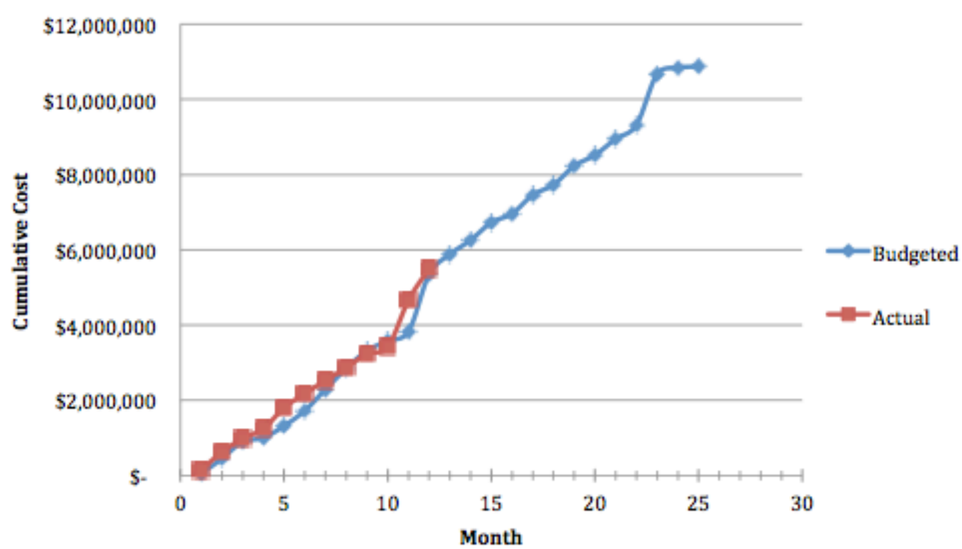
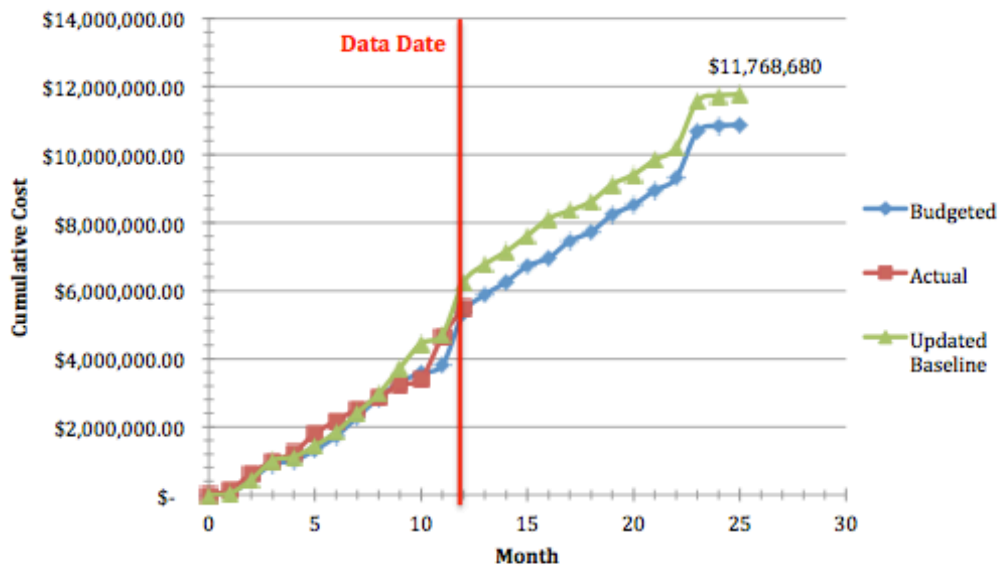


Figure 32b: Example of the Construction Progress Report (Page 2 of 3)

PREDICTION WITH APPROVED CHANGES:



PREDICTION WITH ANTICIPATED CHANGES:

Figure 32c: Example of the Construction Progress Report (Page 3 of 3)

5.3.2 Monthly Progress Payment Reports

In Chapter 4 the process of generating the monthly progress payment reports was presented. The process consists basically of accumulating the data from items performed, constructed and/or installed during each month's period and report the total costs. This report becomes the bill of the contractor each month, thus the need to record and report the data carefully. Table 8 depicts the data needed for the report and the method in which it is obtained or calculated. After recording the data, the report is generated, as shown in Figure 33.

Table 8: Data used to create the Progress Payment Report

Item No.	**Spec.**	**Description**	**Unit**	**Quantity**	**Unit Price**	**Cost this period**
Recorded in the tablet application and uploaded to the database		Matched in the database with the Item Number	Recorded in the tablet application and uploaded to the database		Extracted from the cost proposal by matching the item number	Calculated: *Cost this period = Quantity * Unit Price*

The example described in this Chapter presented the proposed framework with real numbers and situations, for the reader to gain a better understanding of the capabilities and functionalities of the model. By semi-automating the processes proposed by this thesis, the time spent in clerical tasks will be shorten and new progress monitoring reports could be developed. Chapter 6 expands in the conclusions and contributions of the work performed in this thesis work.

Government of Puerto Rico
Department of Transportation and Public Works
Highway and Transportation Authority

MONTHLY PROGRESS PAYMENT REPORT

ACT-0012

Project: West Detour Mayagüez, Phase 3	Date: 30-Mar-11
Contractor: Tamrío, Inc.	Cert. Num.: 12
Project ID: AC-010254	Contract Beginning Date: 26-Mar-10
Federal Num.: CP-102(12) ARRA	Contract Completion Date: 14-Mar-12
Contract Num.: 85025	Revised Completion Date: 14-Mar-12
Oracle Number: S0000102054	Contract Amount: $10,875,000.00
City: Mayagüez, PR	Revised Contract Amount: $11,856,774.43

Item No.	Spec.	Description	Unit	Quantity	Unit Price	Cost this period
11	207-009	PAVEMENT STRUCTURE FILL	CuM	337.96	$ 30.00	$ 10,138.80
19	601-001	CLASS A CONCRETE	CuM	4.85	$ 220.00	$ 1,067.00
20	602-001	REINFORCING STEEL	Pnd	64.86	$ 0.75	$ 48.65
110	613-001	TRAFFIC SIGN ASSEMBLY, C.19...	Each	1.20	$ 560.00	$ 672.00
175	636-040	4" PVC PIPE, SDR 14	LnM	230.98	$ 30.00	$ 6,929.40
177	636-047	4" GATE VALVE	Each	1.00	$ 400.00	$ 400.00
182	636-117	FIRE HYDRANT	Each	1.00	$ 1,700.00	$ 1,700.00
197	654-043	PVC CONDUIT, 2 INCH	LnM	3.05	$ 19.00	$ 57.95
247	401-051	HOT PLANT MIX BIT. PAVEMENT	Ton	2066.46	$ 115.00	$ 237,642.90
248	401-030	CONTROL STRIP SECTION	Ton	387.29	$ 115.00	$ 44,538.35
274	603-030	60 INCH RCP, CLASS IV	LnM	4.00	$ 1,200.00	$ 4,800.00
275	603-574	60 INCH HEADWALL TYPE B	Each	1.00	$ 6,200.00	$ 6,200.00

Work Performed (WP):	$ 848,647.92
5% Retainage (WP):	$ 41,932.40
Reimbursement (WP)(+):	
Sub-Total:	$ 806,715.52
Material on Site (+/-):	$(95,207.29)
Liquidated Damages (LqD)(-):	
Reimbursement (LqD)(+):	
Extra Retainage (+/-):	
Price Adjustment Clause (+/-):	
Safety Penalties - Spec. 638 (-):	
Other (+/-):	
Net Payment:	**$ 711,508.23**
Total to Date (WP):	**$ 5,504,834.52**

_______________ Resident Engineer or Inspector

Accepted by: _______________ Contractor

Recommended by: _______________ Area Supervisor/Regional Director

Approved by: _______________ Construction Area Director

Approved for Payment by: _______________ Finance Area Director

Percent Work Performed: 46.43%

Percent Time: 51.39%

Page 5 of 5

Figure 33: Example of the Monthly Progress Payment Report

CHAPTER 6: CONCLUSIONS

6.1 Summary

Construction is an industry characterized for generating vast amounts of inspection data during the construction process. Construction inspection data allows field personnel to monitor project performance with the ultimate goal of providing quality control and quality assurance, critical aspects for the success of the project. Current practices in highway construction projects for collecting, processing, and filing documents associated to a construction job consume a large amount of time. The use of technology provides a solution to make the daily reporting of highway projects a process more efficient and faster. Moreover, technology provides the capabilities to perform statistic analysis that could help to enhance the project monitoring process.

This thesis presented a framework for automating the daily site reporting and progress monitoring for highway construction projects. The framework presents a process where the data is input to a central database using a combination of modern tablets, such as iPads, Android and Surface Tablets, and regular computers. Afterwards, the data is processed to create daily inspection reports and monitoring reports, which are necessary to keep an adequate record of the project and provide time and cost control. The automation of this process shortens the time and effort required for an engineer to complete inspection tasks, and provides an additional monitoring tool to support the control of the project.

6.2 Conclusions

It is possible to develop and implement a more efficient method for the daily site report generation and filing of the reports in the PRTHA. An automated process that uses current technological tools in combination to a centralized database could be the solution to the problem of using manual processes. The proposed framework presents one solution for the automation of the daily reporting process that can be implemented directly in the application already developed by a research team at the University of Puerto Rico, Mayagüez. This framework takes advantage of the existing application and adds more capabilities, which is more beneficial for the inspectors who would already be using the T.A.I.P. application in their mobile devices.

The proposed framework provides the capability of creating weekly and monthly monitoring progress reports, which do not exist in the current PRHTA practices. The automated process is capable of creating reports, provided the necessary information, that show the original estimated progress, the actual progress, and predictions for the future progress of the project. These reports were created in the example of the model shown in Chapter 5.

The automation of the proposed framework is expected after the completion of this thesis. Once the programming is executed, the PRHTA will have an application that will greatly improve current practices. However, the application should be tested with field inspectors in a real construction project. After the inspectors use the application and all the reports are generated, the efficiency of the system should be tested to find out its real benefits. The expected benefits are time saved in the creation of reports, and improvements in the monitoring of the project. Costs savings due to the decrease in the clerical expense should also be examined.

In addition, the reaction of the inspectors and project administrators to the developed tool should be studied to find out the feasibility of actually implementing the tool in the field. The experienced workforce might be resistant, since it represents a big change to the current practices, but younger generations are expected to be more open to the change, since they are more used to managing all sorts of technological devices. Therefore it is predicted that technological system, such as the one proposed in this thesis, could play an important role in the future of construction.

The effort of automating the reporting process would be incomplete if it is not complemented with the proper training. In the current practice, new construction inspectors receive little or no education for their job, which provokes lack of uniformity in the process. For this reason, it is recommended to give special training to the field inspectors in order to expand their knowledge in the inspection practice, in the reporting process, and the use of technological tools like the one proposed in this work.

6.3 Contributions

The main contribution of this research is the improvement of the administrative aspects related to project progress monitoring and control, and the development of a new model for automating progress reporting and monitoring. The automation of the reporting process not only brings more efficiency to the system, but also provides space for new capabilities to be implemented in the process, and more transparency to avoid conflicts between the different parts involved. This contribution is comprised by:

- *The enhancement of the monitoring process.* The progress of the projects can be checked on a weekly and monthly basis using the reports generated automatically by the application. These reports could contribute to the decision making process by providing information of the actual project progress versus the original estimated progress, and predictions for the remaining portions of the project. Prediction curves generated with the changes approved to the date and the anticipated changes will be provided to the project administrator. With this information at hand, the project administrator will be able to make intelligent decisions based on the predicted outcomes of the project, thus mitigating the effects of the changes in project costs and delivery time.

- *The creation of the Progress Payment Report.* The framework provides a tool to create the Progress Payment Report at the end of each month, or pay period. These reports could be used to corroborate the Progress Payment Report submitted by the Contractor, ensuring that the project is performed with a justified budget according to what is completed on the field each month. The framework allows this process to be automated, thus reducing the clerical tasks of the project administrator.

- *The simplification of the project administrator's job*, providing them more time for other important supervising tasks. The framework simplifies the tasks of reporting and monitoring, thus allowing more time for the project administrator to perform other activities.

- *The simplification of the collection and distribution of inspection reports.* By distributing the reports in digital form, the communication process will be faster and more eco-friendly.

- *The elimination of double manipulation of data, from paper to computer.* With the implementation of the proposed framework, the information will be input directly to the computers, saving time and minimizing the data transferring errors.

- *The minimization in the use of paper.* The use of mobile devices will eliminate the need for paper forms, thus helping the environment. Also the organization and filing of the reports is simplified by using digital forms instead of traditional paper forms. A digital filing system provides more efficient ways to make searches in the database, occupies less space, and could have a backup in a cloud system, thus minimizing the risks of losing documents.

6.4 Areas of Future Research

- *Development of other prediction models for the progress monitoring reports.* Due to the time constraints of this research, the area of forecasting the S-curves was not studied in depth. A future research effort could study in more detail the body of knowledge related to forecasting S-curves, and develop another model of prediction that relates closely to the case of construction in Puerto Rico.

  For the work of this thesis, a model using the Gaussian or normal distribution was considered, but not studied in depth enough as to incorporate it to the framework. In this case, the prediction of the future progress is accomplished by distributing the remaining costs to complete the project in the remaining time expected to finish the job. Since the progress of a construction job has a behavior similar to the Gaussian distribution, with a slow start and finish, and most of the work is held in the middle portion of the project, this approach could be promising.

  Figure 34 depicts an example of the probability density function (PDF) for the normal distribution. The values for PDF are calculated using Equation 6, where μ and σ are the parameters of the distribution (Ang and Tang, 2007). The two parameters represent the mean and the standard deviation, respectively, of the variable X.

$$f_X(x) = \frac{1}{\sigma\sqrt{2\pi}} exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right] \qquad -\infty < x < \infty \qquad (6)$$

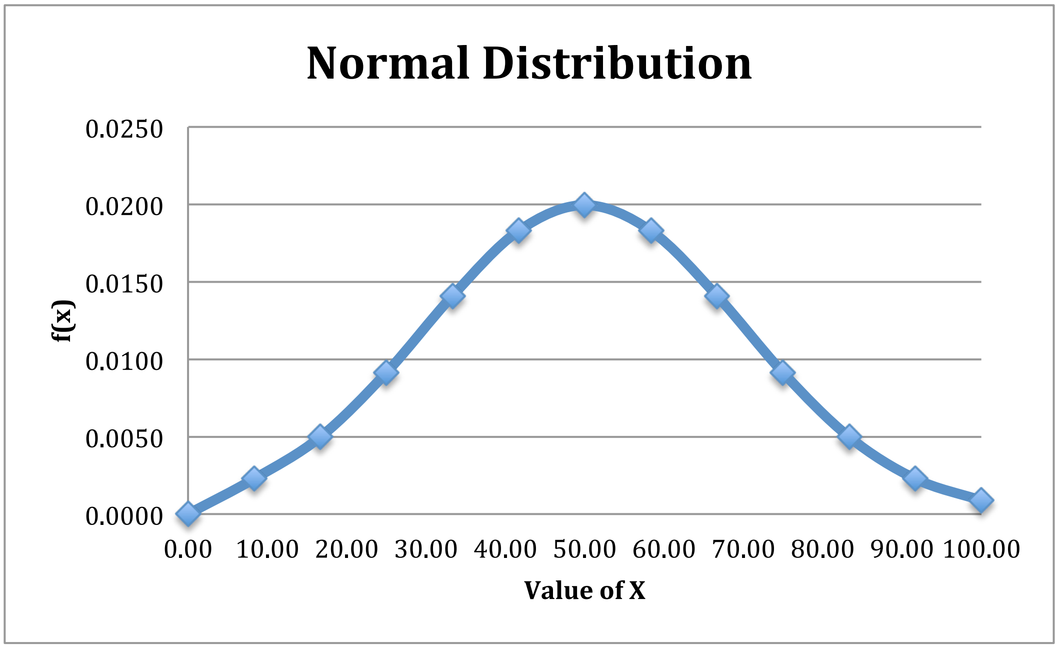


Figure 34: Example of the Gaussian or Normal Distribution

The S-curve could be considered the cumulative distribution function (CDF) of the normal distribution. This means that when the normal distribution is accumulated and plotted, the result is a curve with an s-shape. This concept is illustrated in Figure 35. In this graphical representation, the PDF is equivalent to the percent of work complete during each period, while the CDF is equivalent to the percent of work completed to the date.

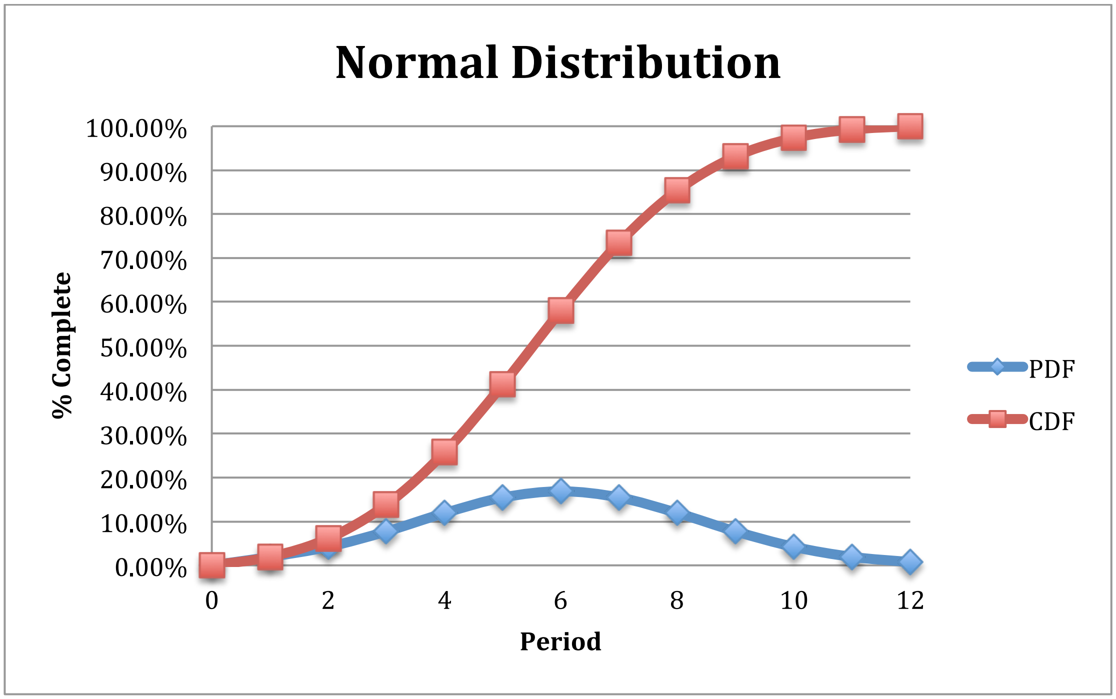


Figure 35: Example of PDF and CDF for the Gaussian or Normal Distribution

By using this prediction method, the values of the normal distribution are calculated and used to distribute the percent to complete the project in the remaining time to complete. With this method the prediction follows an s-shape behavior, similar to the behavior in the field. An example of a set of s-curves generated using this model is shown in Figure 36.

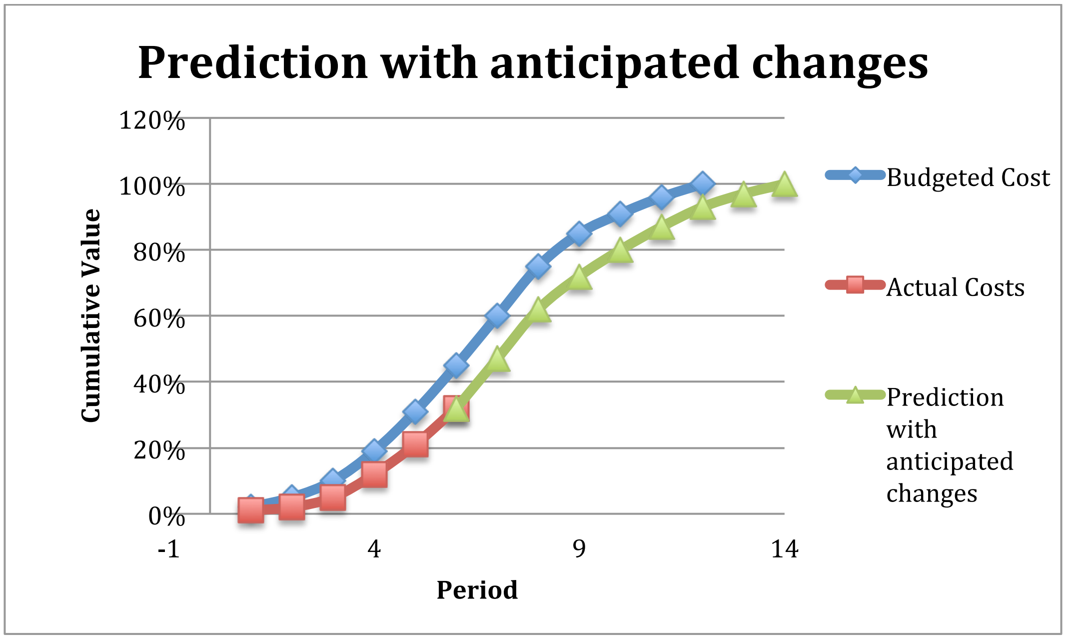


Figure 36: Prediction with anticipated changes S-curves

The model was not incorporated into the framework of this thesis due to the time constraints, but with further research could be considered a useful tool of prediction for construction progress.

- *Development of other progress monitoring reports.* Other types of monitoring reports could be developed depending on the necessities of the officials in the PRHTA. Further study could be made to identify other areas where progress-monitoring reports are needed, and evaluate how these new reports could be implemented in the existing framework.

6.5 Closing Thoughts

Even though clear benefits exist for the use of technology, there are some barriers that have made difficult the implementation of technology in the construction industry. The main reason is the unique character of construction projects, where no two jobs are ever exactly the same. This unique characteristic, combined with the temporary nature of projects, has made unfeasible the implementation of technology in many situations. The type of technology that can be successful in the construction industry is one that can be used in many projects.

The proposed framework is design to address any type of project in the construction of highways. Since all the highway construction in Puerto Rico is regulated by the PRHTA, the methods for daily reporting and progress monitoring are similar, regardless of the peculiarities of the project. Therefore, the implementation of the proposed framework is not only beneficial for the improvement of the efficiency in construction projects, but also feasible for the standards of the industry. All the efforts that could be made to provide safe roads to the users on time and budget should be a first priority for civil engineers and the government, and the framework proposed in this thesis provides a solution to make part of the construction process more efficient.

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