Interactive Voice-Visual Tracking of Construction As-Built Information

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

The documentation of complete and timely as-built information related to construction projects is essential for tracking progress, planning corrective action, and analyzing the schedule. The collection of site information, however, is currently a challenging, time-consuming, and error-prone manual process. To improve the tracking of as-built information, this research focused on the development of a low-cost voice-visual framework that utilizes commonly available communication tools such as email and interactive voice response (IVR). The goal of this research was to create project-wide bidirectional communication between site personnel and head office to automate the tracking of daily site information. The research involved an in-depth analysis of the possible site events and progress-tracking needs related to construction activities. Accordingly, activity-specific email forms and logical-flow diagrams were developed as a means of facilitating site data collection. A framework was then developed that integrates several components: the developed tracking forms; a cloud-based IVR service; a customized scheduling application; and an email application. During construction, the automated system identifies eligible activities to be tracked; collects as-built details from the relevant supervisors; and uses the daily time segments of the schedule as an integrated depository for all as-built details, including progress information, events by all parties, and requests for information (RFIs), quality/safety issues, and other video/audio/drawing-markup notes. The developed system generates detailed as-built schedule that clearly show the evolution of all as-built events and their accurate timing on the daily segments for each activity. The project schedule is thus converted from a static report into information-rich, visualization media, and decision-support tool that provides decision makers with timely progress details so that they can easily follow the project progress , facilitates schedule updates, facilitates accurate schedule forensics, delay analysis, , and the planning of appropriate corrective action. The developed framework was validated though a number of case studies that demonstrated its usefulness and practicality. This research contributes to construction

efficiency through the facilitation of bidirectional communication between site personnel and head office and the provision of timely and legible as-built data for decision-making. Ultimately, the research will assist construction firms to have better control over construction projects and more effective decisions during construction through improved communication.

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Dedication

I dedicate this thesis to

My Parents

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Chapter 1
Introduction

1.1 Background

Construction is one of the world's largest industries, contributing to about 10 % of the gross national product (GNP) of industrialized countries (Allmon et al. 2000). Any improvement in the performance of this industry will thus have a significant economic impact. In Canada, the construction industry employs more than 1,262,200 people and accounts for more than 6.04 % of the gross domestic product (GDP) (Statistics Canada 2012). Despite being large, many researchers (e.g., Moura and Texeira 2006; Ghanem 2007) have reported that the construction industry suffers from low productivity, high accident rates, cost overruns, delays, and poor quality. A study by Nuntasunti (2003) summarized the reasons for the low productivity: fragmentation, the increasing complexity and number of requirements involved in projects, safety and environmental issues, lack of well-defined specifications, the temporary nature of the relationships among the many parties involved, the overly competitive bidding system, and the isolated islands of communication during projects. All of these problems have contributed to a high bankruptcy rate among construction firms.

One of the greatest challenges facing construction managers in controlling projects is keeping track of all actions that take place on-site in order to facilitate performance analysis, detect potential problems, and select appropriate corrective actions (Wang et al. 2007; Russell et al. 2009). Construction progress tracking, however, is not simple because construction projects involve large amounts of information related to a variety of functions, such as scheduling, construction methods, cost management, resources, quality control, and change order management. The communication of this information is dependent on two-way exchanges among a number of parties. Project managers often make important decisions based on this information, which must be received in a timely manner in order to facilitate decisions.

In addition to the sheer volume of construction information, a further complication is that it is provided by a number of different sources and in wide variety of forms (Korde 2005): textual data, as in the case of specifications; quantitative data, such as the number of change orders; scheduling data, such as activity durations (planned and actual); site weather conditions; and cost breakdowns. In addition, construction data generally varies according to time and location (Korde 2005). Because the data comes from different parties, is often unclear, and is improperly documented, it can lead to misunderstandings, incorrect assessments of project performance, and lack of early warnings. There is a need, therefore, for suitable methods for the accurate and timely recording of all site events that represent the evolution of as-built information, which is crucial both at the construction stage of projects and for their future operation and maintenance.

Until recently, the collection of site data has been paper-based, which is inefficient even for small projects and has been recognized as one of the major problems that cause project delays and cost overruns (Gajamani and Varghese 2007). Paper-based data collection is slow, inaccurate, incomplete, time-consuming, and labour-intensive (Davidson and Skibniewski 1995; McCullouch (1997); Navon 2005; Reinhardt et al. 2004; Trupp et al. 2004; Navon and Sacks 2007). These limitations result in project managers and their teams spending most of their time dealing with secondary issues or solving the wrong problems (Navon and Sacks 2007). A study conducted by McCullouch (1997) revealed that 30 % – 50 % of field supervisory personnel time is spent recording and analyzing field data. Another study by Cheok et al. (2000) reported that 2 % of all work on construction sites is devoted to the manual tracking and recording of progress data.

1.2 Research Motivation

The goal of this research was to provide better mechanisms for documenting as-built details and for accurately assessing project performance in order to support project control. This research has been motivated by the aspects explained in the following subsections.

1.2.1 Importance of Progress Tracking and As-Built Information

As-built information plays an important role in both project control and the later operation and maintenance of the project. The as-built information provides feedback to designers and engineers so that they can improve their design, to construction engineers so that they can improve productivity, and to contractors so that they can improve their performance for future jobs (Memon et al. 2006). Inefficient progress tracking and lack of as-built information thus impairs the ability of managers to monitor the schedule, costs, and other performance indicators, which, in turn, reduces their ability to detect and manage the uncertainties associated with a project (Howell and Koskela 2000).

1.2.2 Challenges with Manual Tracking Methods

Despite the importance of as-built tracking, the collection of timely and complete construction field data has been difficult for a number of reasons: the diverse and large number of project participants (Hwang et al. 2003); the variety of sources and forms of information (Korde 2005); and the significant effort required in both the field and the office in order to capture data digitally (Thorpe and Mead 2001). All of these factors make manual on-site data collection time-consuming, labour-intensive, costly, and error-prone, thus leading to project delays, overruns, and miscommunication between the office and the construction site (Kiziltas et al. 2008; Navon and Sacks 2007). As well, late information may mean that project managers must spend a great deal of time solving problems that result from poor coordination, lack of timely information, and inaccurate or out-of-date information.

1.2.3 Importance of Detailed As-Built Information

The typical level of detail associated with the collection of progress information from construction sites is inadequate for full documentation of the as-built evolution of activities. The average duration of activities is commonly in the range of days while the average frequency of reporting is usually monthly (Navon and Sacks 2007). Existing progress-tracking tools also operate at a low and unsatisfactory level of detail. In existing commercial scheduling software, for example, activities are represented as continuous blocks of time (Figure 1.1a) that do not permit mid-activity events to be shown on the schedule. To incorporate a high level of progress detail, Hegazy and Menesi (2010, 2012) presented a Critical Path Segments (CPS) approach that enables a much richer representation of mid-activity details. As shown in Figure 1.1b, activity durations are divided into daily segments, and each time segment can indicate a progress amount or other events made by any party, in addition to notes, and explanations.

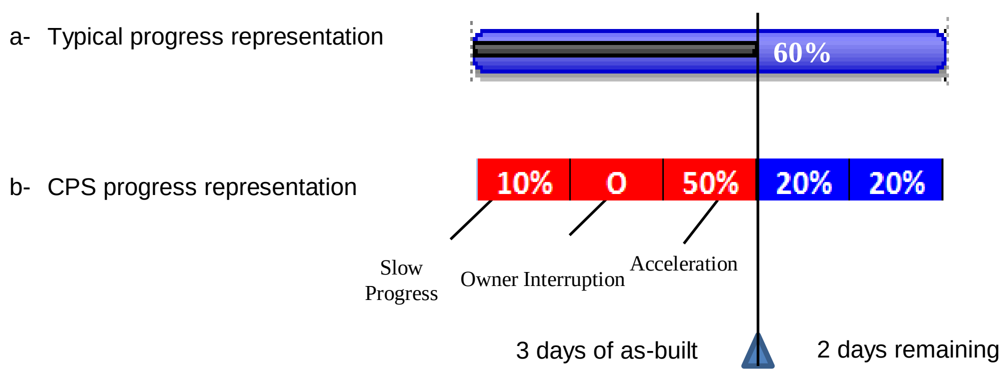

Figure 1.1: Higher level of as-built detail incorporated in CPS representation

Such a generic activity representation clearly shows the evolution of all as-built events and allows an enhanced granular level of detail at the segment level, which is also general enough to facilitate corrective action and schedule analysis. Due to its rich visualization feature and its usefulness for project control, CPS representation has been utilized in this research. The additional details incorporated into this representation, however, require significant effort in order to collect data from the site using manual methods. This research was therefore focused on the automation of the data collection process so that detailed as-built tracking becomes cost-effective and attractive for practitioners.

1.2.4 Availability of Low-Cost and High-Potential Information Technology Tools

Low-cost information technology (IT) tools, such as internet-based telephony, email service, Short Message Service (SMS), and visualization tools, have evolved significantly over the years. These technologies have considerable potential for the effective, timely, and accurate collection and sharing of important field data, which can greatly empower project managers so that they can make better decisions. For example, email has become a popular form of communication and a core technology for data exchange and sharing without geographic barriers (Ahsan et al. 2009). Voice-based tools are another type of IT tool with great promise. Speech-based technologies, such as speech recognition and interactive voice response (IVR) systems have recently matured and can also reduce the time and cost of collecting site information. Tsai et al. (2007) for example, strongly recommended using speech recognition technology for automating site material logs and reported that the cost savings and speed of data collection can be greatly improved if such systems are designed to be interactive. Visualization is another efficient tool that can be used to facilitate progress monitoring and provide a better understanding of project progress (Golparvar-Fard et al. 2009). Visualization of construction progress helps construction project managers effectively compare aspects of the as-built and as-planned performance, identify discrepancies in the progress, better utilize resources, and make timely corrective decisions (Golparvar-Fard et al. 2009)

1.3 Research Scope and Objectives

The overall goal of this research was to improve construction project control by substantially improving progress tracking process through automation and utilization of email and IVR technologies. The main hypothesis in this research are: (1) IVR and email can replace the lengthy manual process and enable daily automated progress tracking of construction activities; and (2) schedule becomes more suitable for project control by visualizing all the daily as-built details directly on the schedule. To test this hypothesis this research developed a framework that utilizes low-cost voice-visual IT technologies to facilitate automated bidirectional daily communication between site personnel and head office. Accordingly, documents the received as-built information details on the daily segments for each activity on the schedule, and generates detailed progress reports to provide decision makers with timely information to facilitate their daily decisions. The detailed objectives of this research are as follow:

- Investigate the requirements related to activities' progress tracking (specifically highway construction projects), the possible site events related to each activity, and the determination of the documentation requirements for each activity. Based on these findings, develop activity-specific forms and flow diagrams to facilitate site data collection;
- Investigate the applicability, efficiency, and practicality of email, SMS, internet-based telephony, interactive voice response, visualization tools, and handheld devices as methods of enhancing site information tracking;
- Develop a framework for automating the daily collection of as-built construction information and for facilitating bidirectional project-wide communication between site personnel and head office. The proposed framework incorporates email, cloud-based IVR service, and a visual drawing-markup tool for documenting as-built information using detailed CPS representation;
- Develop a computer prototype of the proposed framework; and

- Experiment with the framework using different case studies.

This research focuses on the facilitation of as-built information details documentation during the construction stage (e.g., progress amount completed, site events and responsible party, Q/C issues, RFIs, and visual progress location and other comments) for highway construction projects, but the approach can be extended to include other types of projects as well. The as-built information to be tracked in this research are limited to schedule-related progress information details such as progress amount, actual site events and responsible party (e.g., owner, contractor, or third-party), quality control issues, and requests for information (RFIs). Other design-related as-built information such as changes to specifications (e.g., concrete strength, aggregate size, cross sections, dimensions, material types, etc.) can be documented on the schedule as text/voice annotations or drawing markups that are linked to the schedule on the specific time of these events. The developed framework provides construction site personnel with an easy yet efficient mechanism for the accurate tracking of construction progress, the detailed recording of site events, and a timely response to any raised issue(s). This framework has the potential to minimize the time and cost associated with the collection of construction site information, the updating of the schedule, the generation of reports, and the initiation of warning signs. Such system is expected to help construction firms have better control of construction operations and to provide timely information that will assist with decision making.

1.4 Research Methodology

The methodology adopted for the achievement of the above objectives was as described below and as shown in Figure 1.2:

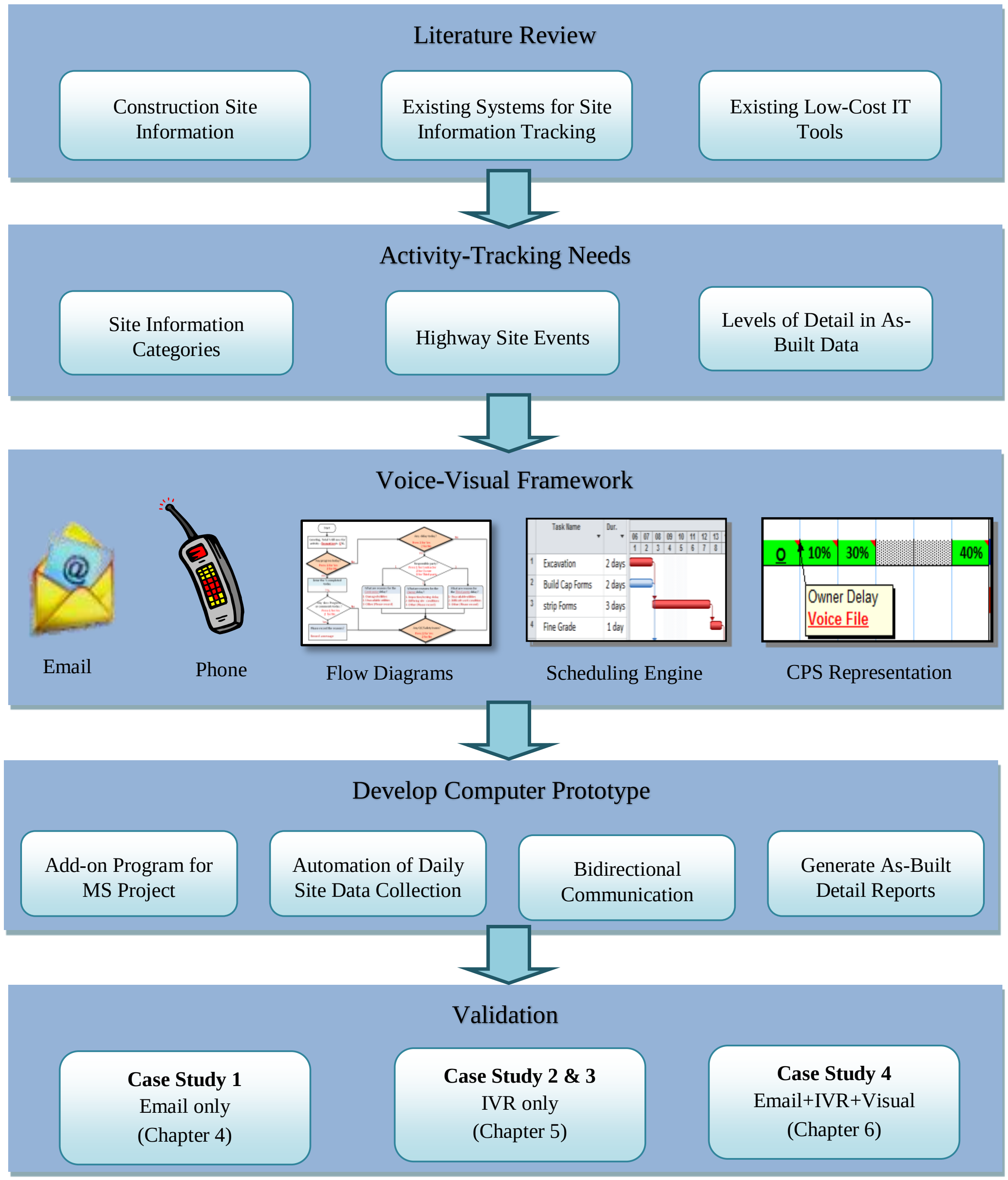

Figure 1.2: Research Methodology

- **Conduct a comprehensive literature review:** A comprehensive literature review has been conducted in order to investigate the requirements associated with activities' progress tracking and possible site events for each activity. The review also focused on progress measurement methods and available techniques for measuring construction progress. Additional goals were to investigate current techniques for documenting and representing daily as-built details, and to examine current automated progress tracking systems and their limitations. Moreover, investigate the availability of other low-cost IT tools that can simplify the collection of site information and provide decision makers with complete and timely information for measuring project performance and/or analyzing project delays.

- **Identify activity-specific tracking needs:** The documentation of complete as-built details has been analyzed with respect to the needs associated with activity tracking, possible site events, and a variety of information categories. An appropriate detailed site-information tracking form has been developed for each activity in order to facilitate site data collection and to provide an easy method of recording all site events. An additional goal was to develop information about the flow of questions for each activity or group of activities (IVR logical flow diagrams) so that activity progress and information about other site events could be collected based on a minimal set of appropriate questions.

  Once the initial forms were developed, they were reviewed by construction experts, whose feedback was considered during the finalization of the tracking forms. The developed tracking forms have the potential to minimize the time and cost required for the collection of complete, efficient and timely site information. The developed activity-tracking forms also constituted the basis for the development of the automated site-information tracking framework.

- **Develop a voice-visual framework:** An innovative framework has been developed that integrates activity-specific forms, a project communication list, cloud-based IVR service, a customised schedule engine for simplifying and automating the tracking of site information, and customized email communication tools. In the developed framework of progress tracking, for eligible activities, contact is automatically initiated with their supervisors in order to capture actual site information for each activity and to represent all received data visually on the daily segments for each activity. This new process renders automated data collection more realistic and less costly compared with existing tools for automated data collection.

- **Develop a computer prototype:** A computer prototype has been developed considering all the elements of the framework for automating daily site information tracking. The prototype was designed to take into account the preferred contacting method for each supervisor as well as alternative methods of collecting the same information in case the supervisor did not respond. The developed prototype acts as a multilevel interactive system: for example, if the activity supervisor requests action or information, the system attempts to respond quickly by contacting the appropriate personnel. The schedule is then updated accordingly so that the latest as-built details appear on the daily segments for each activity, and detailed as-built information reports are generated.

- **Validate the prototype:** The developed prototype has been applied to a number of case studies as a means of testing its applicability, practicality, and usefulness for automating site-information tracking.

1.5 Thesis Organization

The reminder of the thesis is organized as follows:

Chapter 2 presents a detailed literature review related to various types of construction site information, the importance of each type, data collection challenges, and methods of measuring activity progress. This chapter also includes a summary of previous investigations of automated data collection and current IT tools for collecting construction site information.

Chapter 3 discusses the challenges associated with manual as-built tracking and the level of detail required to document as-built data on the schedule. With a focus on highway projects, activity-tracking needs are identified, including possible site events and different categories of information. These tracking needs have then been used for the development of site-information tracking forms and data flow diagrams so that site data can be collected using email and/or voice (through IVR).

Chapter 4 describes the development of the innovative low-cost, high-potential framework for the automation of site-data collection through email, IVR, and visual markup technologies and for the facilitation of bidirectional communication between site personnel and the head office. Also, explained the application of the automated site data collection framework into a computer prototype. The prototype is an email-based system that integrates the previously discussed activity-specific email forms, a project communication list, a customized scheduling application (MS Project), and a customized email application (MS Outlook). The computer prototype was applied in a simple case study for validation and to test its applicability and usefulness in the construction field.

Chapter 5 introduces the utilization of IVR technology for site-information tracking and as-built documentation on the schedule. Included is a discussion of the benefits of IVR for a construction firm, followed by an examination of the implementation of IVR for as-built information collection. IVR has been experimented with two case studies to test the practicality of using IVR only for collecting site information. In the second case study, the IVR prototype was applied in a classroom environment that simulates a large number of project interactions in order to collect progress information using IVR technology.

Chapter 6 discusses the enhancement of the previously presented email-based system: IVR is integrated with visual tools that enable supervisors, according to their preferences, to send the actual as-built details by email or phone, to highlight progress visually, and to add any comments to the attached visual files. The chapter also explains the development of the prototype as well as its validation and usefulness as determined through its application in the case study.

Chapter 7 summarizes the conclusion of this research, highlights its contributions, and presents recommendations for future research.

Chapter 2
Literature Review

This chapter provides a comprehensive review of the literature related to types of construction site information, the importance of each type, the challenges associated with data collection, and methods of measuring activity progress. Also included is a summary of previous investigations of automated data-collection techniques in the construction field and of current low-cost IT tools that can facilitate the tracking of construction site information.

2.1 Construction Site Information

A construction project involves numerous interrelated activities, large amounts of information, and a wide variety of parties who perform independent tasks. Such a process inherently entails large amounts of varying types of information. The substantial amount of information and the large number of information users require an effective and timely flow of information to keep the project on track. Since site information must be conveyed to all project parties, clear, efficient communication is important for ensuring that the work performed by all project participants is successful (Ghanem 2007). Effective control of the project can only result from effective and continuous flow of site information between the project participants, on the one hand, and the management team, on the other hand. Exploring and developing effective methods of collecting and managing construction site information require a better understanding of site information requirements, particularly with respect to tracking construction activities.

In the literature, construction site information has been organized into three main categories: finance, quality, and progress (Scott and Assadi 1999). In general, progress records include information related to monthly and weekly progress reports, daily worksheets, photographs, the as-built schedule, and minutes of meetings (Scott and Assadi 1999). These records are important for enabling decision makers to monitor and control construction processes and to resolve construction conflicts and disputes. In a study performed by Chen and Kamara (2006), construction site information is grouped into twelve categories, as shown in Figure 2.1.

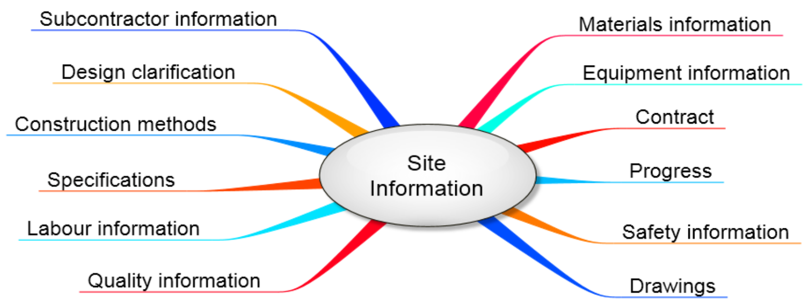

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Figure 2.1: Site Information Categories (Based on Chen and Kamara 2006)

In a more detailed study, De La Garza and Howitt (1998) categorized site information into ten major categories, as shown in Figure 2.2. Each category was divided into more detailed subcategories.

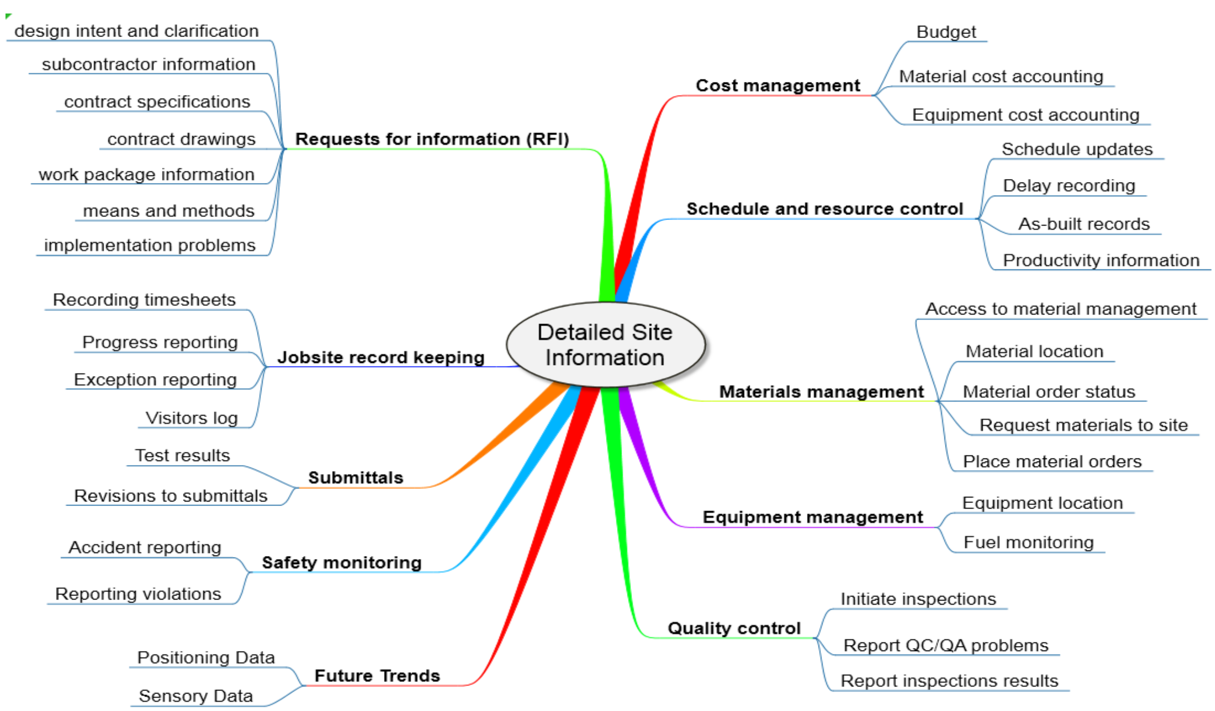


Figure 2.2: Site Information Categories (Based on De La Garza and Howitt 1998)

For example, the schedule information category contains the following four subcategories: schedule updates, delay recording, as-built information, and productivity information.

Another detailed study by Shahid and Froese (1998) categorized site information into seven main categories, each divided into subcategories, as shown in Figure 2.3. For example, the project management category contains ten subcategories: daily work progress, equipment in use and idle on the job site, daily labor force on the job site, daily weather conditions, visitors on the job site, materials requirements, lists of site photographs, negative/roll number of the photograph, date and location of the photograph, and purpose of the photograph.

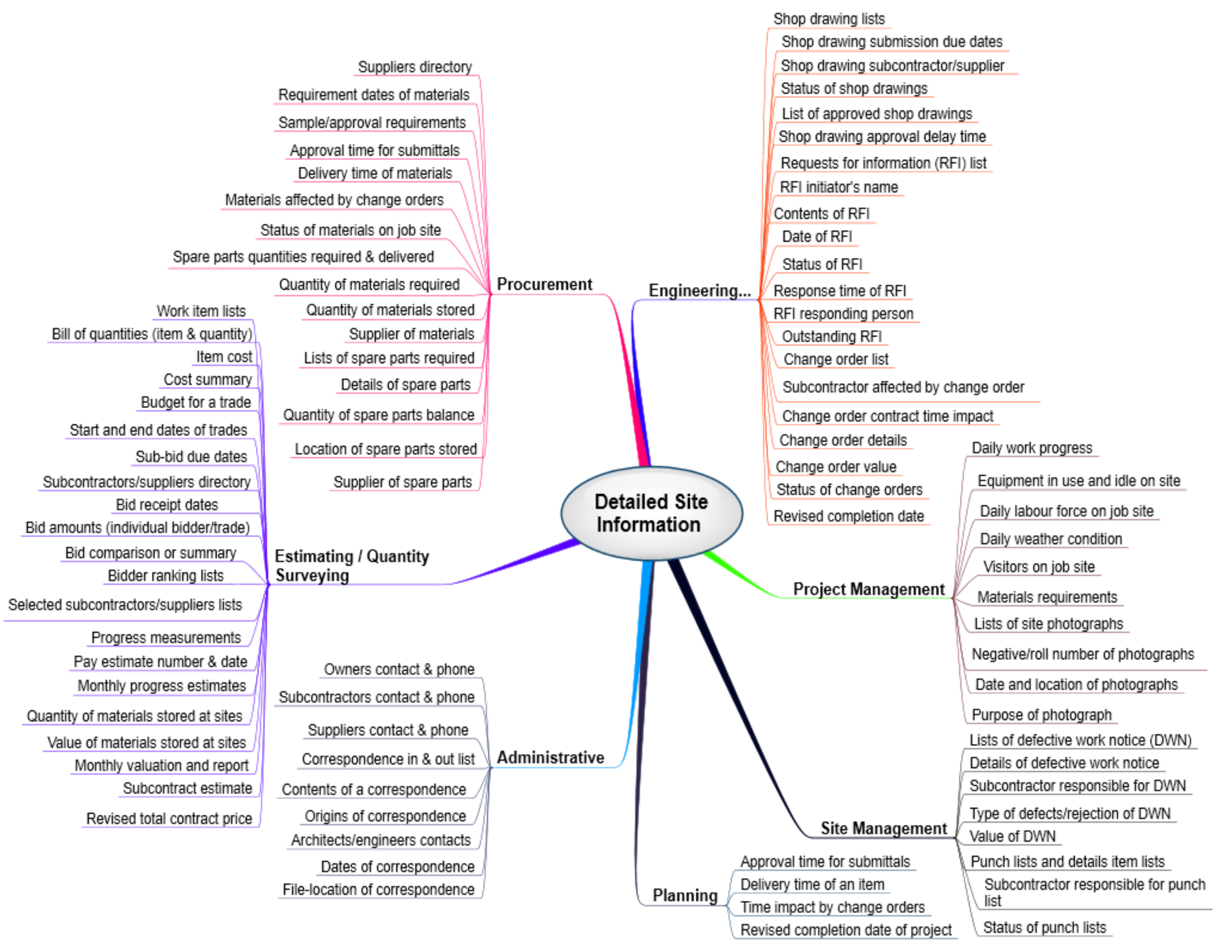


Figure 2.3: Detailed Site Information Categories (Based on Shahid and Froese, 1998).

The large amount of information associated with a construction site is still handled through paper-based tools, which is an inefficient means of communicating and exchanging site information (Bowden et al. 2004). The absence or inefficiency of information exchange can result in site personnel overlooking important issues that require an immediate response and can often cause on-site delays, changes in the schedule, and additional costs (Navon 2005; Reinhardt et al. 2004; Trupp et al. 2004; and Navon and Sacks 2007). A study by Akinci et al. (2006) emphasized that missing or incomplete data results in extra time and costs due to the addition task of verifying the data and repeating the collection process. Managing construction projects requires the constant monitoring of project performance and the issuing of follow-up schedule updates. When the project performance is constantly updated, project managers can take corrective action in a timely manner, thereby mitigating any negative impact on either the costs or schedule (Hwang and Liang 2005).

The most effective method of exchanging information on construction sites is to retrieve or capture information at the point when an event has occurred and at the time when the information is needed. However, such an approach is still infeasible with current traditional data management methods.

2.1.1 Uses of Construction Site Information

The collection of site information is not an objective in itself but is crucial for evaluating the progress of activities and is therefore a factor in recording as-built information, evaluating performance, analyzing delays, preparing invoices, and taking corrective action. Scott and Assadi (1999) identified six categories for the use of site information: assessing timely completion, assisting with financial control, providing feedback to the design team, confirming that the work is completed according to specifications, identifying the need for additional information, and assisting with contractor claims. Table 2.1 summarizes the site information required for each project decision. The next subsections then discuss how site information is used for evaluating the progress of an activity, which is a necessary step in the facilitation of the decisions listed in Table 2.1.

Table 2.1: Project Decisions That Utilize Construction Site Information

Type	Information Needed	Output
Recording As-Built	- A complete set of final drawings - All approved deviations - Actual dates, status, site events, responsibility	- As-built field information
Project Performance Evaluation	- Planned and actual activity dates - Additional activities - Omitted activities - Budget cost and actual cost	- Cost variance (CV) - Schedule variance (SV) - Cost and schedule performance indexes
Delay Analysis	- As-planned schedules - As-built schedules - Progress stop and responsibility	- Identifying and quantifying delays - Delay analysis report
Invoicing	- Actual quantities performed for each activity and their unit prices	- Periodic invoice
Corrective Actions	- Planned activity dates and costs - Actual activity dates and costs - Cost and schedule variances - Test results and inspection reports	- Corrective action plans

2.1.2 Measuring Activity Progress Based on Site Information

Progress measurement is crucial because it can be used to determine how well the project has progressed, to record accurate as-built information for successful project control, and to support decision makers in arriving at efficient decisions based on correct measurements. NYSOT (2003) summarized the characteristics of efficient methods of progress and performance measurement as follows: measurable, reliable and consistent, clear and understandable, verifiable, timely, unaffected by external influences, cost-effective, useful and meaningful, and leading to effective decisions and process improvement.

Since construction activities differ, the percentage of the activity that has been completed can be evaluated in a number of ways. Chin et al. (2004) summarized existing progress measurement methods; their measurement targets as shown in Table 2.2.

Table 2.2: Progress Measurement Methods and Targets (Chin et al. 2004)

Research		Measurement Method	Measurement Target
Thomas & Mathews	1.	Estimated percent complete	Progress state (Individual evaluation)
	2.	Physical progress measurement	Installed quantity
	3.	Earned value	Measurable level of work progress
CII	1.	Unit completed	Installed quantity
	2.	Incremental milestone	Milestone
	3.	Start/finish	Start/finish point of work
	4.	Supervisor opinion	Progress state
	5.	Cost ratio	None
	6.	Weighted or equivalent units	Finish point or progress state of work
Fleming & Koppleman	1.	Weighted milestones	Finish point of milestone
	2.	Fixed formula by task	Finish point of work (0-100) or start /finish point of work (50-50)
	3.	Percent complete & milestone gates	Progress state based on milestone
	4.	Earned standards	None
	5.	Apportioned relationship to discrete work	None
	6.	Level of effort	Time of work

Table 2.3 summarizes in additional detail the common measurement methods listed by the Construction Industry Institute (CII 1987) and gives examples of suitable measurement methods based on the nature of the activity.

Table 2.3: Progress Measurement Methods (Based on CII 1987)

Method	Suitable for Measuring	Examples
Units Completed	Activities that involve repeated production of easily measured work packages that consume roughly equal resources	Linear feet of wire or pipe installed, or cubic yards of concrete placed, etc.
Incremental Milestone	Sequential activities with clearly defined milestones	Pipes received/inspected, pipes supported/ aligned, pipes welded, pipes tested/completed
Start/Finish	Activities that do not have clear milestones or are hard to quantify in terms of time/cost	Cleaning, testing, aligning, etc.
Supervisor Opinion	Minor activities (detailed analysis is unnecessary)	Painting, constructing support facilities, etc.
Cost Ratio	Long-term activities that are allocated bulk cost/time	Project management, quality assurance, etc.
Weighted or Equivalent Units	Long-term activities that include multiple subtasks with different units of measurement	Structural steel erection (includes bolting, shimming, connecting, aligning, etc.)

As shown in Table 2.3, if the work progress is homogeneous from start to end, it can typically be measured either by the unit or by the percentage of work completed. For example, concrete or steel columns can be measured by the number of units finished while excavation and backfilling can be measured according to the quantity accomplished. For non-homogeneous activities, such as electrical and mechanical activities that involve equipment installation, a weight must be assigned to each subtask, and milestones are defined based on these weights. A recent study by Chin et al. (2004) used three criteria for choosing an appropriate measurement method for a work item: the budget weight of a work item, the typical duration of each activity for a work item, and the ease of determining an accurate progress rate for each activity. They also applied three measurement methods for specifying the actual progress for each activity: physical measurements, milestones, and estimated percent complete.

Because the incremental milestone method can be used for a large number of activities, some research has been focused on simplifying its use. Eldin (1989), for example, identified for each activity a number of control points throughout its construction life, with a specific weight (Wi) for each control point based on the activity cost and hours. The simple example shown in Figure 2.4 indicates that a steel reinforcement activity may have four control points (milestones): receiving, preparation, fixing, and finishing.

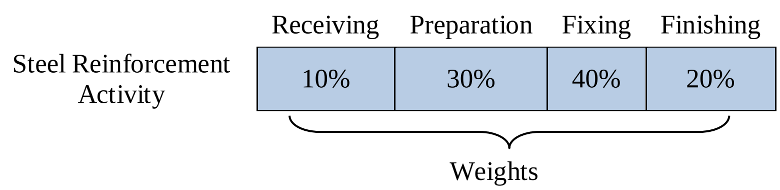


Figure 2.4: Control Points for a Steel Reinforcement Activity

Eldin suggested that this method is practical because it requires only data that can be acquired from visual inspection. The measurement of actual progress using this method is illustrated through a simple example of a foundation task with four subtasks, as shown in Figure 2.5. Each subtask is associated with different control points (milestones) for measuring its progress.

						Measured in the field					Calculated	
Subtask Description	Control Point Weights % **(W_i)**					Control Point Status **(P_i)**					Subtask Weight **(SW_i)**	Subtask % Complete
	1	2	3	4	5	1	2	3	4	5		
Excavation	5	20	15	40	20	100	100	100	100	100	0.43	100
Formwork	50	10	40	-	-	100	100	50	-	-	0.05	80
Steel Reinforcement	10	30	40	20	-	50	50	0	0	0	0.32	20
Concreting	10	60	30	-	-	0	0	0	0	0	0.20	0
												52%

Figure 2.5: Progress Measurement for a Foundation Task Using Control Points (Based on Eldin 1989)

The percentage completed for each subtask is first determined using Equation 2-1. The work progress for the foundation can then be calculated from Equation 2-2.

$$\text{Subtask \% Complete } (\mathbf{S_i}) = \sum_{j=1}^{5} W_{ij}.P_{ij} \qquad \mathbf{2.1}$$

$$\text{Task Progress (\% Complete)} = \sum_{i=1}^{I} S_i.SW_i \qquad \mathbf{2.2}$$

where i is the item number

j is control point number

W_{ij} is the weight of control point j for subtask i

P_{ij} is the actual progress accomplished on control point j for subtask i

S_i is the percent complete for subtask i

SW_i is the weight for subtask i

Once the percentages complete are evaluated for the activities, earned value (EV) analysis (Fleming and Koppelman 1996) can be performed in order to evaluate both the schedule and cost performance of the project during the relevant reporting period. The EV method compares the amount of work planned with that actually accomplished in order to determine whether both the cost and schedule performance are as planned. The EV thus helps project managers monitor cost overruns and project delays (Chou et al. 2010). Figure 2.6 shows a graphical representation of the EV method, in which the following performance indicators can be used to measure project performance:

- Cost variance (CV) = EV – AC
- Cost performance index (CPI) = EV / AV
- Schedule variance (SV) = EV – PV
- Schedule performance index (SPI) = EV / PV

where PV represents planned work and is known as the budgeted cost of the work scheduled (BCWS)

EV represents the actual payments also known as the budgeted cost of the work performed (BCWP)

AC represents actual costs and is known as the actual cost of the work performed (ACWP)

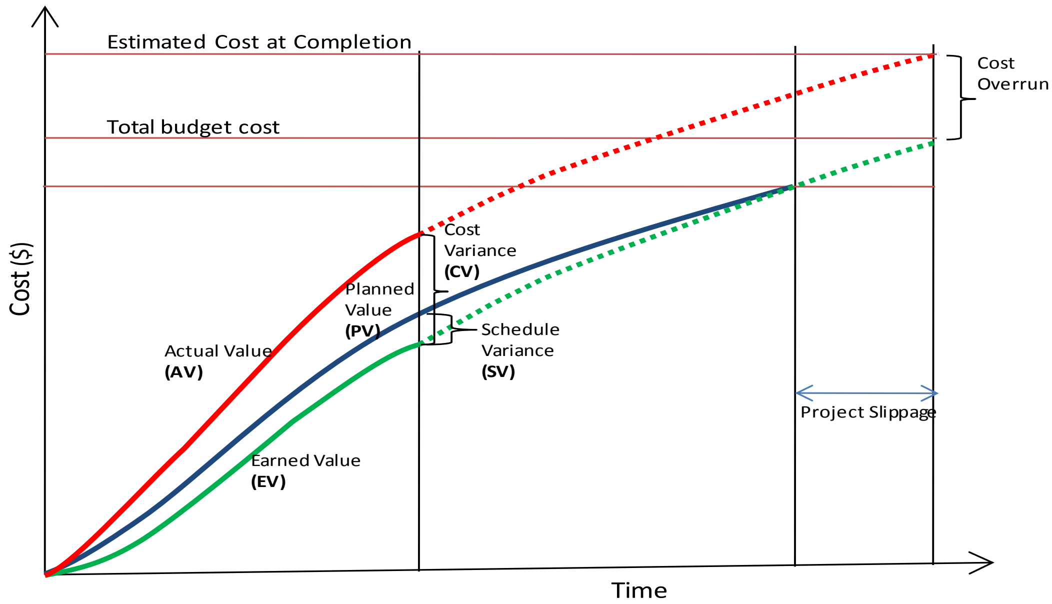


Figure 2.6: Graphical Representation of the Earned Value Method (Chou et al. 2010)**.**

2.2 Software Systems for Site Data Collection

Several commercial software systems are available for project management. Primavera Project Planner (Primavera 2013) and Microsoft Project (MS Project 2013), for example, are the most common software applications for scheduling and controlling construction projects. These programs provide a means of scheduling and tracking project progress; however, access is limited to trained personnel (Peña-Mora and Dwivedi 2002). These software packages also provide commercial web-enabled applications for accessing the project schedule and other project information online in real time. Head office personnel can manually send email messages requesting new progress information so that they can then manually update the schedule which is inefficient, particularly when the project involves a large number of activities.

Web-based applications have also been developed as a means of facilitating data sharing, exchanging, and project communication. Examples are Bentley Transmittal (2013), Projecttalk (2013), ProjectSolve (2013), e-builder (2013), and Projectmates (2013). Some of these systems (e.g., e-builder) can be integrated with current scheduling software (e.g., Primavera and MS Project) so that project progress can be monitored. Such applications enable authorized personnel to share project information in real time but are not designed to support real-time responses to immediate requests (Peña-Mora and Dwivedi 2002).

With respect to a reduction in paper work, other emerging trends involve applying construction management applications on iPads and smartphones so that supervisors can immediately synchronize construction details with head office. Table 2.4 and Figure 2.7 summarize the primary characteristics of some of the software available on tablet computers for recording construction site information. Construction Superintendent (2013), for example, has been designed to be applied on small tablets and offers generic construction forms so that site information can be easily collected and sent back to head office. Autodesk BIM 360 Field (2013) is building information model BIM-based software that can help construction personnel document construction details (e.g., daily site reports, inspection reports, and drawing modifications) on their tablets and then synchronize the saved data with head office. It also allows site personnel to add markups on drawings, but the markups are linked to drawings rather than to specific activities in the schedule. Other systems listed in Table 2.4, such as Onsite:AEC (2013), Newforma's Punch List (2013), and Latista Punch List (2013), can also be used to record daily site reports electronically, attach photos, and synchronize reports with head office, navigate drawings and attach notes, photos, modifications, and notifications (e.g., Bentley Navigator 2013; Autodesk Buzzsaw 2013). Among the most useful systems, Asta Powerproject (2013) is powerful software for planning and controlling construction projects. It has its own scheduling engine that operates in a manner similar to that of the MS Project and Primavera systems, but it does not include the CPS representation mentioned briefly in Chapter 1. This feature is discussed in detail in

Chapter 3. One of its add-ins, Asta Sitecontrol (2013), enables supervisors (site personnel) to record on a separate spreadsheet the daily progress percentage but no other events.

Despite the usefulness of the applications listed in Table 2.4 and Figure 2.7, they lack a number of features that are important for project control, as shown in the table. Basically, their recorded data does not appear directly on the project schedule and thus cannot provide timely schedule updates to help decision makers take better corrective action. As with existing project management software, they are also unable to provide immediate and automated bidirectional communication between site personnel and head office in order to respond to urgent RFIs.

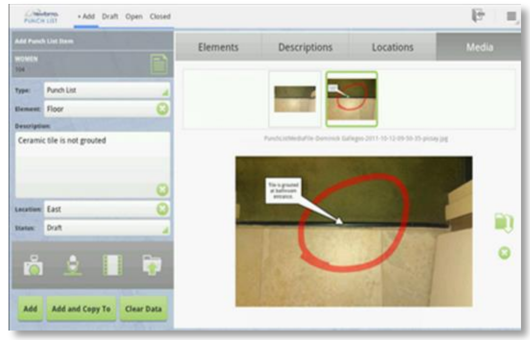
Table 2.4: Software Systems for the Collection of Site Data

	Progress and cost tracking						**Drawing tracking**				**RFI tracking**	
Software	Has ready-to-use forms for site reports	Has its own scheduling engine	Tracks actual costs /resources	Records daily activity progress	Shows site events on the schedule	Links site reports to the schedule	Permits navigation of drawings	Allows attachments of photos /notes	Shows markups on drawings	Links drawing markups to activities	Allows requests for information (RFIs)	Automatically handles RFIs
Construction Superintendent	√	-	-	-	-	-	-	-	-	-	√	-
Autodesk BIM 360 Field	√	-	-	-	-	-	√	√	-	-	√	-
Onsite:AEC	√	-	-	-	-	-	-	√	-	-	-	-
SafetyNet	√	-	-	-	-	-	-	-	-	-	-	-
Autodesk Buzzsaw	-	-	-	-	-	-	√	√	-	-	-	-
Bentley Navigator	-	-	-	-	-	-	√	√	-	-	-	-
Newforma’s Punch List	√	-	-	-	-	-	-	√	-	-	√	-
Latista Punch List	√	-	-	-	-	-	-	√	-	-	√	-
Asta & Sitecontrol	√	√	√	√	-	-	-	-	-	-	√	-

Onsite:AEC

Forms for site progress reports, site issues, photos

Newforma's Punch List

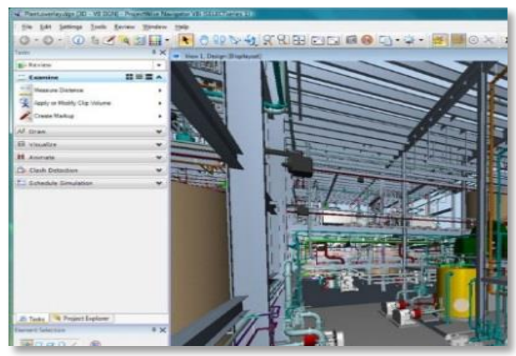


Ready-to-use forms for capturing, assigning managing, and verifying punch lists in the field

Latista Punch List

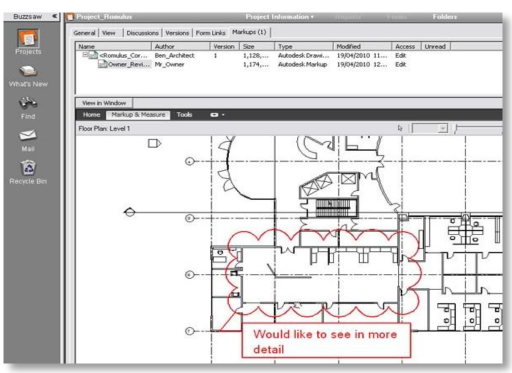
Ready-to-use forms and checklists for site reports, photos, notes, and markup

Bentley Navigator



Share, exchange, navigate, and mark up drawings

Autodesk Buzzsaw



Enables project teams to view, mark up, and exchange project information from the field

Asta Sitecontrol

System with scheduling engine for recording progress percentage on a spreadsheet

Figure 2.7: Software Systems for the Collection of Site Data

2.3 Automating the Collection of Site Data

Accurate as-built information not only provides project field personnel with feedback about project performance and progress but also provides estimators with new information so that the accuracy of their next estimates can be adjusted (Hwang et al. 2003). An additional benefit of such information is that it enhances the profitability of the operation and maintenance phase during the lifetime of a project (Trupp et al. 2004). As-built information also enables construction managers to predict actual project performance and to make better-informed decisions in complex environments (Rojas and Lee 2007). As well, all parties have access to information about activities that can ultimately affect the cost, schedule, or performance of the work.

A number of information technology (IT) tools have recently become affordable and can be used to collect data in a variety of formats, including text, pictures, voice, and video. Such tools can provide timely and accurate data for project control (Hwang et al. 2003) and for enhancing communication and coordination among participants (Wang et al. 2007). Automation, however, expedites data collection and minimizes associated costs. The benefits of automation systems can be summarized as follows:

- **Increased time savings and reduced duplication of data:** As soon as data are received, they can be organized and used to update the time schedule so that no delay or extra time is required for repeating the collection of inaccurate or incomplete data.
- **Accurate and quick data retrieval:** If the data received are as correct and timely as required, they can be retrieved quickly and accurately, which facilitates schedule analysis and the implementation of corrective action.

- **Minimum and consistent input**: The data received are consistent, complete, and exactly needed for updating the project schedule and analyzing project information so that quicker and better corrective action can be taken at the appropriate time.
- **No requirement for skilled staff:** The automated system does not require skilled staff for manual form completion.

Extensive research has been conducted with the goal of automating the tracking of progress and the collection of site data. The integration of IT and computerized systems has increased the efficiency of on-site data collection (Shahid and Froese 1998). Despite the substantial number of studies related to the automation of the collection of site information, more effort is still needed in order to improve the efficiency and effectiveness of automation and to minimize the cost of purchasing new IT tools, installing the system, training staff, and operating and maintaining the system. The following subsection provides an overview of the use of IT visualization tools in the construction field.

2.3.1 Visualization Tools

Lack of accurate visual representations of information results in construction managers struggling with copious amounts of data (Song et al. 2005) that are usually time and location variant and are generated and handled by multiple project participants. Inadequate representation of site information and lack of a visual format are considered major reasons for poor or late decisions (Golparvar-Fard et al. 2009). Presenting construction site information visually is thus an effective means of monitoring progress, controlling a project, and providing an understanding of complex construction situations.

Since the mid-1990s, multimedia (audio and visual) technologies have been proposed for use with construction projects. Multimedia information includes digital photographs, videos, and audio recordings. Such information can be captured at a construction site and stored in a computer. Multimedia tools are important because they enable information to be visualized and problem areas to be highlighted (Abudayyeh 1997, Hegazy et al. 2008). An information management model developed by Abudayyeh (1997) included an attached video camera and microphone for recording all events related to the progress of an activity. The video camera incorporated a time-lapse capability that allowed lengthy operations to be displayed in a shorter time. The developed model linked the project schedule with timely multimedia field data (e.g., audio, video, and images). Such a system has the potential to support decision making and thus improve processes related to delay management, claims situations, and other construction disputes. Hegazy et al. (2008) have developed a building inspection model installed in a handheld device supported by a video camera. Their system can store all of the inspection details for building items in a visual format along with captured images/videos that help decision makers better understand the current performance of the item/building.

With recent advances in visualization and computer technologies, a number of studies reported in the literature have proposed 4D visualization as a method of linking 3D design data with schedule information (Russell et al. 2009). Models based on this concept can be used to simulate graphically the sequence of construction operations, thereby providing site personnel with a visual understanding of the construction process (Fischer and Kunz 2004; Ibrahim et al. 2008). Mahalingam et al. (2010) recently surveyed the applicability of 4D visualization in construction for all management levels, and reported that upper management and site personnel would benefit from its use because the 4D-simulation that would then be available to compensate their lack of site-related knowledge. Despite the research related to the tracking of construction progress through a comparison of 3D CAD models with 3D models extracted from image recognition, the systems developed still cannot prepare an as-built model without human intervention during the camera-matching process (Son and Kim, 2010). To improve visual progress tracking, Liang et al. (2011) integrated 4D-PosCon software and robotic total station to track and visualize the position and orientation of building components during the erection process. Another work has integrated GIS with a 4D model for visualizing and reviewing the construction project schedule, cost estimates, and quantity takeoffs as an alternative to existing 4D CAD tools. This work includes consideration of both the spatial and non-spatial aspects of a construction project (Bansal and Pal 2007; Bansal and Pal 2009a; Bansal and Pal 2009b).

2.3.2 Recent Studies of the Automated Collection of Site Data

Wireless technologies can be used for improving the accuracy and timeliness of the collection of data from construction sites and the exchange of the data with project participants (Ghanem 2007). A number of advanced automated data collection (ADC) technologies are used today for real-time on-site performance measurement (Navon and Sacks 2007): barcoding, radio frequency identification (RFID), image recognition, 3D laser scanning, photogrammetry, and global positioning systems (GPS). This section presents a review of published studies related to the automation of the tracking of construction site information using IT tools.

Barcoding: One of the oldest information technologies employed in construction engineering, barcoding is nevertheless still being used in some applications due to its low cost. With this technology, a series of parallel and adjacent bars are scanned with a barcode reader, or scanner, which is a handheld or stationary input device used to capture and read the information contained in a barcode about the item in question. This method allows real-time data to be collected. Barcode technology has been proposed primarily for materials tracking, inventory, construction progress tracking, and labour tracking (Navon and Sacks 2007); for tracking and controlling engineering deliverables, such as drawings, reports, and specifications (Shehab and Moselhi 2005); and for the management of documents (Shehab et al. 2009).

Radio Frequency Identification: RFID is an automatic identification technology in which radio frequencies are used to capture and transmit field data. Site information is communicated electronically via radio waves so that line-of-sight is not required for stored data to be transmitted.

Numerous researchers have applied RFID for the automated collection of data, such as tracking equipment; materials; and other resources, including labour. For example Ghanem and AbdelRazig (2006) applied an RFID wireless system for tracking construction progress. Montaser and Moselhi (2012) utilized RFID technology for tracking earthmoving operations. Song et al. (2006) used RFID technology for the automatic identification and tracking of individual pipe spools. They reported that the benefits of using RFID technology in automated pipe spool tracking may include reduced time for identifying and locating pipe spools upon receipt and prior to shipping; more accurate and timely information about shipping, receiving, and inventory; a reduction in the number of misplaced pipes and associated search time; and an increase in the reliability of the pipe-fitting schedule. Similar to RFID technology, Shahi et al. (2013) utilized Ultra Wide Band (UWB) positioning system to track the progress of construction activities (e.g., welding and inspection) of pipelines. The overall advantages of RFID technology are its wide reading range, its ability to operate without line-of-sight, and its durability in a construction environment with respect to lighting and weather conditions (Song et al. 2006). The major limitations of the use of RFID systems in the construction industry are the high initial and maintenance costs of these systems (Hammad and Motamedi 2007) and the limited lifetime and periodic battery replacement associated with an active RFID type (Kiziltas et al. 2008).

Image Recognition: Rebolj et al. (2008) developed an integrated method of automated data collection based on image recognition. Their method combined three components: an automated activity-tracking subsystem based on image recognition, an automated materials-tracking subsystem, and mobile computer-supported communication. Navon and Sacks (2007) discussed the employment of video cameras for data collection and construction monitoring using real-time site photographs from a variety of angles and converting them into progress information. Abeid et al. (2003) developed PHOTO-NET II, a real-time monitoring system that links time-lapse images of construction activities with the critical path method (CPM) and progress control techniques. This system can acquire and store digital images and display them in sequence to create a movie recording of construction activities. The extraction of a 3D model from image recognition output for automated data collection has limitations (Navon and Sacks 2007): this area needs additional research in order to improve pattern recognition and to resolve problems that result from varied lighting conditions and the difficulty of translating the raw data into information that is meaningful for construction management.

3D Laser Scanning: 3D laser scanning is a technique used to gather spatial data, including all of the geometric information needed for building a 3D model (Trupp et al. 2004). 3D laser scanning can be used for accurately measuring volumes and for identifying 3D geometric components, features that make it suitable for measuring items such as the amount of earthwork or tracking the progress of a number of structural elements (Trupp et al. 2004; and Kern 2002; Moselhi and El-Omari 2007). Bosche et al. (2008) integrated a 3D CAD model object with 3D laser scans for tracking construction progress. Gao et al. (2012) and Liu et al. (2012) utilized 3D laser scanning to capture actual construction progress and used the extracted information to develop a complete as-built BIM. Moselhi and El-Omari (2007) reported that one of the major limitations of 3D laser scanning is the time required for scanning the construction site from a variety of positions in order to obtain the amount of information required for the modeling process. They improved this limitation by incorporating digital images with a 3D laser scan that reduces the time required for the scanning process and enhances the resolution of scanned objects. El-Omari and Moselhi (2009) continued their study of automated data collection by integrating a 3D laser scanner with photogrammetry in order to track the quantity of work performed. Their method addresses some of the limitations associated with each individual technique, such as the number of scans required and the time needed for each scan to produce acceptable results during the 3D modeling process. It also overcomes challenges associated with the use of photogrammetry for modeling 3D images of objects that have unclear geometrical properties.

Photogrammetry: Photogrammetry is a technique used to extract the geometric properties (3D data) of an object based on photos taken from different angles. Photogrammetry can be used to build a 3D model from 2D images. Dai and Lu (2010) have used photogrammetry to collect the geometric measurements and orientations of building elements in order to record as-built information. These systems can provide benefits for the construction field with respect to determining the quantities of materials installed and assisting in the preparation of as-built information.

Global Positioning Systems (GPS): GPS is a satellite-based technology widely used in the construction field with respect to the position and navigation of construction activities (Navon and Sacks 2007). The functional ability of the technology is dependent on the reception of signals from satellites in order to locate the position of a specific object attached to a tag (El-Omari and Moselhi 2009). GPS can be used for tracking materials and the progress of steel structures throughout the construction process, from manufacturing to the site gate, from inventory until installation, and even for future maintenance purposes (El-Omari and Moselhi 2009). Similar to GPS positioning, Shen et al. (2012) utilized a robotic total station and sensors to automate the process of data collection and positioning of tunnel boring machine in the 3D underground space.

While these high-end IT technologies have significant potential for future application in construction firms, some researchers have reported barriers to their wide use. Ghanem (2007) surveyed several IT tools and reported the following drawbacks: lack of collaboration, high cost, insufficient technological support, a requirement for extensive user training, and a lack of metrics for assessing value and quantifying the benefits of these technologies. Numerous expenses must be considered when IT approaches are applied in construction: the purchase of the equipment and software, the maintenance and upgrading of the hardware, the upgrading and licensing of the software, the fee for wireless service, the salaries of in-house technical support personnel, and the training of the users. De la Garza and Howitt (1998) also added as other important barriers the need for data security and the risk of data loss.

2.4 Existing Low-Cost IT Tools

Several low-cost tools have greatly grown to facilitate communication on construction sites and can be used to automate site data collection: web-based telephony (internet-based telephony), text-to-speech (TTS) systems, and voice recognition, in addition to email and SMS. The benefits of such tools are no or low setup costs, low operational costs, and operating simplicity that entails no training for site personnel with respect to the recording of daily site activities. Such technologies can help project participants collect and share information in a timely and accurate manner and offer assistance with project managers' decisions by providing essential data more quickly. The use of these technologies and their benefits are discussed in the following subsections.

2.4.1 Internet-Based Telephony

Despite progress in the use of IT in the construction field, the telephone is still the tool most commonly used for communication in the industry (Egbu and Boterill 2002; Howard and Petersen 2001; Ahsan et al. 2009). Web-based telephony employs internet protocol (IP) telephony for sending and receiving data over the internet. This technology utilizes existing internet connections (cable, DSL, wireless, or dial-up) and personal computers that plug directly into the regular telephone network. Overall, web-based telephony is a powerful and economical communication tool that facilitates all types of data transmission (e.g., email, voice, data, and fax) with lower line charges, network costs, and IT expenses (Beyh and Kagioglou 2004). Web-based telephony also reduces operational costs and improves service quality (Liao and Tseng 2010). Using IP telephony for construction communication provides opportunities for retrieving audio/video information along with other project data so that better decisions can be made and all relevant project participants can easily be kept up to date with project progress (Ahsan et al. 2007). Additional advantages of internet-based telephony are summarized in Figure 2.8.

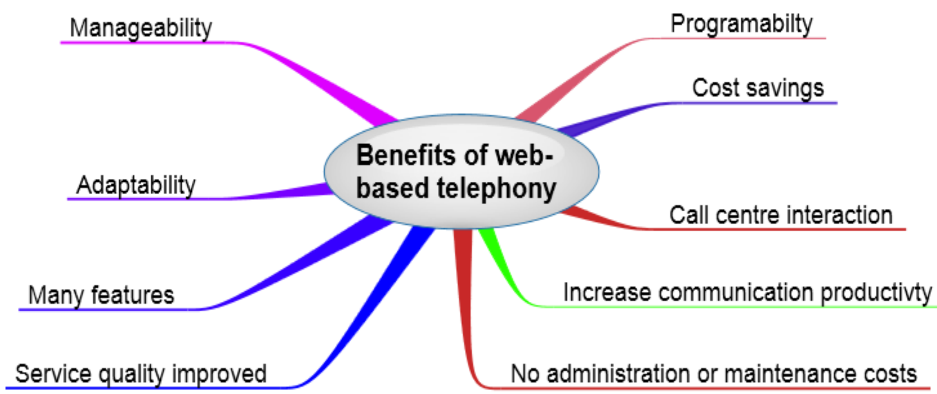


Figure 2.8: Benefits of Web-Based Telephony

Many websites currently offer internet telephony services with high voice quality and no disconnection. Some of these websites provide an application programming interface (API) developer to customize these services for sending/receiving information, scheduling calls, sending results to a project database or website, etc. They also have features for communicating with respondents through interactive voice response (IVR), which makes the usage of internet telephony effective and useful for the collection of site information. Some of these features are summarized in Table 2.5

The use of internet-based telephony can enhance the efficiency of a construction site by facilitating project communication, the exchange of site information, and the provision of timely access to information for all project participants. These tools can thus improve the tracking of site information and enable managers to take better corrective action.

Table 2.5: Features Available in Some Web-Based Telephony Systems

Property	**Description**
Hosted IVR	Enables users to create web-based interactive voice response applications
Call Logs	Provides detailed phone call analysis, including date, duration, and other details
Vote by Phone	Enables users to configure a survey online; after the vote results available for viewing online in real time
Developer API	Allows user to integrate IVR with personally designed websites or databases to customize internet-based telephony for scheduling the calling and receiving of responses
Email/Voice Notification	Enables notifications to be sent to users or groups of people via email or phone calls
Responses Sent via Email	Permits responses to be sent with audio file attachments to users' emails

Text-to-Speech Systems: A powerful feature that can be integrated with any computer application, a text-to-speech (TTS) system converts text into audio format by automatically producing speech. The advantage of TTS is that it enables computers to produce synthetic speech from the text output of an application (Schroeter et al. 2002). Current advanced software can produce continuous and regular speech from text sentences; the sound is exactly like human speech, including intonation. TTS can transfer text format into audio format suitable for exchanging site information and measuring work progress (Schroeter et al. 2002). Such tools are currently integrated with many voice-based systems in order to facilitate the communication and collection of information.

Interactive Voice Response (IVR)**:** IVR technology allows interaction between callers and a phone system in order to acquire or enter information into a database. IVR enables the caller to select from a preset menu of options to enable a specific activity to occur, such as paying a bill, scheduling an appointment, requesting information, or calling for a construction field inspection. Today's IVR systems also offer speech recognition, text-to-speech features, and the ability to fax or email required forms and information. In recent years, with enhanced phone and computer technology, IVR has expanded to include a variety of features such as the capacity to post and review inspection results immediately, fax or email inspection reports and other information, and fax or email required forms and documents requested by users.

Some cities in Canada and the U.S. (e.g., City of London, City of Toronto, Washington Country Government) have been employing IVR technology since 1990 as a means of facilitating and automating the provision of information and assistance required by their customers. Operational seven days a week (almost 24 hours a day), this type of service is useful in construction for activities that include scheduling, rescheduling, or cancelling inspections; checking or reviewing the status of requests; obtaining inspection results; and leaving messages for inspectors or contractors. IVR can also be used to connect site personnel (e.g., inspectors or contractors) automatically with head office, to enter or retrieve information from a database system, to respond to urgent requests for information, and to convey an immediate brief notification to a group of people. The benefits of IVR can be summarized as follows:

Instant notifications to a group of people: IVR can provide timely notification to customers, including by fax, emails and text message, and can also permit outbound phone calls. Examples of IVR notifications include announcements about important meetings, the rescheduling or cancelling of an order, alerts about information sent by email or fax, and urgent safety notices.

Replies to urgent requests for information: IVR can enable immediate responses to both regular and urgent requests for information from inspectors or contractors by transferring them to the party responsible for providing it and can retrieve the information required from saved databases.

Reduction in wasted time: IVR can significantly reduce the amount of time spent waiting for inspections to be scheduled, performed, recorded into the project database, and then reported to the contractor. The continuous communication channel between the construction site and inspectors/contractors means that inspections can begin as soon as the job site is ready, and contractors can be notified immediately with inspection results, which effectively minimizes wasted time.

Reduction in Cost: IVR can substantially decrease the number of unnecessary visits by owners, consultants, contractors, and inspectors. The time and paper work that IVR saves also represent lower costs.

2.4.2 Use of Email for Construction Communication

Email is an efficient method of exchanging digitized information quickly and efficiently among project participants. The advantages of using email for sending and receiving data can be summarized as follows:

- Email is easy to use, is delivered instantly, and is accessible from anywhere at any time.
- All information types can be sent and received: document files, photos, videos, or voice recordings.
- The information received can be documented and used for progress measurement, delay analysis, project control, report preparation, or the processing of claim disputes.

Email has become a popular core technology for data exchange and sharing (Carroll, J. 1993). Companies can use email applications for data exchange/collection throughout an organization and can track the progress of the communication (Hales 1996; Wikforss and Löfgren 2007). A recent survey by Ahsan et al. (2009) examined the storage of communications produced during the life of a project. Email was ranked second after printed documents as a means of storing site information, as shown in Figure 2.9. This study emphasized the increasing importance of email for communication at construction sites as compared to other data collection tools, such as paper and pencil, email-based forms, spreadsheet software, database software, web-based surveys, and web-based applications, another study by Elamin (2009) classified email as an effective means of communication for reviewing or extracting data received. The criteria used in Elamin's (2009) study were setup cost, difficulty of project setup, versatility, training requirement, portability/accessibility, ability to manage data, ability to track progress, ability to present data, and ability to store and retrieve data.

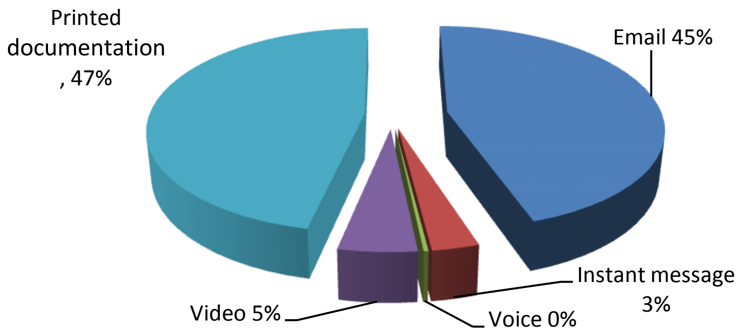


Figure 2.9: Communications Storage Media in UK Construction Firms (Ahsan et al. 2009)

2.4.3 Voice-Based Applications in Construction

With the rapid advances in technology, voice-based systems have improved substantially over the years. The use of voice has recently matured, and advanced features such as voice recognition and voice commands have been incorporated (Sunkpho and Garrett 2000; Reinhardt and Scherer 2000). Sunkpho and Garrett (2000) for example, used voice commands to facilitate the documentation of bridge inspection through the use of handheld devices. Voice recognition was also utilized in construction by researchers in two studies (Tsai et al. 2007; Tsai 2009) as a means of recording and updating site material logs. Their system is not only less expensive but also automatically corrects data-entry errors by confirming the data entry. Table 2.6 (Tsai 2009) summarizes a comparison of barcoding, RFID, and speech recognition technology for recording material logs. Voice recognition is an efficient tool that can be integrated with any voice-based system to enable auto-interaction with humans and can be used for tracking site information in order to record work progress and other site events.

Table 2.6: Comparison of Barcoding, RFID, and Speech Systems (Tsai 2009).

Evaluation	Barcodes	RFID	Speech recognition
How is information stored?	Barcode labels	RFID tags	Voice
How is the stored information received?	Barcode readers	RFID readers	Electronic devices
What is the communication relationship between activity workers and operation devices?	One-way	One-way	Two-way
How are errors modified?	Manual	Manual	Automatic
Can the solution transfer information within WLANs?	Yes	Yes	Yes
Does the solution require additional costs?	Yes	Yes	No

As mentioned, the telephone is still considered the tool most commonly used for voice-based communication. Telephone systems currently operate over the internet using a Voice over Internet Protocol (VoIP), or internet telephony. The survey by Ahsan et al. (2009) about communication preferences in UK construction revealed that communication by phone and cell phone were the first and second preferences for both incoming and outgoing communication, email ranked third, with SMS fourth, as shown in Table 2.7. Such a powerful and low-cost tools can provide substantial savings in communication expenses (Beyh and Kagioglou2004; Liao and Tseng 2010).

Among the powerful voice-based technologies for telephone communication is IVR, which has been used extensively by a number of companies for technical support purposes, but has not yet been utilized for construction site communication. IVR is an efficient tool that has immense potential for cost-effective automatic bidirectional communication between a site and head office with no geographic barriers.

Table 2.7: Communication Preferences in UK Construction (Ahsan et al. 2009)

Rank	Outgoing Communication	Incoming Communication
1	Telephone	Mobile Phone
2	Mobile Phone	Telephone
3	Email	Email
4	SMS	SMS
5	Instant Messenger	Instant Messenger
6	Walkie Talkie/Radio	Walkie Talkie/Radio

2.4.4 Handheld Computing

Handheld computers are gaining popularity in the construction field and have been identified as important IT support for construction sites (Hwang et al. 2003). Handheld computers can enhance project management by providing site personnel with a variety of information, such as resource data, project delivery information, and progress information (Ghanem 2007). They can be used at construction sites to facilitate project management, schedule management, facility inspection, and site reporting, and they can run application software that supports users' daily work functions. Significant research has investigated the use of handheld computers on construction sites for collecting, storing, and exchanging site information (e.g., Ward et al. 2004; Bowden et al. 2004; Löfgren 2007). The main types of mobile computing hardware available at construction sites are personal digital assistants (PDAs), handheld computers, pen tablet/touch PCs, and rugged notebook PCs.

Personal Digital Assistants: Current PDAs have powerful potential at construction sites for a number of reasons: speed, memory capacity, communication possibilities, reliability, small size, long power independence, and superior hardware and software standardization (Cus-Babic et al. 2003). PDAs can perform word processing functions, handle spreadsheet and industry-specific applications, and provide email and internet access (Ghanem 2007). The ease with which they can be synchronized with desktop computers enables their use for the collection of data from the construction site and the communication of the data back to office servers. They can also be connected to a wireless network so that they function as soft phones, and they can be programmed to use VoIP techniques to communicate with other personnel by voice and/or video (Ahsan et al. 2006). Their advantages also include integration with other technologies, such as digital cameras, GPS, barcodes, and RFID. For example, a PDA has been attached to barcode readers in order to support the management of the supply and storage of materials on site (Tserng et al. 2005). PDAs offer superior mobility because of their small size: they can fit into a pocket, allowing hands-free use. However, improvements in data entry have been recommended for PDAs due to restrictions such as inadequate keyboards (Ghanem 2007).

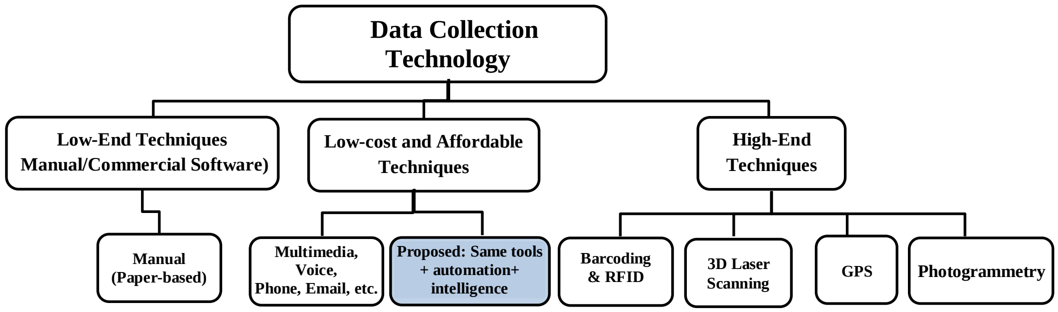
Handheld Computers: Handheld computers are larger than PDAs. They have the same basic functionality of a notebook computer but in a smaller package. They generally run a Windows-based operating system and are more suitable for a construction site than PDAs (Ghanem 2007). Their keyboards and screens are smaller than those of PDAs, which makes them even more convenient to carry but more difficult to operate and view.

Tablet PCs: Tablet PCs have been used for site information management, enabling crews to improve their productivity while ensuring that construction quality standards are achieved (Löfgren 2007; Ward et al. 2004). The use of tablet PCs on-site is restricted by their limited portability, their large size, and their high cost (Ghanem 2007).

Rugged Notebooks: Rugged notebooks are simply laptop computers that have been designed for harsh environments: they have enhanced resistance to shock, sunlight, dust, and water (Löfgren 2007). They can be mounted on all-terrain vehicles that are exposed to rigorous conditions, such as earth-moving equipment or military vehicles. These laptops have all the capabilities of their non-rugged partners and are generally the same size as an average- or small-sized laptop (Ghanem 2007).

2.5 Conclusion

Until recently, site information has been collected through paper-based systems, which is not only time-consuming and labour-intensive but also provides incomplete and/or inaccurate information. This chapter has provided a comprehensive literature review of the types of construction site information and methods of measuring activity progress. The importance of timely, accurate, effective, and complete field data for successful construction project control has been emphasized. The chapter has included a description of the increasing use of IT in the construction industry for tracking work progress, materials, and labour. To address the challenges related to site information tracking, researchers have proposed numerous methods for improvement, as shown at the top of Figure 2.10, which compares the features of a variety of methods and tools. As shown in this figure, current tools can be classified as "Low-End Techniques," such as paper-based and commercial software; "Low-cost and Affordable Techniques"; and "High-End Techniques". As can be seen, "High-End Techniques" still need more research before they can be ready for application in construction firms. In addition, current software applications for data collection and project management, as discussed earlier in this chapter, are not linking the received progress information, markups on the top of drawing files, and other comments from construction site to their relevant activities on the project schedule. As such, handicap the decision makers to understand the full picture of activities progress evolution, accordingly lead to delay in taking accurate corrective actions, incorrect schedule analysis, project delays, and cost overruns. However, improvements to "Low-cost and Affordable Techniques," for example, by integrating them into an automated data collection system, can be applied immediately at construction firms as a means of facilitating the cost-effective collection of progress information details, documenting them properly in one database, and visually represent the received information on the daily segments for each activity in the schedule.



	Manual (Paper-based)	Multimedia, Voice, Phone, Email, etc.	Proposed: Same tools + automation+ intelligence	Barcoding & RFID	3D Laser Scanning	GPS	Photogrammetry
Setup and Cost	Low	Moderate	Moderate	Moderate	High	High	High
Auto Data Collection	No	No	Yes	Yes	Yes	Yes	Yes
Track Daily Progress	No	Yes	Yes	Yes	Yes	Yes	Yes
Ability to Present Data	No	Yes	Yes	Yes	Yes	Yes	Yes
Storage & Retreival of Data	No	Manual	Yes	Yes	Yes	Yes	Yes
Ability to Manage Data	No	Yes	Yes	Yes	Yes	Yes	Yes
Auto Progress Analysis	No	Manual	Yes	On-going	On-going	On-going	On-going
Audio & Video Attachments	No	Manual	Yes	No	No	No	No
Uses	Small projects	All activities & projects	All activities & projects	Tracking equip. & materials	Creating 3D as-built	Tracking equip. & materials	Creating 3D as-built
Comment	Time-consuming, costly, and unstructured		Promising	Still under extensive research & development			

Figure 2.10: Comparison of Available Technologies for the Collection of Site Data

Therefore, for practical reasons and faster implementation, this research was aimed at utilizing existing low-cost and promising IT tools (e.g., email, IVR, and visual tools) in order to establish a simplified approach for automatically recording timely and complete site information on a daily basis. As a result, the developed system will provide project managers with the accurate, complete, and timely information they need to facilitate day-to-day decisions and to automatically document the evolution of as-built schedules.

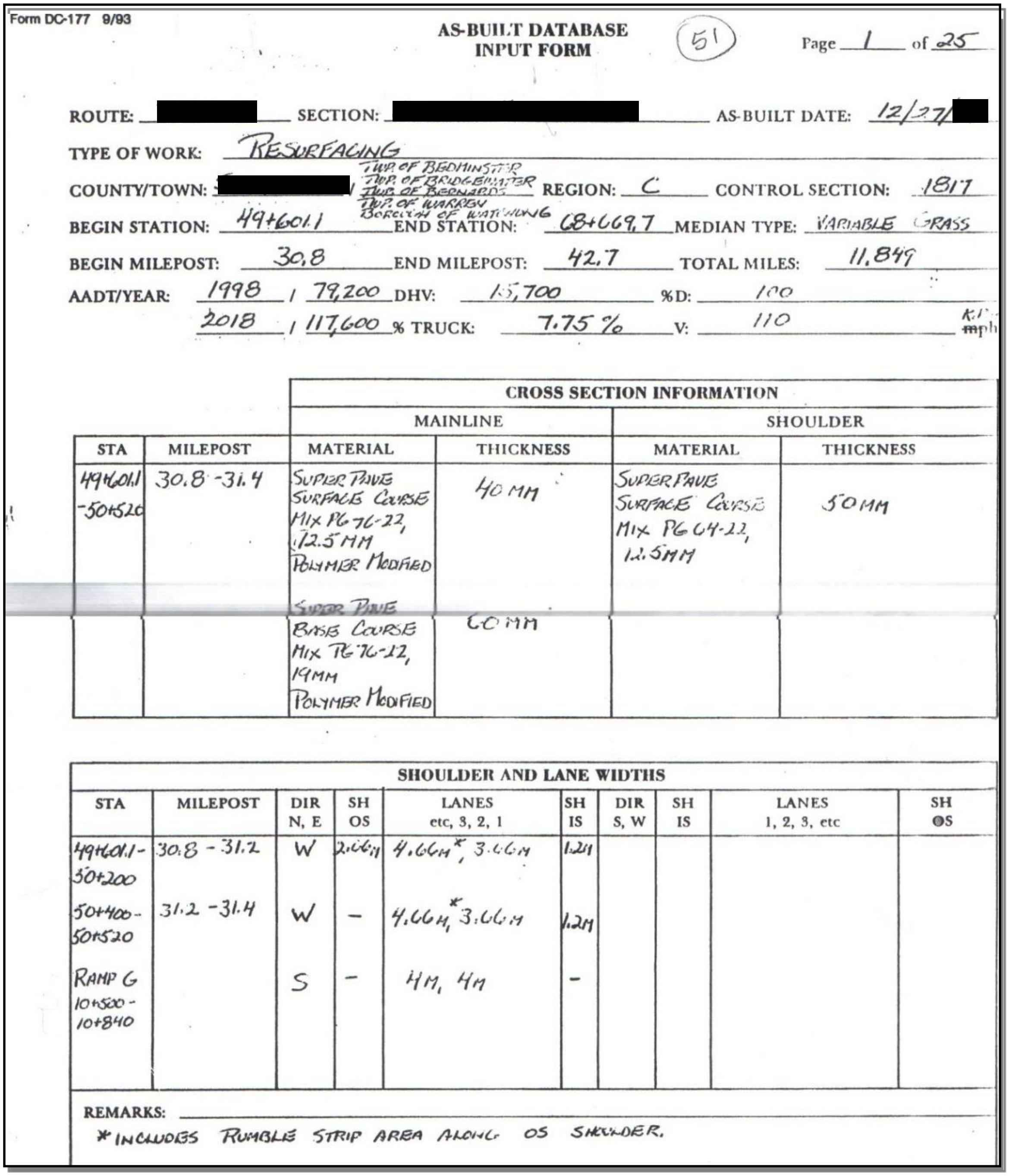
Chapter 3
Analysis of As-Built Tracking Needs

3.1 Introduction

This chapter introduces the challenges associated with manual as-built tracking and the level of detail required for documenting as-built data on the schedule. With a focus on highway projects, the requirements for activity tracking are analyzed, and information categories, including possible site events, are identified. Also described is the subsequent use of these tracking needs for the development of site information tracking forms and data flow diagrams for the collection of site data using email and/or voice, through interactive voice response (IVR).

3.2 Challenges with Manual As-Built Tracking

The collection of site information is not an objective in itself but is a crucial step in the evaluation of the progress of activities, the recording of as-built information, assistance with project performance evaluation, the performance of delay analysis, the preparation of invoices, and effective decisions about optimal corrective action. Inefficient progress tracking and lack of as-built information handicaps the ability of managers to monitor the schedule, costs, and other performance indicators (Howell and Koskela 2000). To analyze the challenges associated with the typical manual process for as-built documentation, sample data related to as-built drawings and as-built documentation forms for highway rehabilitation projects were collected from a large consulting company (Stantec). Examples of the data are shown in Figure 3.1 and Figure 3.2. The disadvantages of the manual process are: data is recorded on a lengthy text-based form that has no visual link to the location of the work done on the drawings; progress information often does not refer to the relevant activities; and site events of different parties are not recorded on the schedule. As an examination of a sample of existing as-built information input form shown in Figure 3.1 indicates, the difficulty of translating the information from the form into the schedule.



Form DC-177 9/93

AS-BUILT DATABASE INPUT FORM (51) Page 1 of 25

ROUTE: [redacted] SECTION: [redacted] AS-BUILT DATE: 12/27/[redacted]

TYPE OF WORK: RESURFACING

COUNTY/TOWN: [redacted] / TWP. OF BEDMINSTER, TWP. OF BRIDGEWATER, ~~TWP. OF BERNARDS~~, TWP. OF WARREN, BOROUGH OF WATCHUNG REGION: C CONTROL SECTION: 1817

BEGIN STATION: 49+601.1 END STATION: 68+669.7 MEDIAN TYPE: VARIABLE GRASS

BEGIN MILEPOST: 30.8 END MILEPOST: 42.7 TOTAL MILES: 11.849

AADT/YEAR: 1998 / 79,200 DHV: 15,700 %D: 100

2018 / 117,600 % TRUCK: 7.75 % V: 110 K.P. ~~mph~~

		CROSS SECTION INFORMATION			
		MAINLINE		SHOULDER	
STA	MILEPOST	MATERIAL	THICKNESS	MATERIAL	THICKNESS
49+601.1 -50+520	30.8 -31.4	SUPER PAVE SURFACE COURSE MIX PG-76-22, 12.5MM POLYMER MODIFIED	40 MM	SUPER PAVE SURFACE COURSE MIX PG 64-22, 12.5MM	50 MM
		SUPER PAVE BASE COURSE MIX PG 76-22, 19MM POLYMER MODIFIED	60 MM		

SHOULDER AND LANE WIDTHS									
STA	MILEPOST	DIR N, E	SH OS	LANES etc, 3, 2, 1	SH IS	DIR S, W	SH IS	LANES 1, 2, 3, etc	SH OS
49+601.1-50+200	30.8 - 31.2	W	2.66M	4.66M*, 3.66M	1.2M				
50+400-50+520	31.2 - 31.4	W	–	4.66M*, 3.66M	1.2M				
RAMP G 10+500 - 10+840		S	–	4M, 4M	–				

REMARKS:
*INCLUDES RUMBLE STRIP AREA ALONG OS SHOULDER.

Figure 3.1: Sample Manual As-Built Input Form for a Highway Renewal Project

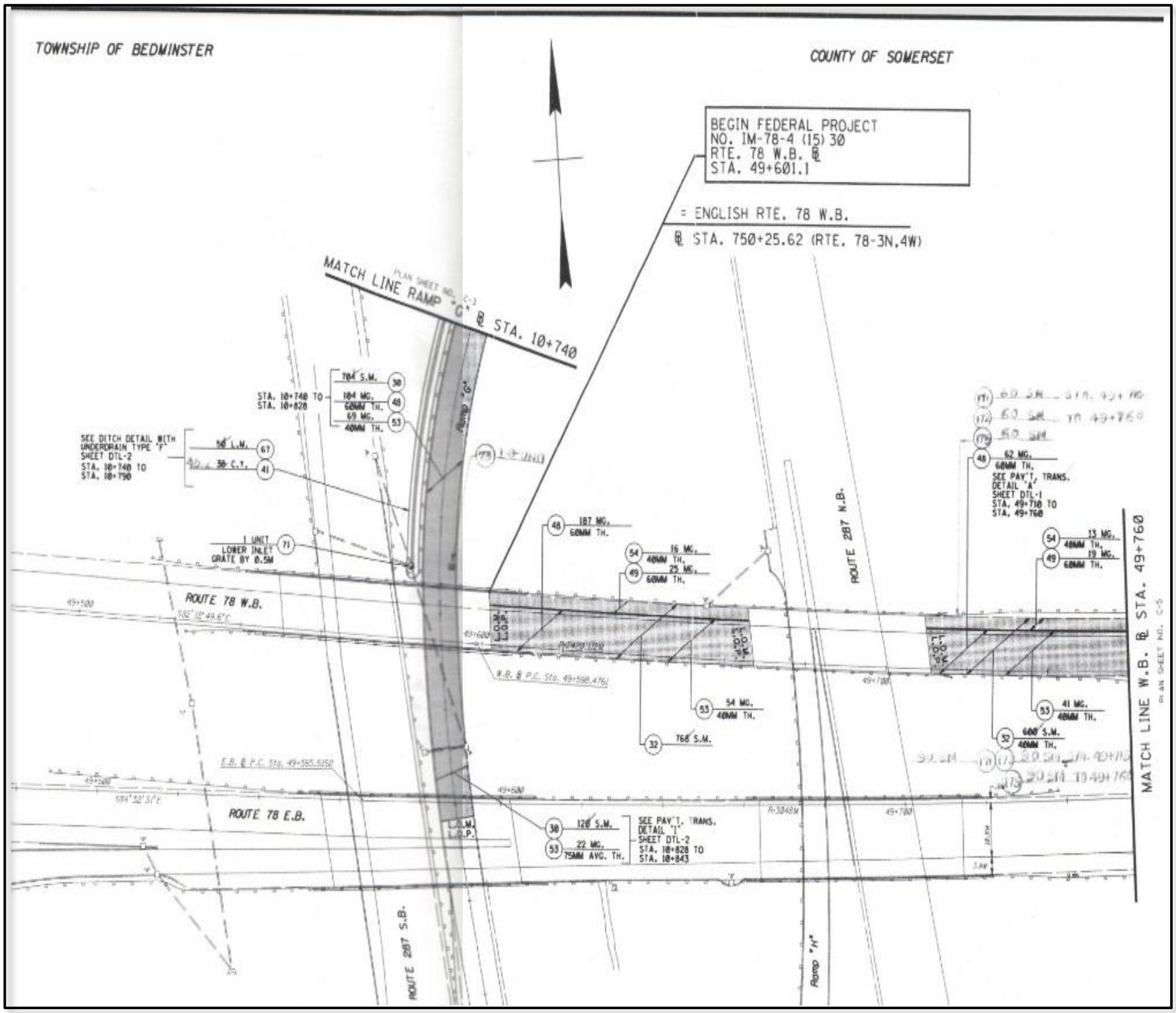


Figure 3.2: Sample Drawing with Manual As-Built Highlight

Another example of a general daily progress report is shown in Figure 3.3. This report can be an important source of data essential for updating the schedule and supporting project managers' decisions. Despite its importance, this typical paper-based form requires substantial effort for supervisors to complete and thus represents a heavy daily burden. A single generic form may also be unsuitable for the variety of activities associated with construction projects, and the form has no direct link to the drawing or to the schedule, and is very difficult to extract useful information (e.g., work interruptions and responsible parties) for individual activities. As evidence of these limitations, the results of construction surveys by Scott and Assadi (1999) indicated that 63 % of site supervisors fail to accurately record progress events when they occur. The survey also revealed that 62 % of site supervisors do not keep a complete as-built record of actual site events, thus making it difficult to analyze construction progress and determine appropriate corrective action.

DAILY PROGRESS REPORT NO: [redacted]

CONTRACT #: [redacted] **Reconstruction of** [redacted]

CONTRACTOR:	[redacted]		Thursday Feb 18, 2010
[redacted] **SITE INSPECTOR:**	[redacted]	**WEATHER:**	Overcast A.M. (- 2° C), Overcast P.M (1C)
WORKING DAY:	N/A	**WORKING HRS:**	7am –5pm

ISSUES (INCL. SAFETY):

▪

DESCRIPTION OF TODAY'S ACTIVITIES & PROGRESS OF WORK:

ITEM No.		
E.012		[redacted] placing outside forms for Pier 4 lift 2. Placing inside forms for Pier 3 lift 4. [redacted] assisting with placing outside forms for Pier 4 lift 2. Heating inside forms for Pier 4 lift2.
E.022		[redacted] installing steel rebar for pier wall, north and south side for Pier 3, lift 4. D.C.C crane assist Harris with placing rebar for Pier 3 lift 4.
K. 012.02		[redacted] placing rebar for Northside and Eastside thrust blocks for WC2 and placing forms for Northside, Eastside, and Westside thrust blocks for WC2.
E001		[redacted] inspects placement of Granular 'A' base for Eastside Abutment. [redacted] assists by excavating for placement of Granular 'A' for East Abutment base. Cusentino assist [redacted] by grading the Granular 'A' for East Abutment base with [redacted] Dozer.
K.005.01		[redacted] have commenced the boring operation again now that the boring machine is fixed and that the grounding for the operation has been upgraded. They[redacted]ed placement of platform at top entry shaft for the 1200 mm watermain for entry into elevator. [redacted] report that the worker elevator is operational. (One top man and four in the hole).
E.010		**Deep** drill and pour concrete for caisson 6 & 7 for W/S Abutment.
E.010		[redacted] test concrete for caisson 6 & 7 for W/S Abutment

LABOUR	NUM	HRS EACH	CODE	LABOUR	NUM	HRS EACH	CODE	LABOUR	NUM	HRS EACH	CODE
[redacted]				[redacted]				[redacted]			
Foreman	1	9.0		Foreman	1	9.0	E001	Foreman	1	9.5	K.005.01
Labourer	10	9.0	E.012	Drivers				Operator	1	9.5	
				Operator				Labourers	5	9.5	
Operator	1	8.0	E.022								
Foremen	1	9.0	E001								
Labourer	2	9.0	E001								
Driver	2	9.0	E001								
[redacted]								[redacted]			
Engineering Technician	1	3.0	E.010	[redacted]				Foremen	1	7.5	K.012.02
				Foremen	1	8.5	E.010	Foremen	1	9.5	
[redacted]				Operator	1	8.5		Operator	1	9.5	
Operator	1	5.5	E.012	Labour	1	8.5		Labourer	3	9.5	
								Foremen	1	2.0	E001
								Operator	1	2.0	
				[redacted]							
				Foremen	1	8.0					
				Ironworker	6	8.0	E.022				

Figure 3.3: Sample Daily Progress Report

One objective of this research was thus to expedite progress tracking and delay analysis through the facilitation of the recording of as-built details, including site events so that they can be immediately represented on the daily segments for each activity shown on the schedule.

3.3 Approaches for Mid-Activity Representations

The project manager’s ability to decide on appropriate corrective action or to perform forensic schedule analysis requires sufficient detail about the evolution of progress events of all parties, including work stops, acceleration, rework, etc. Traditionally, existing commercial scheduling tools represent project activities as continuous blocks of time and include neither clear representation of mid-activity events on the schedule nor their analysis by the schedule engine. Numerous researchers have therefore discussed a variety of ways of “tricking” the software in order to represent mid-activity events (e.g., owner interruption). Stumpf (2000), for example, manipulated the software by breaking a single activity into several smaller sub-activities and then adding additional relationships, as shown in Figure 3.4a and 3.4b for a case involving three activities with some delays. Such manipulation is necessary in order to force the software to recognize these events and thus facilitate schedule analysis. However, it substantially increases the number of activities, makes the schedule difficult to read, requires considerable effort, and does not represent a systematic simple-to-use approach to documenting and managing the schedule during construction.

To avoid such cumbersome manipulation and to incorporate mid-activity events directly into the schedule and its critical path computation, Hegazy and Menesi (2010; 2012) developed a Critical Path Segments (CPS) technique. Figure 3.4 shows a comparison of the cumbersome manipulated schedule based on Stumpf’s approach (Figure 3.4b) and the new, legible CPS representation (Figure 3.4c). With the CPS technique, progress is clearly represented so that schedule analysis can be carried out accurately, with less disagreement among parties. The as-built data is shown as a chain of time segments (default is one day each), with mid-activity events being recorded on the individual segments. Figure 3.5 shows the difference between the typical representation of activity progress, which only elongates the activity bar when mid-activity events occur, and the CPS representation, which shows the entire evolution of the daily progress that resulted in the 50 % complete (sum of all of the daily progress amounts, subtracting the rework amount).

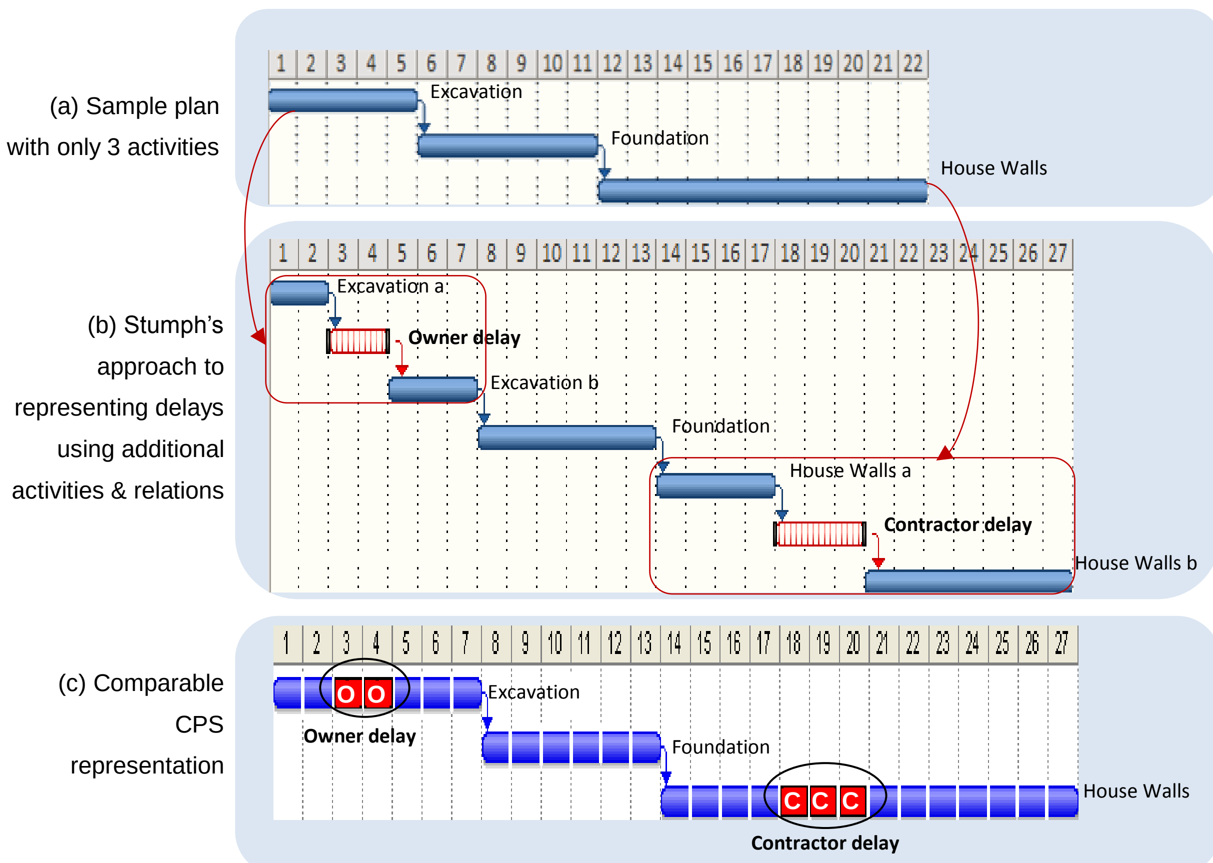


Figure 3.4: Advantage of the CPS Technique for Documenting As-Built Events

The CPS generic representation of the activities clearly shows the evolution of all as-built events and their timing. With the CPS method, the schedule computation also includes consideration of the daily events with respect to the critical path analysis, which is a powerful feature that avoids errors in the calculation of the critical path. Due to its rich visualization and its usefulness for project control, the CPS representation has been used in this research.

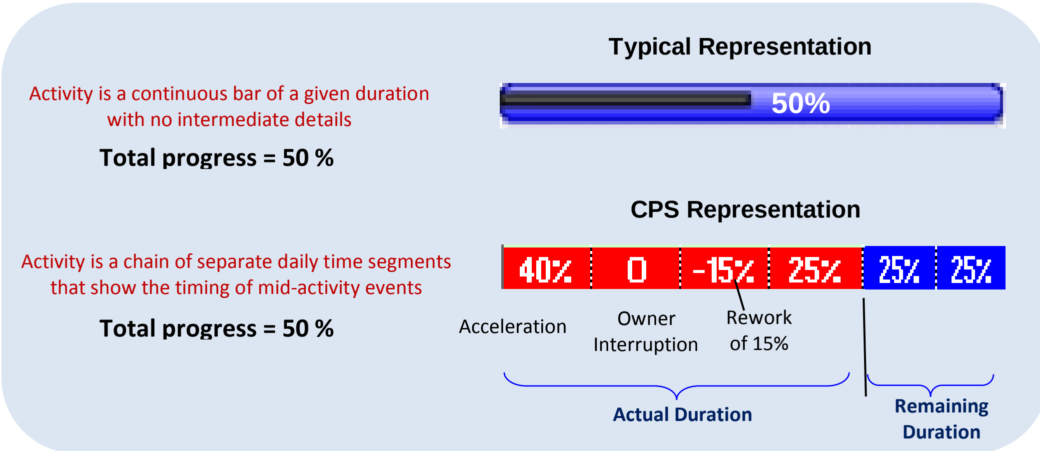
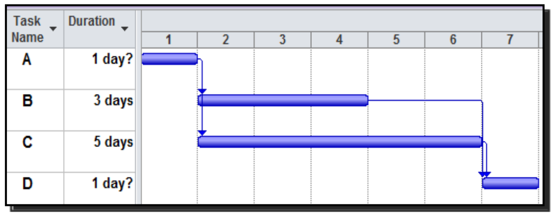


Figure 3.5: Illustration of the High Level of Detail in CPS Representation

3.4 Level of Detail in As-Built Documentation

To introduce practical support for project control, it is important to examine the level of detail in as-built documentation on the schedule. Basically, an additional level of detail is necessary only if such detail has a direct impact on project control decisions. An example of different levels of as-built detail is shown in Figure 3.6. The figure indicates the as-planned schedule for a simple four-activity instance with respect to four different cases of as-built details. In this example, activities B and C both follow activity A and are then followed by activity D. The as-planned duration is seven days (the top path has two days of total float), while the as-built duration is nine days (the top path became critical), with a project delay of two days. A brief explanation of the four cases and an analysis of their as-built schedules follow:

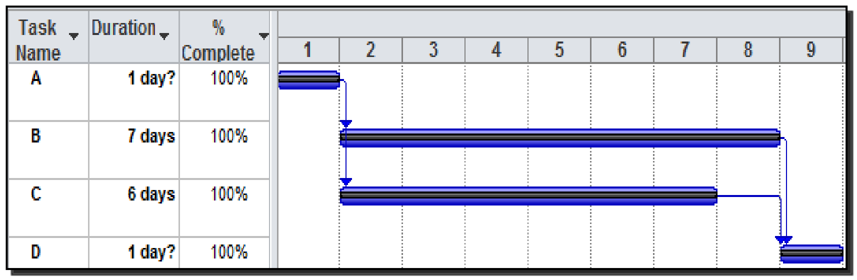
As-planned schedule



As-built schedules with different levels of progress details

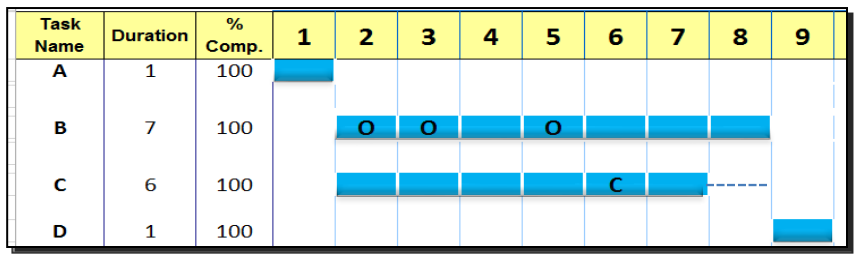
Case1: Few progress details:
Start & finish of activities & % complete.

Analysis:
2-day contractor delay due to lack of information



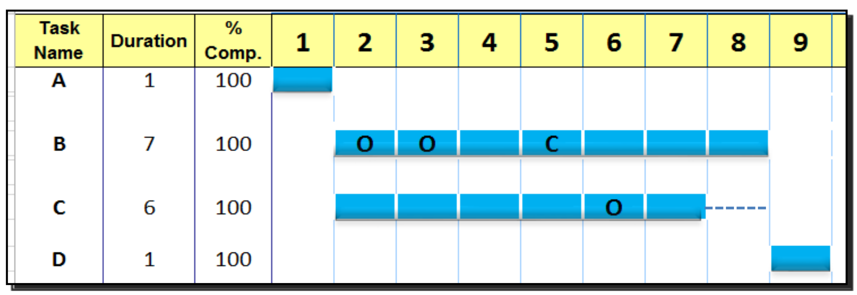
Case 2: Additional progress details: Rough timing of work interruptions by parties

Analysis:
1-day owner delay +
1-day contractor delay



Case 3: Additional progress details: Accurate timing of work interruptions by parties, no progress amount

Analysis:
2-day contractor delay



Case 4: Additional progress details: accurate daily progress amount, rework, slowdown, acceleration, etc.

Analysis:
1-day contractor & owner delay +
1-day contractor delay

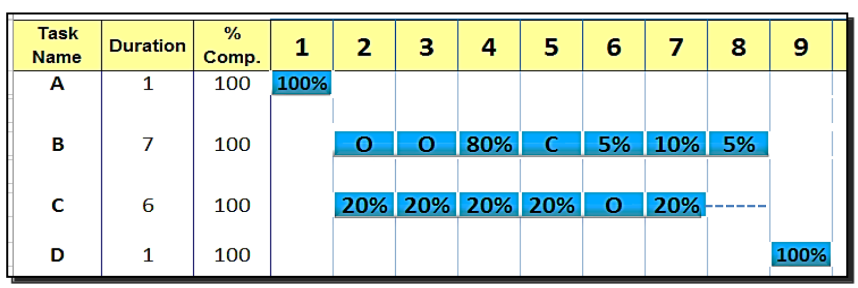


Figure 3.6: Different Levels of Detail in As-Built Documentation Shown on the Schedule

Case 1: This case shows a typical representation of progress as provided by existing commercial software. This as-built schedule can be determined using the least amount of information: the actual start and actual finish times for each activity (percentage complete is 100 %). Such a level of information, however, is insufficient for justifying whether the contractor is entitled to two days of extension or whether weather conditions or other factors have created the project delay. The lack of detail results in the responsibility for the two-day project delay therefore being allocated solely to the contractor.

Case 2: This case shows an extra level of as-built detail, based on which some owner and contractor interruptions are assumed to be indicated roughly on the schedule (O indicates owner, and C indicates contractor). In this situation, the two O interruptions for activity B consume two float days. Accordingly, two critical paths exist as per the events until the end of day 3. Afterwards, the owner delays the project one day due to the interruption in day 5. Afterwards, the contractor delays the project one more day. The resulting responsibility allocated for the project delays is one day to owner and one day to contractor.

Case 3: This case shows the same level of detail as in case 2 but with slight changes to increase the accuracy of the event timings, but without accurate amounts of daily progress. Case 3 therefore reveals the value of accuracy in the recording of site events. In this case as well, until the end of day 3, two critical paths exist because of the events. The C interruption on day 5 then causes one day of project delay, thus creating a one-day float on the bottom path, which is consumed by the O interruption on day 6. The result is that the contractor delays the project one additional day. The responsibility for the project delays is therefore assigned as two days for contractor, which differs from the result in case 2, thus showing that accurate event timing alters the analysis and consequent decisions.

Case 4: This case incorporates the recording of the highest level of as-built details with respect to the accurate timing of events as well as the accurate amount of daily progress. This approach can therefore indicate the acceleration to activity B on day 4 and the slow progress on days 6 to 8. Based on the events, two critical paths also exist until the end of day 3 in this case. The subsequent 80 % progress, which represents accelerated performance, creates a one-day float on the top path because activity B is expected to finish earlier. This float, however, is consumed by the contractor's interruption on day 5, thus creating two critical paths again. The analysis then proceeds from day 6 as in case 2, resulting in the responsibility for the project delays being assigned as one day shared between contractor and owner and one day to contractor.

It should be noted that the extra information included in cases 2, 3, and 4 may be available in a variety of manual forms or documents, without being shown on the schedule. The schedule in this case is just one of many scattered project documents that are difficult to combine. This circumstance presents typical challenges with respect to documenting the as-built evolution and to making decisions about corrective action. It should also be noted that the above schedule analysis of the cases shown in Figure 3.6 is taken from the daily windows analysis of Hegazy and Menesi (2008). Based on the results, the critical path(s) of the project fluctuate differently in each case so that the results (responsibility for the two days of project delay) are thus sensitive to the level of detail in each case, which clearly indicates that a lower level of detail results in incorrect forensic analysis and, consequently, in ineffective corrective action.

Therefore, the collection of complete construction site information on a daily basis is necessary if the project manager and decision makers are to make timely decisions. CPS representation, for example, clearly shows the evolution of all as-built events and allows a more granular level of detail at the segment level, which is general enough to facilitate corrective action and schedule analysis. The additional details included in this representation, however, require substantial effort in order to collect data from the site using manual methods. The goal of this research was therefore to determine methods of automating the data collection process using affordable IT technologies such as email and IVR systems.

3.5 Activity-Specific Site Events and Tracking Needs

The first step toward the development of an automated framework for construction as-built tracking was to develop a better understanding of site information as well as the tracking needs and possible site events related to a variety of activities. To achieve that objective, the extensive literature review presented in Chapter 2 was carried out, and in-depth interviews were conducted with construction experts in order to obtain information about the tracking needs for each activity and the best approach to tracking site information (email or phone). This research focuses on highway construction projects because they involve only a limited number of activities that can be more easily managed for research purposes. Due to the broad nature of as-built tracking for this type of project, automating the process will provide substantial benefit.

3.5.1 Possible Site Events

The identification of possible daily site events for each activity will significantly facilitate the collection of complete and accurate site information, and the events can also be integrated into an automated system in order to minimize the time and cost associated with the collection of site data. Following a comprehensive analysis of the literature related to the specific common delays, site requirements, construction precautions, and daily site events associated with highway activities (e.g., Ahmed et al. 2002; Ellis and Thomas 2002; Assaf and Al-Hejji 2006; Ministry of Transportation and Infrastructure 2012), the first step was to analyze the collected samples of daily as-built forms and as-built drawings for highway projects. Based on this analysis, activity-specific site events and tracking needs were developed. Table 3.1 summarizes the information from the literature, including activity-specific site events related to the owner, the contractor, and neither (i.e., third party); measurement units; and any activity-specific considerations. This information was used for the development of site information tracking forms for facilitating fast and complete as-built documentation.

Table 3.1: Site Events Related to Highway Construction Activities

Activity Name		Possible Interruptions	Progress Measure	Freq.	Special Considerations
Mobilization	O:*	1- Delay in site handover or access	Lump Sum	Start/ Finish	- Precautions to protect existing facilities - Safety for users (barriers, signs, lights) - Notification of the local police, fire, ambulance, municipality, school board, and public transit
	C:*	1- Delay in material/ equipment delivery 2- Delay in obtaining permits			
	N:*	1- Bad weather			
Clearing & Grubbing	O:	1- Late permits for right-of-way 2- Work scope changes 3- Differing site conditions	M2	Daily	- Possibility of contractor being required to use close-cut, no-grub practices - "Clearing" grubbing to be fully completed at least 300 m in advance of grading operations
	C:	1- Distant disposal area 2- Equipment shortage or breakdowns			
	N:	1- Bad weather			
Survey & Staking	O:	1- Approval delay 2- Modifications to drawings/specifications	M2	Start/ Finish	- Project manager to be notified about any conflict, such as existing water line located at same location as the proposed sewer line
	C:	1- Error in benchmarking 2- Unqualified workforce 3- Difficult site conditions			
	N:	1- Bad weather			
Excavation	O:	1- Delay in inspection or testing 2- Differing site conditions	M3	Daily	- Maintenance of the stability of adjacent ground - All waste sites to be vegetated immediately after finishing disposal, or suitable temporary erosion control to be developed - Excavation to be measured after completion of the clearing and grubbing
	C:	1- Damage to existing utilities, poles, or lines 2- Unavailability or delay of site utilities 3- Difficult site conditions			
	N:	1- Bad weather			

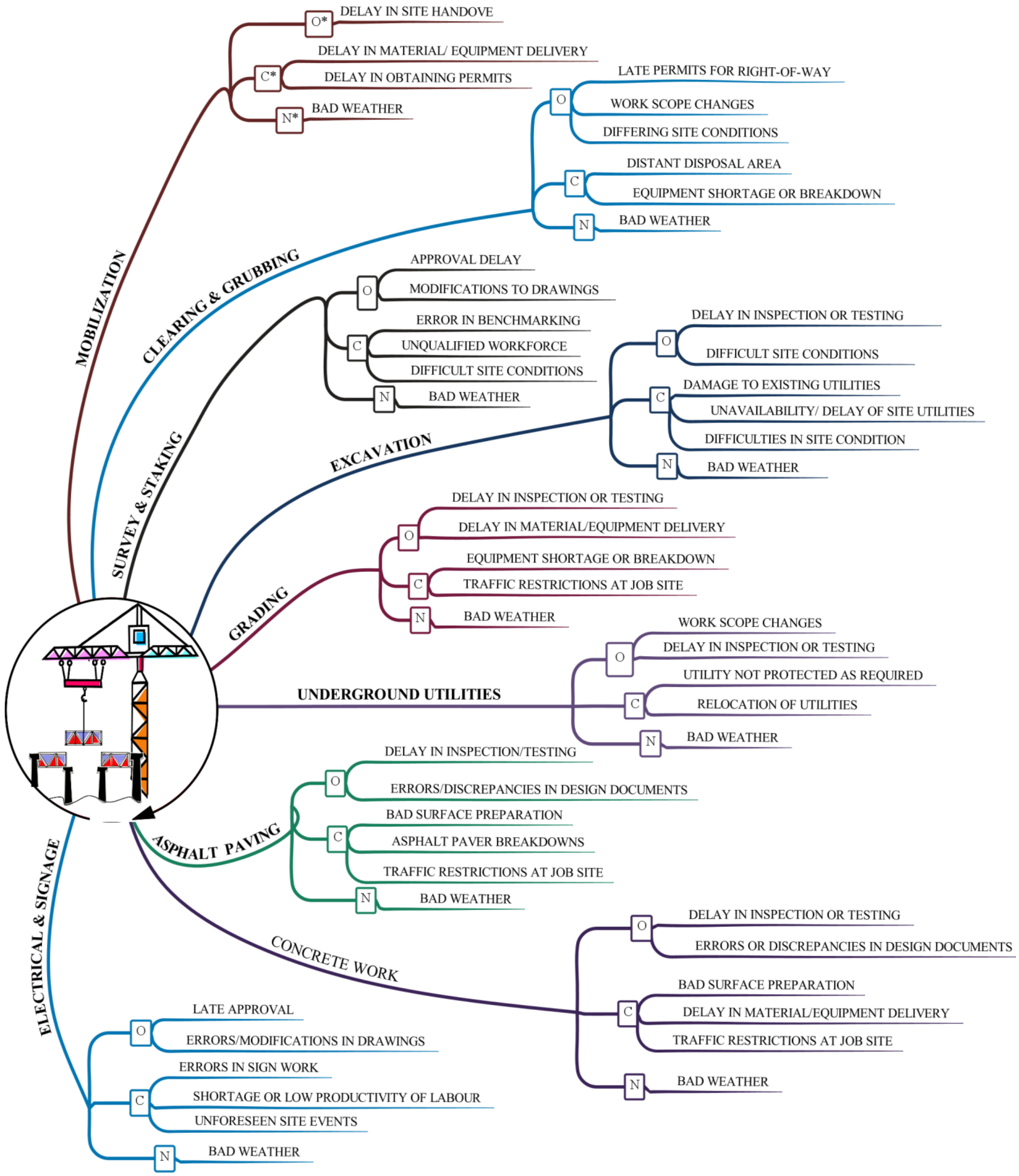
*O: Owner; C: Contractor ; N: Neither (third-party)

Table 3.1 cont.: Site Events Related to Highway Construction Activities

Activity Name		Possible Interruptions	Progress Measure	Freq.	Special Considerations
Grading (Granular Surfacing Base and Sub-base)	O:	1- Delay in inspection or testing	M2	Daily	- All aggregates to meet QC specifications - No construction during snow, heavy rain, freezing or other unsuitable conditions - Aggregate not to be placed on frozen, wet, or rutted subgrade, sub-base, base, or surface
	C:	1- Delay in material/equipment delivery 2- Equipment shortage or breakdowns 3- Traffic restrictions at job site			
	N:	1- Bad weather			
Underground Utilities	O:	1- Delay in inspection or testing 2- Work scope changes	Lump Sum	Daily	- Precautions to protect existing utility services - Ensuring of correct locations of the utilities - Contractor responsible for diverting, relocating, or re-routing utilities or other facilities during construction, if required
	C:	1- Utility not protected as required 2- Relocation of utilities 3- Unforeseen site events			
	N:	1- Bad weather			
Asphalt Paving	O:	1- Delay in inspection/testing 2- Errors or discrepancies in design documents	M2/ Ton	Daily	- Damage to the waterproofing membrane to be avoided - Excessive heat of paver screed burner to be avoided - Paver to move continuously at constant speed - Hauling trucks to maintain a steady mix supply to the paver
	C:	1- Bad surface preparation 2- Asphalt paver breakdowns 3- Traffic restrictions at job site			
	N:	1- Bad weather			
Concrete Work	O:	1- Delay in inspection or testing 2- Errors or discrepancies in design documents	M3	Daily	- Secure reinforcing steel/dowels - Reinforcing steel to be clean - QC in batching, mixing, transporting, placing, consolidating, finishing, curing, and testing - All concrete and other waste to be prevented from entering any watercourse
	C:	1- Bad surface preparation 2- Delay in material/equipment delivery 3- Traffic restrictions at job site			
	N:	1- Bad weather			
Electrical & Signage	O:	1- Late approval 2- Errors in/modifications to drawings/specifications	Each	Daily	- Contractor to locate and protect existing utilities - Contractor to check for conflicts with overhead lines prior to excavating for concrete bases
	C:	1- Errors in sign work 2 Labour shortage/low productivity 3- Unforeseen site events			
	N:	1- Bad weather			

*O: Owner; C: Contractor; N: Neither (third-party)

Figure 3.7 provides a visual summary of construction site events for highway projects.



*O: Owner; C: Contractor; N: Neither (Third-party)

Figure 3.7: Site Events Related to Highway Activities

For each activity, the most common site events related to owner, contractor, and neither ("O", "C", and "N") are indicated; the supervisor can then simply identify the events experienced during the actual construction. In some cases, the activity may experience a combination of delays during the same day (e.g., "O+C", "O+N", "C+N" or "O+C+N"). In this case the supervisor should select the different reasons for these delays and their responsible party. Accordingly the IVR flow diagram shown in Figure 3.7 should be designed to accommodate these combinations and this is open for future research.

3.5.2 Activity-Specific Tracking Needs

Based on the information collected, the literature survey related to site information (Figure 2.1 – Figure 2.3), and the activity-specific site events listed in Table 3.1, six categories of information (Figure 3.8) were identified as representative of the tracking needs for activities:

1. General
2. Progress Measurement
3. Site Events
4. Quality Control Issues
5. Requests for Information (RFI)
6. Other

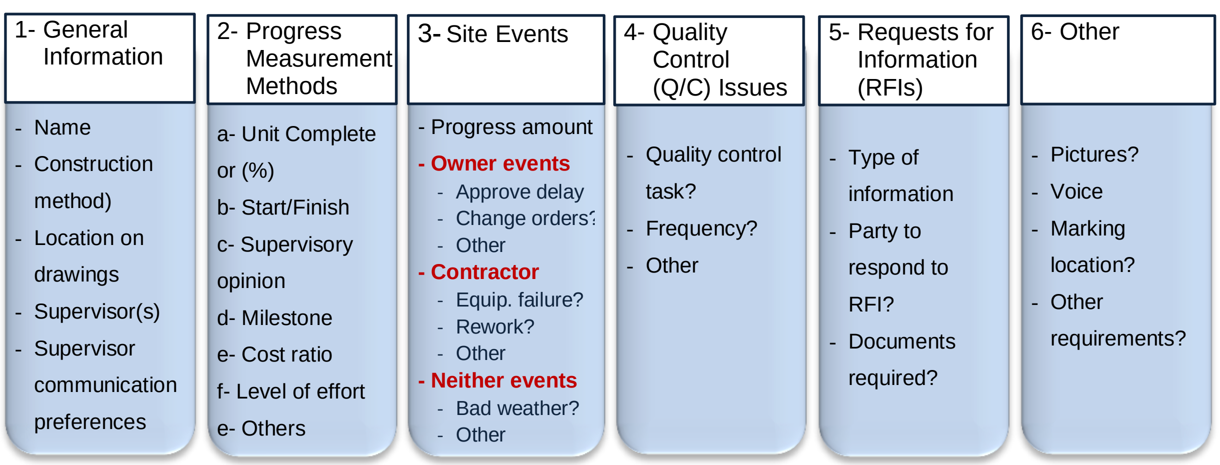
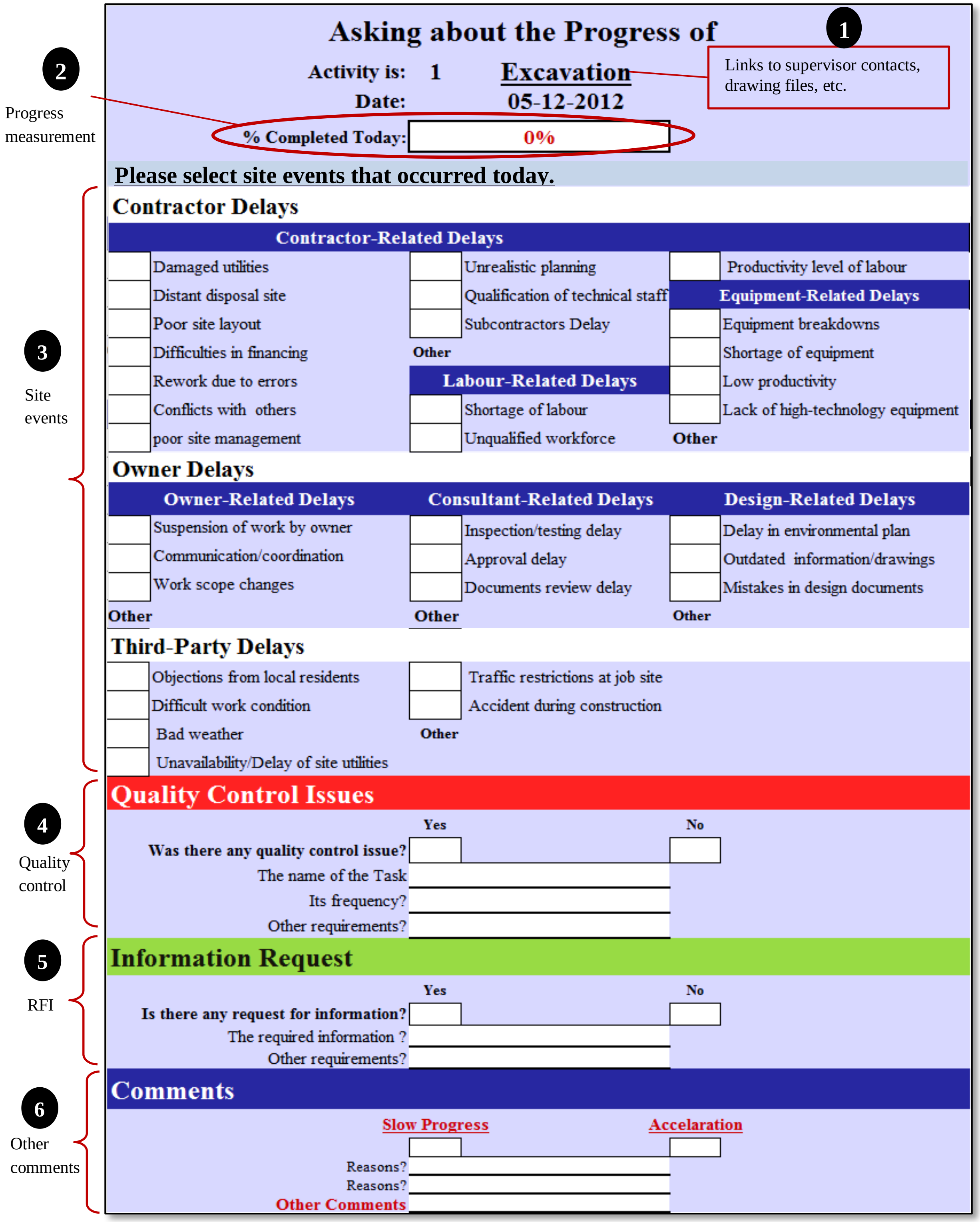


Figure 3.8: Activity Tracking Needs

The information listed in the first two categories differs according to activity and was required in order to set up the default data in the developed data-collection system. Categories 3 to 6 in Figure 3.8 represent information that will be collected during the actual progress of each activity. Based on Figure 3.8, specific forms were developed for highway project activities. Each activity form contains its specific information (e.g., Figure 3.9), as follows:

1. **General information**: This information includes supervisor contacts, activity drawing files, etc.
2. **Progress measurement method:** As shown in Figure 3.9, for excavation, the percentage complete is measured based on the completion of the units completed (method (a) in Figure 3.8) that apply to excavation.
3. **Site events:** These include possible activity-specific events that can occur during construction. They differ from one activity to another, and some activities may share the same events (e.g., sub-base and base courses). These events can relate to one or more of the following parties: contractor, owner, or neither. Excavation, for example, as shown in Figure 3.9, may include delays assigned to the contractor because of damage to underground utilities, a distant disposal site, or equipment failure. Delay events attributable to the owner may include approval delays, mistakes in drawings or specifications, and others. Third-party events that are the responsibility of neither the contractor nor the owner may include bad weather, difficult work conditions, etc.
4. **Quality control (Q/C) issues:** This category applies to any activity. The supervisor can identify the quality control issues that occurred on a specific day and the action and resources required for solving these problems.
5. **Requests for information (RFIs)**: These events also apply to any activity. In this category, for any request, the supervisor can attach a voice recording or write a text note about the information.


Asking about the Progress of

Activity is: 1 Excavation

Date: 05-12-2012

% Completed Today: 0%

Links to supervisor contacts, drawing files, etc.

1

2 Progress measurement

Please select site events that occurred today.

3 Site events

Contractor Delays

Contractor-Related Delays		
Damaged utilities	Unrealistic planning	Productivity level of labour
Distant disposal site	Qualification of technical staff	**Equipment-Related Delays**
Poor site layout	Subcontractors Delay	Equipment breakdowns
Difficulties in financing	Other	Shortage of equipment
Rework due to errors	**Labour-Related Delays**	Low productivity
Conflicts with others	Shortage of labour	Lack of high-technology equipment
poor site management	Unqualified workforce	Other

Owner Delays

Owner-Related Delays	Consultant-Related Delays	Design-Related Delays
Suspension of work by owner	Inspection/testing delay	Delay in environmental plan
Communication/coordination	Approval delay	Outdated information/drawings
Work scope changes	Documents review delay	Mistakes in design documents
Other	Other	Other

Third-Party Delays

Objections from local residents	Traffic restrictions at job site
Difficult work condition	Accident during construction
Bad weather	Other
Unavailability/Delay of site utilities	

4 Quality control

Quality Control Issues

Yes No

Was there any quality control issue?

The name of the Task

Its frequency?

Other requirements?

5 RFI

Information Request

Yes No

Is there any request for information?

The required information ?

Other requirements?

6 Other comments

Comments

Slow Progress Accelaration

Reasons?

Reasons?

Other Comments

Figure 3.9: Sample of an Activity-Tracking Form for Excavation

6. **Other comments:** These include any comments, pictures, voice recordings, or text that the supervisor attaches to an email.

After a preliminary tracking form was developed for each activity, the forms were discussed with construction experts in order to obtain their feedback and to refine the final versions (as shown in Appendix A).

3.5.3 Flow Diagrams for Site Information Tracking

To enable IVR tracking, activity flow diagrams were developed, including a logical sequence of questions related to each activity so that as-built information can be tracked by telephone. The idea behind the development of such flow diagrams is to minimize the number of questions asked during an IVR session. The first step was to analyze the activity-specific site events related to the various parties (owner, contractor, and third party) discussed earlier (Figure 3.7), tracking needs categories, and different scenarios of possible site events (e.g., progress, delay, etc.) have been analyzed. Based on this information, activity-specific IVR flow diagrams were designed as a means of facilitating the simple collection of as-built data by phone. A sample IVR flow diagram is shown in Figure 3.10, which also indicates the dynamic questions related to four categories of information (shaded diamonds in Figure 3.10): progress amount; delay events attributable to different parties and the reasons; quality control/safety issues; and requests for information (RFIs). Other IVR flow diagrams suitable for highway projects are included in Appendix B.

Each activity or group of activities may follow the same dynamic IVR flow diagram, which automatically triggers the sequence and content of questions according to the current status of the activity, possible site events, and the user's previous answers (e.g., the call is directed to a specific branch that is determined based on the previous answer). Such dynamic features can collect complete site information and save time for the supervisors. The pre-designed IVR flow diagrams make collecting as-built information both simple and fast.

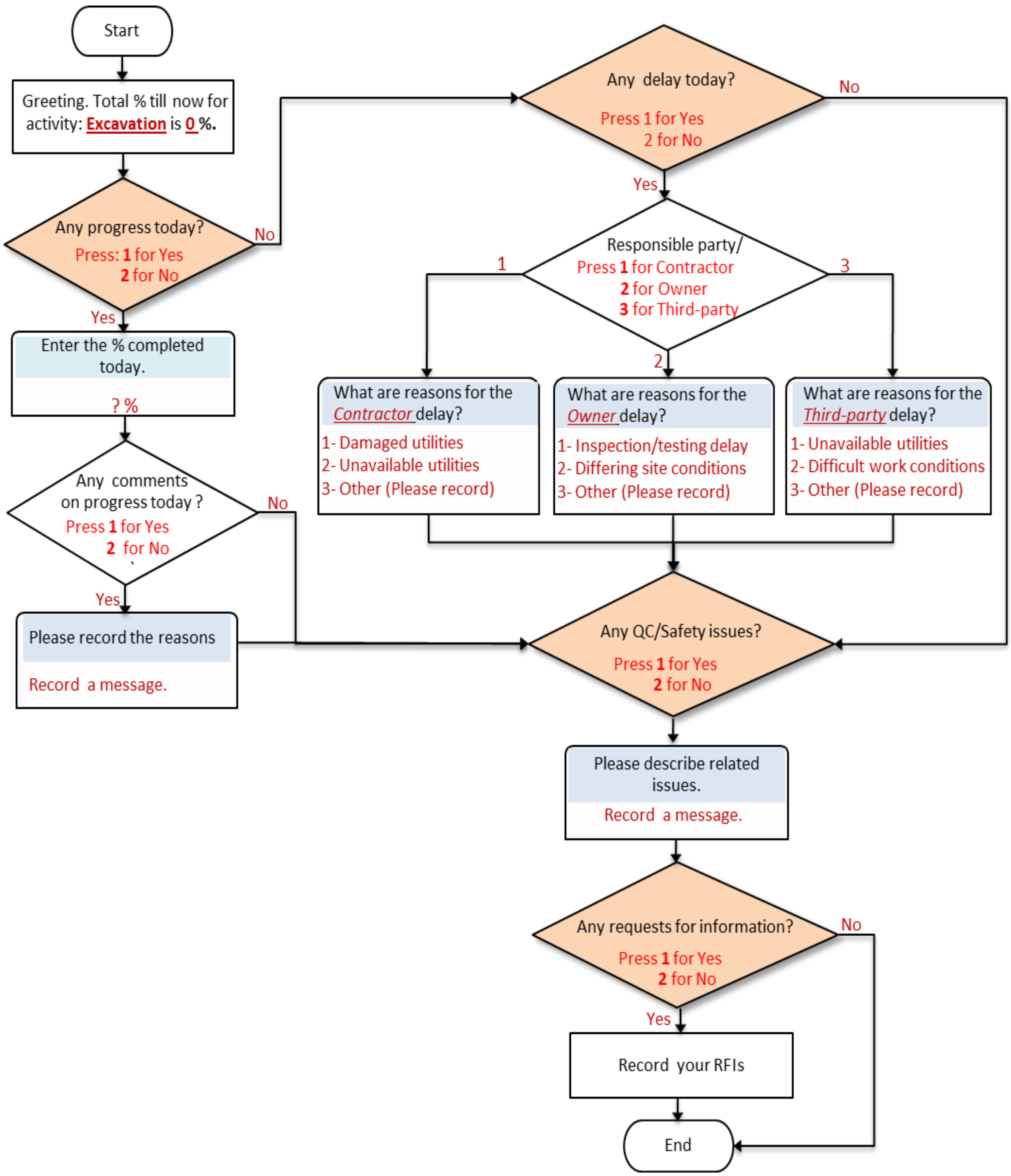


Figure 3.10: Example of an IVR Flow Diagram

As shown in Figure 3.10, if the respondent presses 1 as a “Yes” response to the first question (“Any progress today?”), the left-side branch is followed (e.g., the respondent is asked to enter the amount of progress completed on that day). If the respondent presses 2 to indicate that a delay (work stop) occurred, the system follows the set of questions shown in the right-side branch. Based on the sequence of buttons pressed and the messages recorded, the system documents the daily progress, the reasons for delays, and any other site events.

3.6 Conclusion

The ability of the project manager to decide on appropriate corrective action or to perform forensic schedule analysis requires sufficient detail about the evolution of progress events for all parties. This chapter thus first discussed the challenges related to the documentation of as-built details and then described the level of as-built detail that must be documented on the schedule in order to facilitate schedule analysis and determine optimal corrective action. First, with a focus on highway projects, sample daily as-built forms were analyzed and an analysis of the related literature was carried out. Based on this background, activity-specific site events related to the owner, contractor, and third party; measurement units; and activity considerations were developed. This information was then used in order to design activity-specific tracking needs that can facilitate the collection of site data using email or IVR. With the use of these pre-designed formulations of activity-tracking needs, collecting as-built information is simple and fast.

Chapter 4
Proposed Framework for As-Built Tracking

4.1 Introduction

This chapter introduces the design of the integrated framework for the automation of daily as-built information using email, interactive voice response (IVR), and visual marking tools as a means of providing a visual representation of the latest as-built information directly on annotated daily schedule segments. The development of a prototype that utilizes email as a project-wide tool for bidirectional communication between project participants and head office is then described. The email prototype has been applied to a simple case study in order to demonstrate the proposed concept and its benefits. Chapter 5 describes the enhancement of the prototype using IVR and visual data-recording features.

4.2 Design of the Framework

To facilitate the tracking of construction site information, a low-cost framework for automating the collection of site data was designed as a means of documenting the latest as-built details on daily activity segments. The framework utilizes the activity-specific tracking needs, possible site events, and activity flow diagrams discussed earlier for the automatic collection of as-built updates and the generation of detailed progress reports. The design of the framework incorporates the components shown in Figure 4.1.

The framework utilizes activity-specific tracking needs (discussed in Chapter 3) as input in order to provide visual as-built details on the schedule. At the core of the framework, as shown in Figure 4.1, are several integrated and customized tools, including an email application, an IVR cloud service, a visual marking tool, a scheduling engine, a controller engine, and a reporting and schedule-updating system (output). The main controller is responsible for automating the interactions among the various components and their functions: initiating progress requests, saving received information, reading received responses, responding to requests for information (RFIs), and generating progress reports.

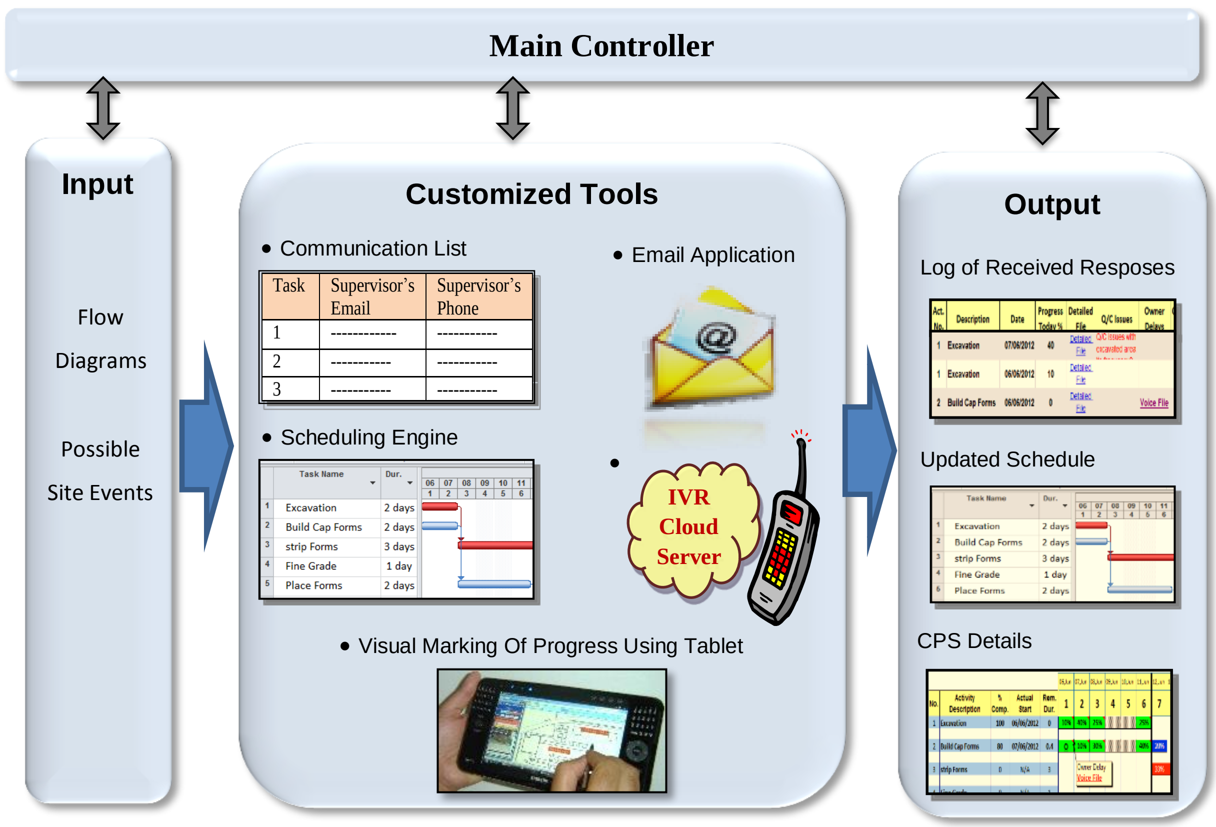


Figure 4.1: Components of the Proposed Voice-Visual Tracking Framework

Details of the key framework components are as follows:

1. **Activity-specific tracking needs:** Activity-specific tracking needs, as shown in Figures 3.9 and 3.10, include different categories of site information: progress updates; site events; quality control issues; RFIs; and other comments, photos, voice recordings, etc. The first step in the framework

design is the definition of the activity-specific forms for the collection of site data. These forms and prebuilt templates facilitate the quick, automated collection of activity site information.

2. **Project communication list**: A project communication list defines the communication parties, including the contact information for the supervisors who will respond to progress requests as well as for the parties responsible for answering any RFIs.

3. **Customized scheduling engine:** The framework can be applied as an add-on to existing scheduling software as a means of simplifying the as-built documentation process and of representing the information received in both traditional and detailed critical path segment (CPS) formats. The scheduling engine can therefore be programmed so that the activities become aware of their planned progress and automatically initiate communications to request updates about actual progress. The framework developed new schedule calculations in order to deal with high level of details collected by the developed system. The new schedule engine recognizes different site events and the responsible party (e.g., owner, contractor, neither, or owner + contractor), as shown in Figure 4.2.

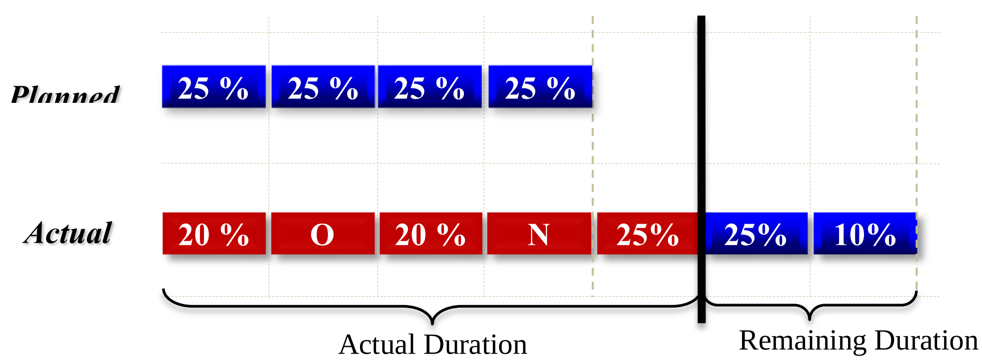


Figure 4.2: New As-Built Schedule Representation

It also considers activities' durations, relationships, and other constraints to develop a detailed as-built schedule report in CPS format that shows each activity as chain of segments. Each segment can show the percentage completed (slow progress, as-planned, or acceleration), work stop due to owner responsibility "O", contractor responsibility "C", third-party responsibility "N", or "O+C". Accordingly the remaining duration can be calculated accurately based on Equations 4.1-4.3, for example the four-day activity shown in Figure 4.2, the daily planned progress based on Equation 4.1 is calculated as 25%, actual progress to date has been calculated based on the percentage of work completed to date considering the owner interruption on day two and neither interruption on day 4 as 65%. The remaining 35% will be distributed as 25% on the first day based on the planned progress and 10% after that.

Daily planned progress (%) = 1/planned duration Equation **4.1**

Actual Progress to Date (%) = Σ all % complete & considering (O, C & N)s Equation **4.2**

Remaining Duration = Roundup [(1 - Actual Progress to Date)/Daily planned progress)] Equation **4.3**

4. **Customized email application tool:** A customized email application requests progress updates by sending emails with the activity-specific tracking form as a body message (e.g., Figure 3.9). Each project has a customized email folder in the customized email application where all related responses received are automatically saved.

5. **IVR cloud-based service**: IVR cloud servers communicate with multiple parties simultaneously and follow predefined call-flow diagrams that specify how the IVR session is to be a controlled based on user answer. This technique reduces the time required for the collection of site information and provides unlimited low-cost parallel calling suitable for tracking site information from a large number of site personnel simultaneously. From the many commercial systems available, ifbyphone (2012) was selected because of its high level of voice quality, unlimited parallel calls, customizability, and flexible send/receive features.

6. **Visual tools**: The framework uses a visual marking tool that enables supervisors to highlight the location of progress events on CAD drawings or images. To facilitate the incorporation of this feature, a drawing or image file is associated with each activity.

7. **Subjectivity-check mechanism**: Since the framework collects high level of details, the collected data may have level of subjectivity or uncertainty for different reasons: the supervisor can not calculate the correct quantity of work done; lack of clarity of responsibility of events, particularly when both owner and contractors contributed to the delay; or data-entry errors (e.g., % complete adds up to more than 100%). The system, as shown in Figure 4.3, analyzes the received information and brings the controversial issues to the project manager to resolve them before updating the project schedule.

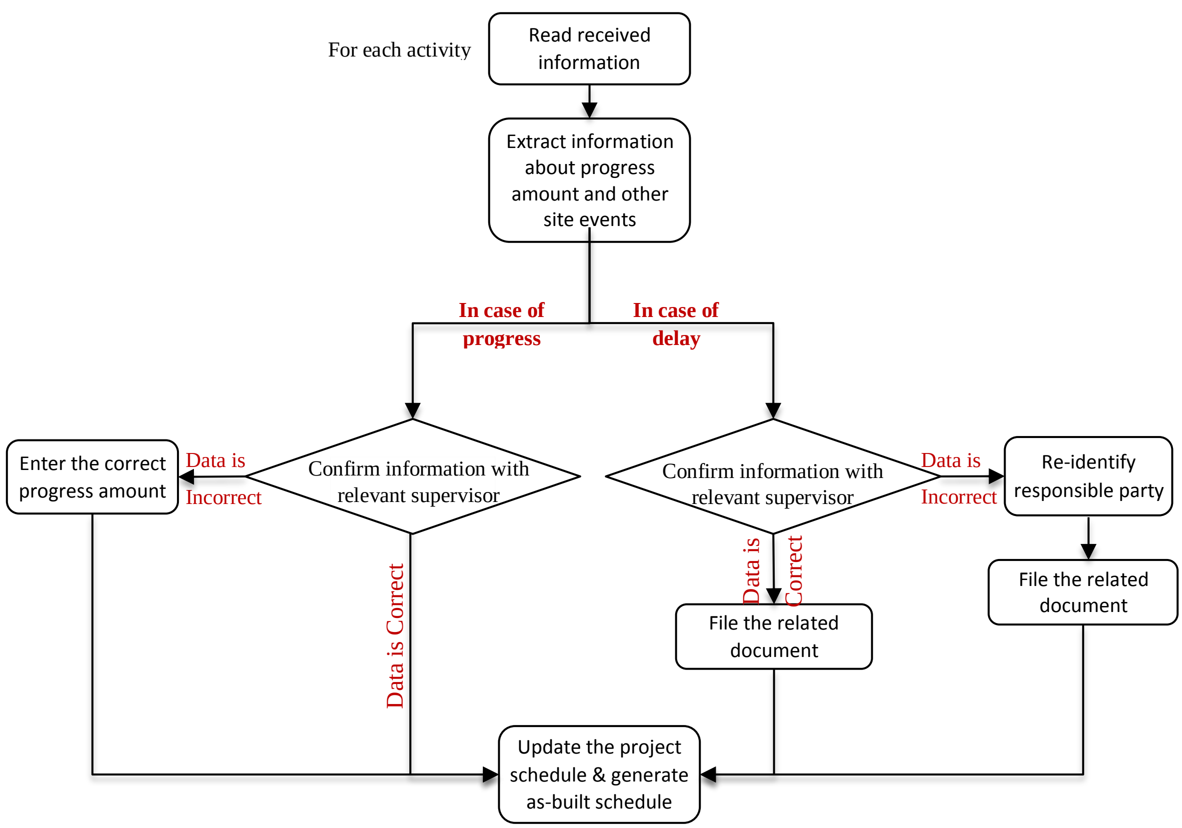


Figure 4.3: Mechanism to Check Subjectivity of Received Information

The updated information will be sent back immediately to relevant supervisors to check and confirm. In case of progress the system will ask the supervisor to confirm the amount or re-enter the correct amount. In case of delay, as shown in Figure 4.3, the system will ask the supervisor to confirm the responsible party (O, C, N, or O+C) or re-identify the responsible party in case of data are incorrect, then tell him to keep the supporting documents of this events. Once the confirmed information are received, the system immediately updates the project schedule and record the confirmed information on the relevant time segment on as-built schedule and replace the old information in project database.

8. **Reporting tool:** A customized reporting tool provides a log of all responses received, any updates to the project status, and a detailed progress report in CPS format.

The workflow of the proposed framework is shown in Figure 4.4. In the first step, the main controller identifies the activities eligible for progress tracking (activities not yet completed or activities whose predecessors have been completed). Once the activities are defined, step 2 involves the retrieval of the supervisors' contact information from the project communication list: name, email address, cell phone number, alternative phone number, etc. The individual's preferred contact method (email or IVR) is then used to communicate with the activity supervisor on that date (step 3). The system is designed to contact supervisors at the end of the day by sending the activity email form or by calling through the IVR server, according to the activity flow diagram. In the case of no progress (delay), for example, the supervisor specifies the party responsible for the delay, the reasons for the delay, and the supporting documents, if any. As part of the response, the supervisor may specify an RFI, in this case, when the RFI is received, the system automatically initiates a new call to the person responsible for responding. A notification message can also be issued to the relevant parties when a response is received.

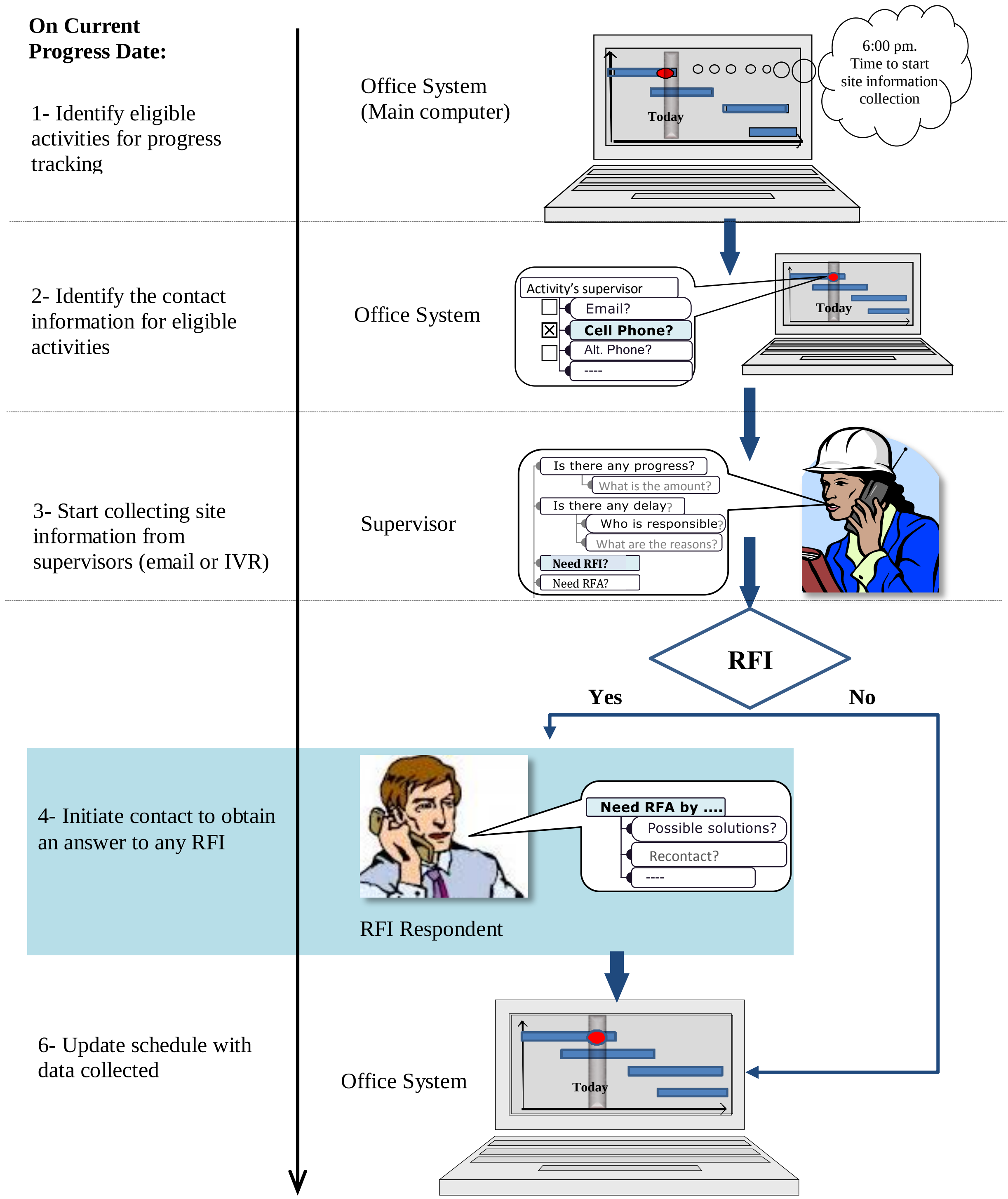


Figure 4.4: Design of the As-Built Documentation Workflow

The last step in the site information tracking (step 6) is the updating of the project schedule based on the as-built data received and saved into the project database. The proposed framework thus works as a multilevel interactive system that provides up-to-date information and helps managers determine timely solutions to problems.

4.3 Implementation: Email-Based System

After the as-built tracking framework was designed, it was implemented followed three stages: first, using email alone (Hegazy and Abdel-Monem, 2012); second, using IVR alone (Chapter 5); and third, using a combination of email, IVR, and visual marking (Chapter 6). The implemented email-based prototype of the proposed framework is shown in

Figure 4.5. The prototype integrates four main components: a project communication list, activity-specific email forms; a customized scheduling engine; and a customized email application.

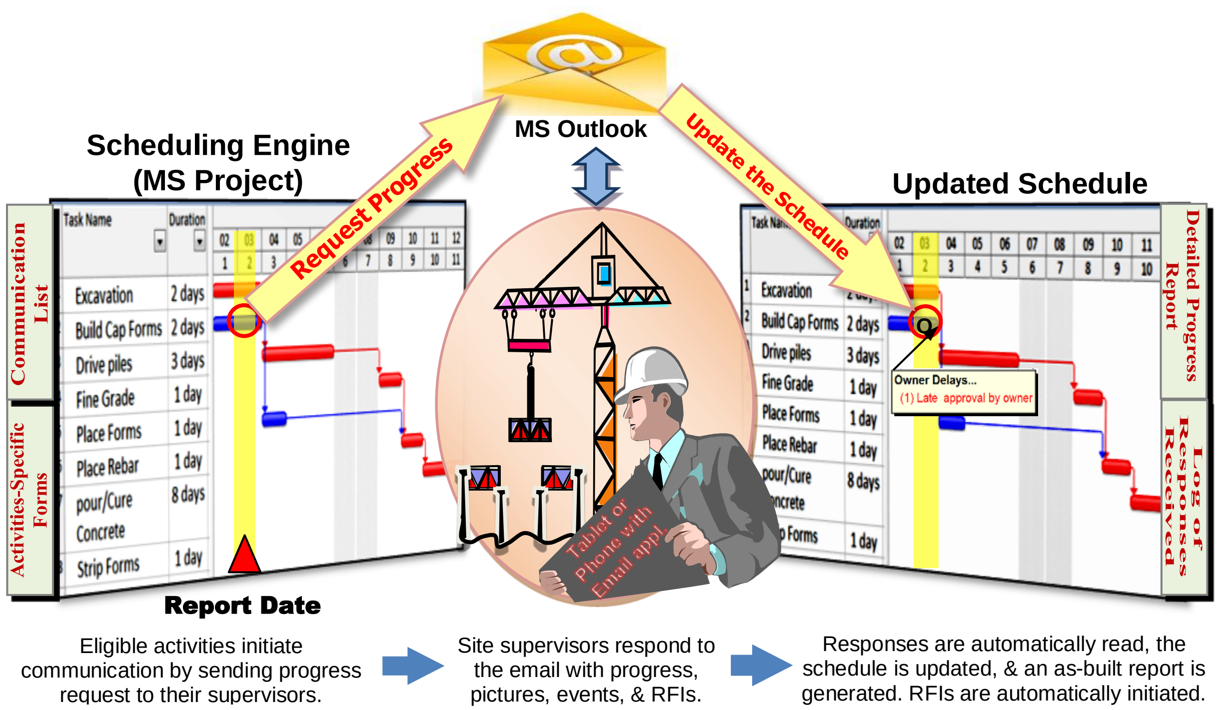


Figure 4.5: Framework Prototype Using Email

For the email prototype, MS Project was employed as a scheduling engine and also for the development of macros for the system controller. MS Project is a powerful, simple-to-use scheduling tool that can be easily customized. MS Outlook was utilized in the email prototype because of its availability, ease-of-use, and programmability. All of the prototype components were developed in a Visual Basic Application (VBA) environment that is available in all of the integrated software (MS Project, MS Excel, and MS Outlook).

The prototype incorporates activity-specific email forms developed based on the activity-tracking needs discussed in Chapter 3 (Abdel-Monem et al. 2012). Each email form was created as an html file formatted as an email message. The email forms appropriate for highway construction activities are included in Appendix A. The forms allow daily collection of a variety of data, in a simple and user-friendly manner: progress %, delays, responsible party, quality control issues, RFIs, and others. The workflow of the prototype follows the steps shown in Figure 4.4.

4.4 Experimentation: Case Study 1

The developed email prototype was applied to a simple case study of a bridge-pier construction project. The eight activities involved in the case study and their estimated durations were defined in Microsoft Project, as shown in Figure 4.6. The project was expected to take 16 working days (22 days including weekends), starting from December 1, 2011. The main system options allow the user to modify the existing communication list or add a new one, start the email-based data collection, read the latest responses received, check for any RFIs, update the schedule, and generate a full as-built report.

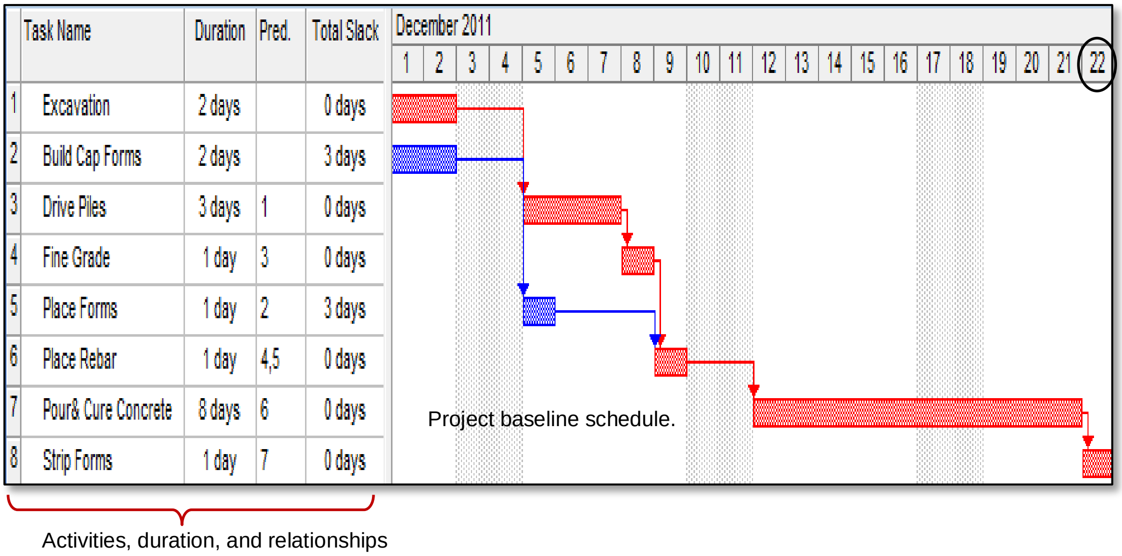


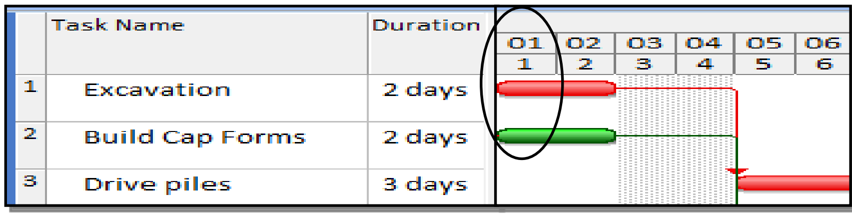
Figure 4.6: Bridge-Pier Foundation Case Study

The process of as-built tracking, as it applied to the case study, can be summarized as shown in Figure 4.7. The following is the detailed step-by-step process:

1. **Identify eligible activities:** When the user initiates the data collection using the email-based system, or when the system self-initiates daily at a preset specific time, the process begins with the automatic identification of the activities that are planned to start (i.e., starting activities or activities whose predecessors are completed) or that are still continuing on the current progress date, as highlighted in step 1 of Figure 4.7. In the case study, activities 1 and 2 are due to start on the first day of the project.

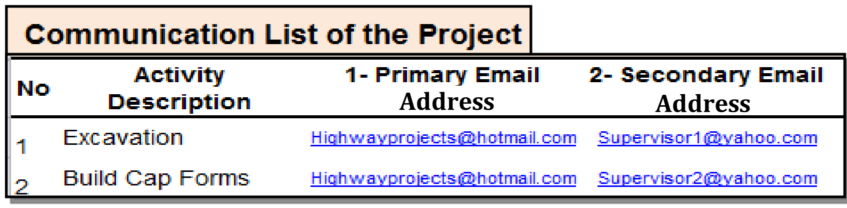
2. **Retrieve the communication list:** Once eligible activities have been identified, the system retrieves the predefined project communication list, as shown in Figure 4.8; loads the email address for the activities' supervisors and the contact information for the person responsible for responding to an RFI; and identifies the activity-specific email form for each activity, as shown in the right-hand section of Figure 4.8 .

1. On the current date, the progress tracking process is initiated for eligible activities.



Details in Figure 4.6

2. Supervisor's contact information is retrieved.

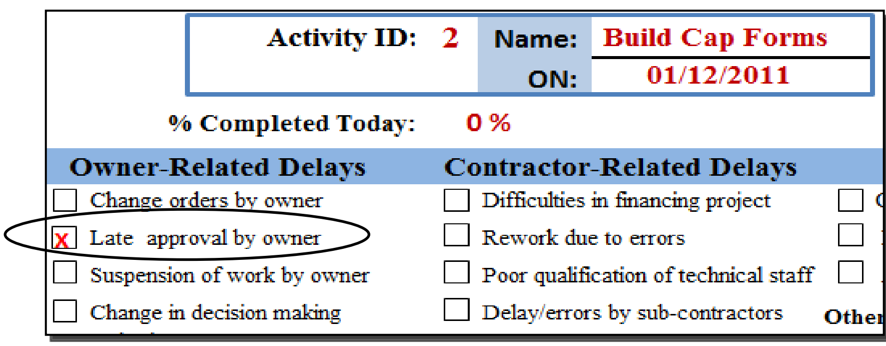


Communication List of the Project

No	Activity Description	1- Primary Email Address	2- Secondary Email Address
1	Excavation	Highwayprojects@hotmail.com	Supervisor1@yahoo.com
2	Build Cap Forms	Highwayprojects@hotmail.com	Supervisor2@yahoo.com

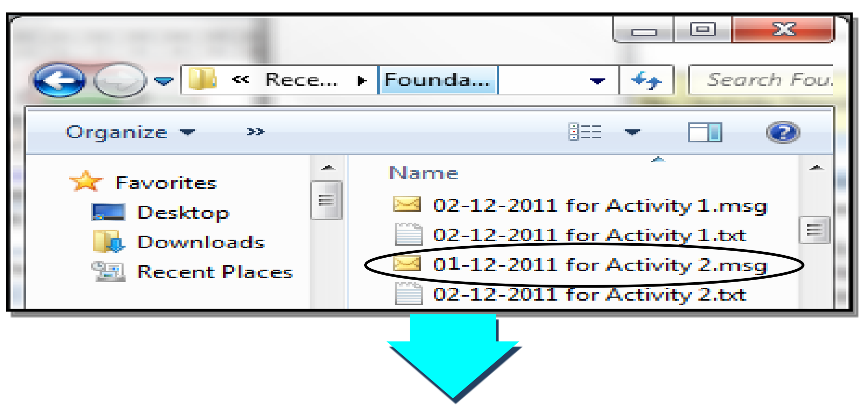
Details in Figure 4.8.

3. Email forms are sent.



Details in Figure 3.9

4. Responses are received.



5. Activity is automatically updated and an as-built report is created.

Details in Figure 4.11

Figure 4.7: Email-Based As-Built Tracking Process

Project Communication List

No.	Activity Description	Supervisor Contacts: 1- Primary Email Address	Supervisor Contacts: 2- Secondary Email Address	Responsible Contacts: Email	Associated-Email Forms
1	Excavation	Highwayprojects@hotmail.com	m_shawky_s@yahoo.com	m_shawky_s@yahoo.com	Excavation.x
2	Build Cap Forms	Highwayprojects@hotmail.com	m_shawky_s@yahoo.com	Highwayprojects@hotmail.com	Concreting.x
3	Drive piles	Highwayprojects@hotmail.com	m_shawky_s@yahoo.com	Highwayprojects@hotmail.com	Concreting.x
4	Fine Grade	Highwayprojects@hotmail.com	m.shawky.s@gmail.com	Highwayprojects@hotmail.com	Base & Sub-
5	Place Forms	Highwayprojects@hotmail.com	m_shawky_s@hotmail.con	Highwayprojects@hotmail.com	Concreting.x
6	Place Rebar	Highwayprojects@hotmail.com	m_shawky_s@yahoo.com	Highwayprojects@hotmail.com	Concreting.x
7	pour/Cure Concre	Highwayprojects@hotmail.com	Supervisor7@yahoo.com	Highwayprojects@hotmail.com	Concreting.x
8	Strip Forms	Highwayprojects@hotmail.com	Supervisor8@yahoo.com	Highwayprojects@hotmail.com	Concreting.x

Figure 4.8: **Sample Project Communication List**

3. **Request progress:** In this step, the system automatically initiates progress requests by sending email forms (step 3 of Figure 4.7) to the relevant supervisors. Each supervisor then responds to the email by simply entering the progress amount performed on that date and the reasons for slow progress, if any. When delays occur, the supervisor can select the party responsible and the reasons for that delay. The supervisor can also highlight any quality control issues encountered on that day; can request additional information (RFI); and can add comments, photos, voice recordings, etc. The email forms were designed to be specific for each activity and to include all related information so that the supervisor can simply and quickly highlight the actual daily site events that have occurred.

4. **Read responses:** As soon as the supervisors have replied to the email request, the responses and any attachments are saved in the MS Outlook folder designated for that project, as shown in the left-hand section of Figure 4.9. The system then loads the latest email responses, reads the

information, and saves it into the project database (step 4 in Figure 4.7), along with any other documents, such as photos.

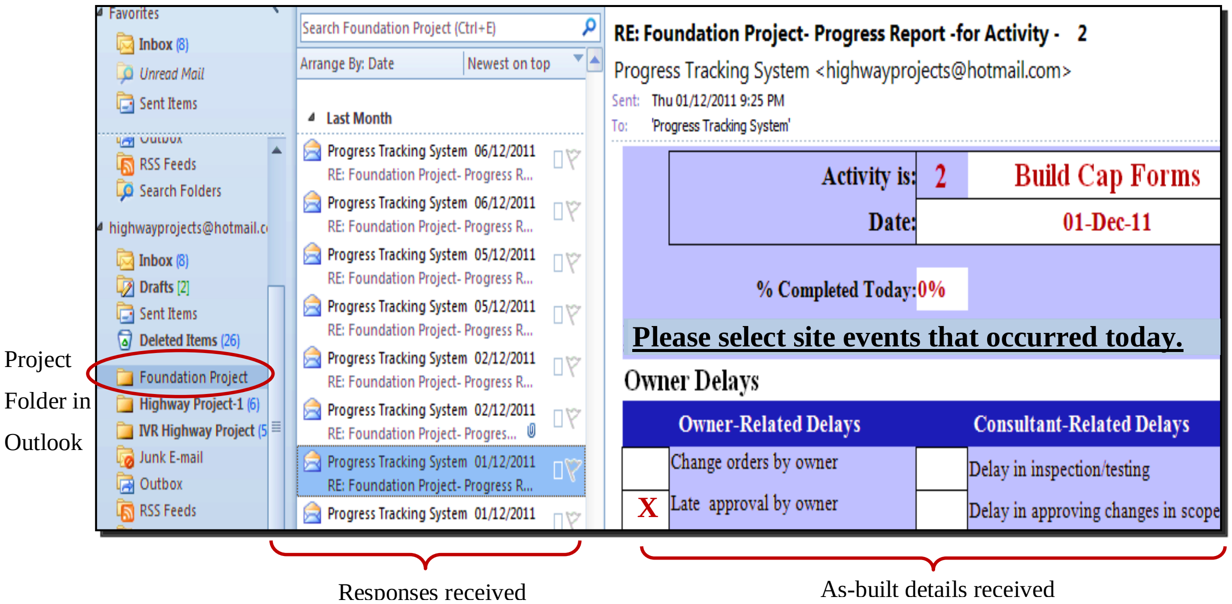


Figure 4.9: **Email Responses Received and Saved in the Project Email Folder**

5. **Update project information:** After reading the progress data, the system automatically updates the project schedule and saves all site events related to each activity along with any attached files. The system accurately updates the daily segments of each activity with information received on each day. Figure 4.10 shows the verified schedule updates. At the end of day 1 (December 1st), for example, the status of activities “Excavation” and “Build Cap Forms” has been updated to show that Excavation involved slow progress (10 % on day 1, as opposed to 50 % per its two-day planned duration). The reason for the slow progress was documented in the email log and on the as-built schedule as “Shortage of Labour”, which is the contractor’s responsibility. On the same day, the Build Cap Forms activity had zero percentage complete due to the owner’s late approval of the start of work (owner’s responsibility). The system thus

provides an as-built report that is more informative and more useful for corrective action planning and schedule analysis.

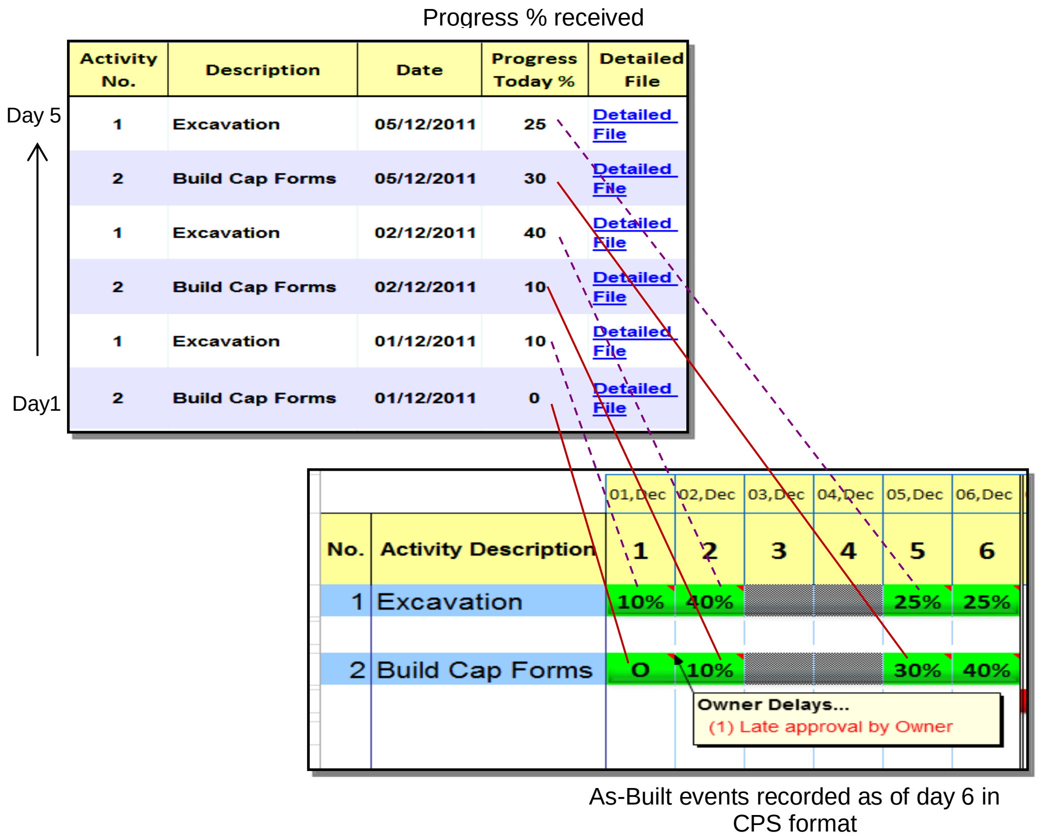


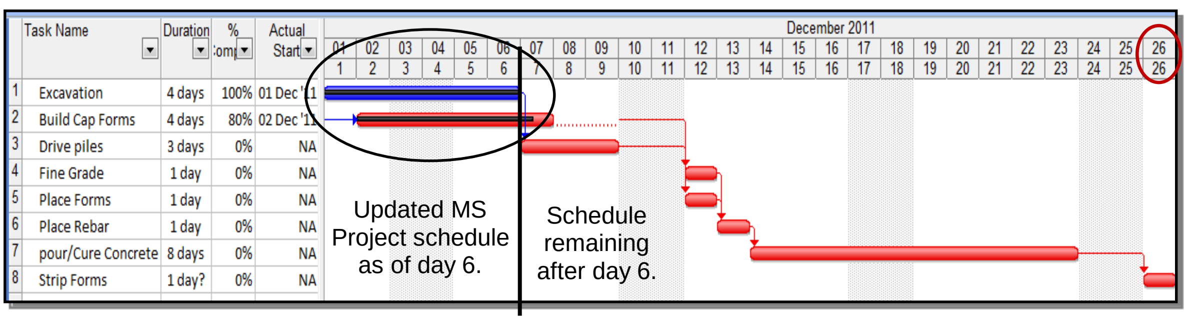
Figure 4.10: Verified Schedule Update

The system automatically generates three as-built information reports. The log of all communications received (Figure 4.11a) includes a record of actual site events related to each activity along with any attached files. Each row of the log represents a response received, including all data and hyperlinks to all attached files. In addition to the detailed log, two important reports are automatically generated by the system: an automated update to the MS Project file for the project with the cumulative percentage complete for each activity adjusted according to the latest information (Figure 4.11b), and a detailed as-built schedule that shows the evolution of all events on a daily basis, with all details included as comments on the associated days of the activities (Figure 4.11c).

a) Partial log of Email resposes received

	Activity No.	Description	Date	Progress Today %	Detailed File	Q/C Issues	Owner Delays	Contractor Delays	External Delays	Request For Information	Comments
Day 5	1	Excavation	05/12/2011	25	Detailed File					Excavation depth is unclear.	Slow Progress -Shortage of Labor
	2	Build Cap Forms	05/12/2011	30	Detailed File						Slow Progress -Low productivity level of labors
	1	Excavation	02/12/2011	40	Detailed File	Q/C issues with excavated area					
	2	Build Cap Forms	02/12/2011	10	Detailed File						Slow Progress -Shortage of Labor
	1	Excavation	01/12/2011	10	Detailed File						Slow Progress -Shortage of Labor
Day1	2	Build Cap Forms	01/12/2011	0	Detailed File		Owner Delay Late approval by owner				

b) MS Project schedule update



c) As-built evolution report

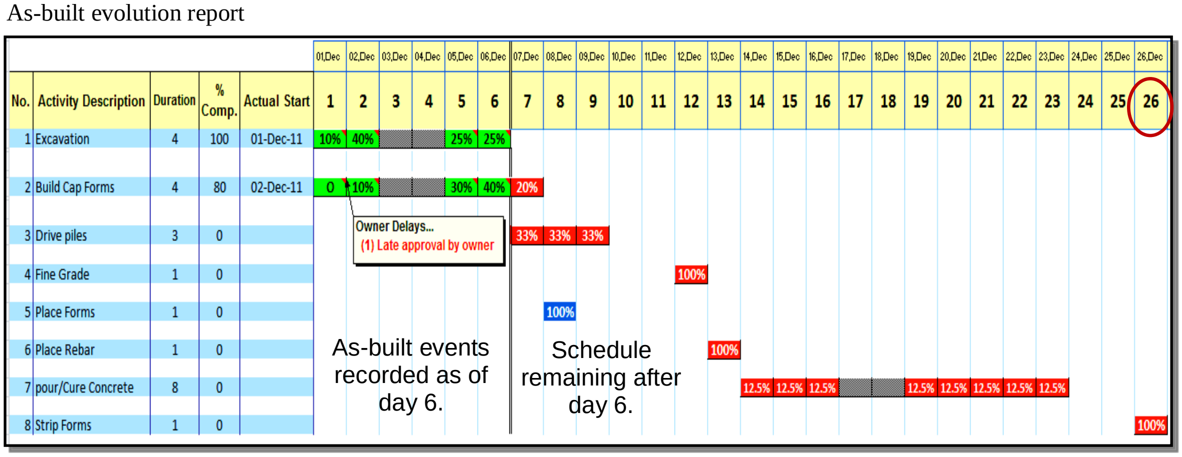


Figure 4.11: Log of Email Communications and Schedule Reports

Both reports show that the project duration is extended to 26 days (two-day delay). The MS Project schedule report can show only bars of completed and ongoing tasks being extended, without any progress details. The as-built report, on the other hand, provides all of the daily details, with additional information shown as comments on the relevant days.

6. **Respond to RFIs:** After the project schedule is updated, the system automatically checks to determine whether any RFIs or quality control issues have been reported. For example, on December 5th, the excavation supervisor requested additional information in order to clarify the excavation depth. Upon receipt of the request, the system automatically forwards it to the email address of the person responsible for providing a response (Figure 4.12), according to the project communication list.

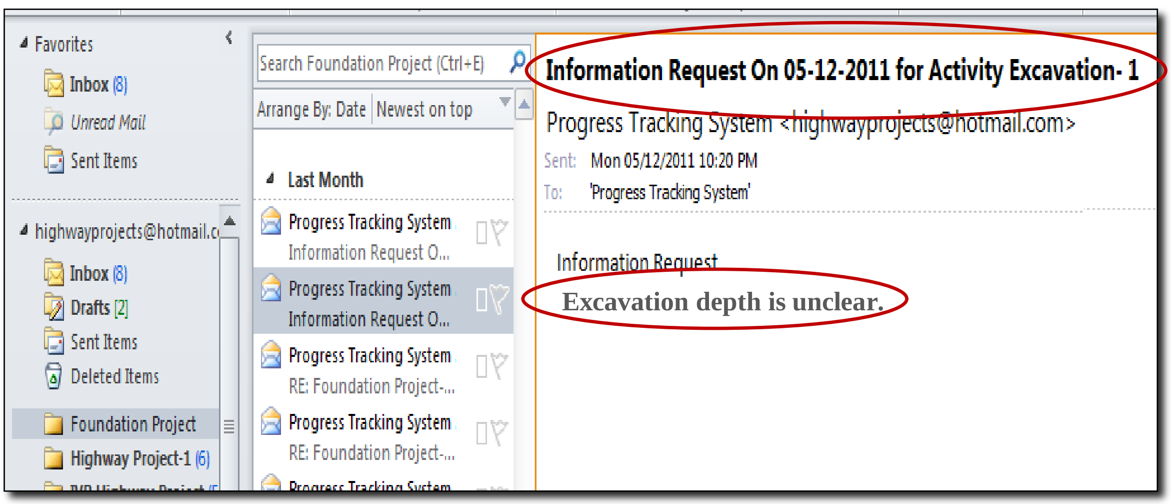


Figure 4.12: **RFI Sent to the Person Responsible**

The email prototype system for as-built documentation was also applied to a number of other case studies in order to test its functionality and to identify potential improvements. The results of the initial testing show that the structure of the system and its ability to be implemented as an add-on to existing project management tools offer a numerous benefits, including the following:

- The system integrates common affordable tools: MS Excel, MS Project, and MS Outlook. All of these tools have compatible versions of the VBA programming language and thus allow fast prototyping and full automation of the system functions.
- Implementation as an add-on to MS Project provides access to the wide array of built-in features available in the existing software, including easy-to-use procedures for defining the activities and their relationships, project-resource leveling, and the ability to handle large projects.
- The simple, logical, activity-specific email form enables supervisors to respond quickly and to attach photos, videos, and voice and text notes, along with the progress information.
- Project activities are programmed to be aware of their progress status so that the communication for the collection of progress data can be automatically initiated for eligible activities.
- The system's bidirectional communication ability means that timely responses can be obtained for any RFIs.
- The automatically generated as-built schedule acts as a visualization and documentation tool for all daily progress details (e.g., progress percentage, delays, responsible party, quality control issues). The system is thus especially suited for providing detailed schedule analysis and facilitation of corrective action.
- The system automatically updates the schedule in MS Project and also generates a full as-built schedule report using the CPS format (Figure 4.11b, 4.9c).

4.5 Conclusion

This chapter has described the development of the simplified and low-cost framework for the automated tracking of daily as-built information acquired from construction site personnel, using emails, IVR, and visual tools. The framework integrates activity-specific tracking needs, a project communication list, visual tools, a customized scheduling engine, and a customized email application for automating the collection of site data. The framework was developed into a computer prototype and applied to a simple case study of the construction of a bridge-pier foundation in order to demonstrate the developed concept. The email-based prototype system has the potential to minimize the time and cost associated with a number of construction processes: collecting site information, updating the schedule, generating report, and initiating warning signs. The system is expected to help construction firms achieve better control over construction operations and to provide timely information for decision making. In addition, it allows automated bidirectional communication between site personnel and head office and demonstrates the use of common communication technology in order to improve collaboration and greatly enhance work productivity in the construction industry, benefits that can be replicated in other domains.

Chapter 5
Using Interactive Voice Response

This chapter presents the use of interactive voice response (IVR) technology for tracking site information and documenting as-built details on the schedule. The benefits of IVR for construction firms are first discussed, followed by a description of the implementation of IVR for the collection of as-built information. The practicality of using IVR alone for the collection of site information was tested through two case studies. The second case study was conducted in a classroom exercise that simulates a large number of project interactions.

5.1 Benefits of IVR

IVR is a telephony technology that allows interaction between callers and a phone system for the purposes of acquiring information and entering it into a database. IVR enables the caller to select from preset options to enable a specific activity to occur, such as paying a bill, scheduling an appointment, or calling for a construction field inspection. IVR has been used extensively by a variety of companies for technical support purposes, but it has not yet been utilized for construction site communication.

Numerous cloud-based telephony servers (e.g., ifpyphone 2012) currently offer IVR applications that can be easily programmed and integrated with any other application. Such applications can provide unlimited parallel calling and can send responses back to a client database. These cloud-based servers offer advanced features such as speech recognition, text-to-speech, and voice-to-email. This technology thus has significant potential for facilitating cost-effective automatic bidirectional communication between site personnel and head office, with no geographic barriers. The advantages and disadvantages of using manual collection methods, email, IVR technology, and a combination of email and IVR are summarized in Table 5.1.

Table 5.1: Comparison of Data Collection Methods

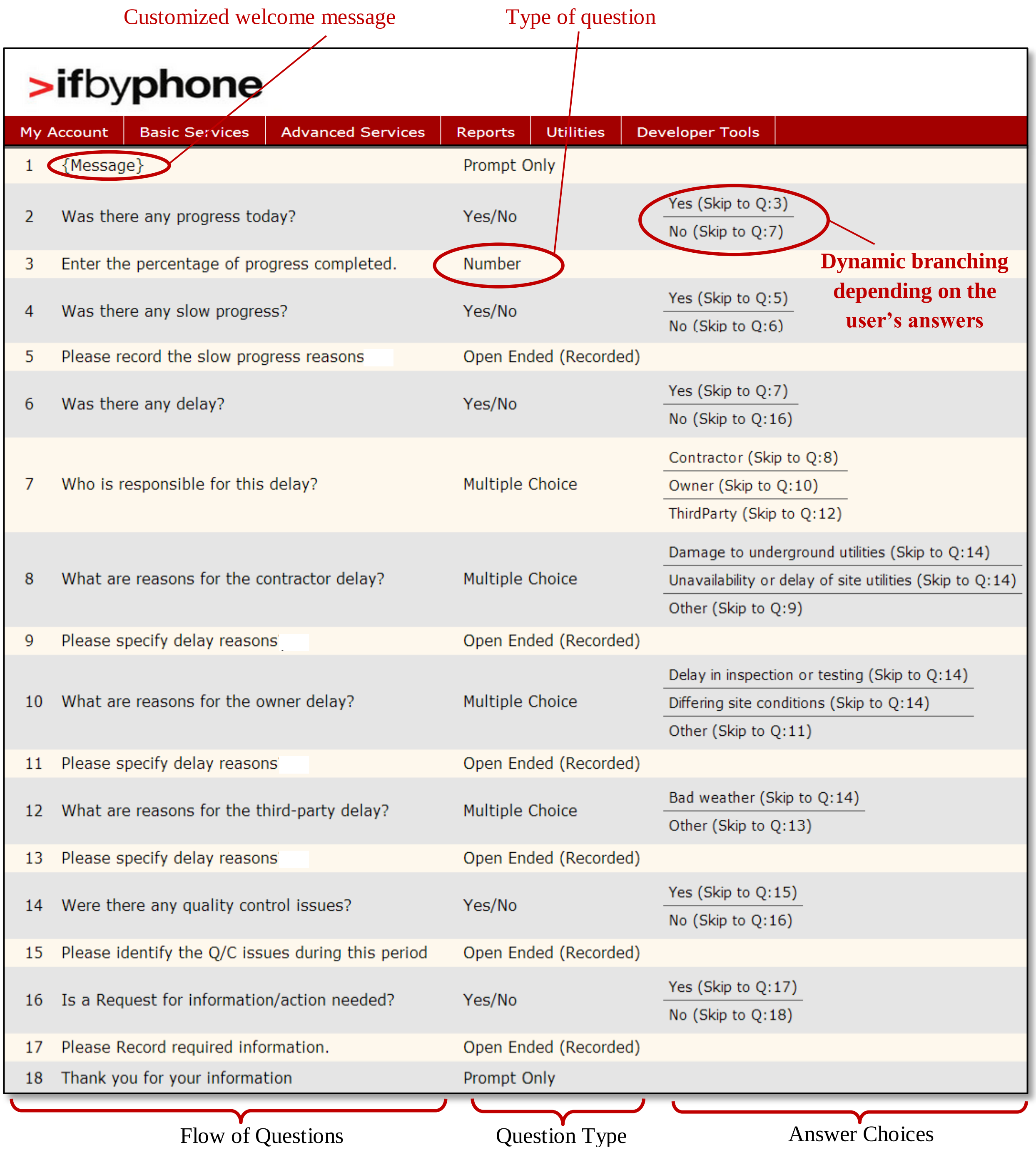
Technology	Manual	Email	IVR	Email+IVR
Advantages	- No requirement for internet access or wireless connection	- Users able to see visual representations and review questions and answers - Enough time for users to review answers before responding - Users able to attach photos, videos, and other documents	- Access to everyone everywhere at any time - Quick responses - Immediate forwarding of urgent information - Time-saving, efficiency, and convenience - Recorded messages that can document site events - Immediate transfer of calls, send ready-forms, emails, or faxes	Combination of the individual advantages of email and IVR
Disadvantages	- Labor intensive - Possibility of extra visits required to collect or confirm information - Longer time for recording data into database	- Possibility some users not having access to the internet - Difficulty in replying during working hours - Difficulty in replying from cellular phones	- User confusion about long surveys and multiple choices - Difficulty backing up to correct previous answers - User error in the selection of responses (e.g., 3 instead of 2)	Individual disadvantages of IVR and email overcome

As mentioned earlier in Chapter 2, different cities in Canada and the United States have been employing IVR technology since 1990 as a means of facilitating and automating the provision of information and assistance required by their customers. This type of service is useful in construction for activities that include immediate scheduling, rescheduling or cancelling inspections; obtaining inspection results; and leaving messages for inspectors or contractors. In recent years, with enhanced phone and computer technology, IVR has expanded to include a variety of features such as the capacity to immediately post and review inspection results, fax or email inspection reports and other information, and fax or email required forms and documents requested by users. IVR can therefore be used to connect site personnel (e.g., inspectors or contractors) automatically with head office, to enter or retrieve information from a database system, to respond to urgent requests for information, and to convey an immediate brief notification to a group of people.

5.2 IVR Implementation

The IVR logical flow diagrams discussed in Chapter 3 (Figure 3.10), which represent the logical sequence of questions to be followed during an IVR session, have been designed in order to collect complete site information as it relates to four categories: progress amount, site events, quality control issues, and any requests for information (RFIs). The activity IVR call-flow diagrams have been implemented in ifbyphone (2012); each IVR flow diagram is fully represented by 18 questions, as shown in Figure 5.1. ifbyphone allows users to customize the call-flow questions by choosing multiple choice, question prompts, the playing of a recorded message (text or audio), voice recording, etc. It also allows dynamic questions to be customized; for example, according to the supervisor's response, the system automatically retrieves the last-updated information from the project database; changes the flow of questions; or in the case of information requests, forwards the call to another party for a response.

The setup of question 2, for example, asks whether any progress occurred on that date and offers two choices (press 1 for "yes" or press 2 for "no"), as shown in Figure 5.2. Telephony web-based servers ask the user to select whether the questions are read to the supervisor using text-to-speech technology (TTS) or whether the system designer can use his/her custom-recorded message. All 18 questions shown in Figure 5.1 have been similarly implemented on ifbyphone. The flow diagram is dynamic in the sense that the sequence of questions is changed depending on the activity status, site events that have occurred, and the user's answer to a previous question (progress, delay, etc.).



1	{Message}	Prompt Only	
2	Was there any progress today?	Yes/No	Yes (Skip to Q:3) No (Skip to Q:7)
3	Enter the percentage of progress completed.	Number	
4	Was there any slow progress?	Yes/No	Yes (Skip to Q:5) No (Skip to Q:6)
5	Please record the slow progress reasons	Open Ended (Recorded)	
6	Was there any delay?	Yes/No	Yes (Skip to Q:7) No (Skip to Q:16)
7	Who is responsible for this delay?	Multiple Choice	Contractor (Skip to Q:8) Owner (Skip to Q:10) ThirdParty (Skip to Q:12)
8	What are reasons for the contractor delay?	Multiple Choice	Damage to underground utilities (Skip to Q:14) Unavailability or delay of site utilities (Skip to Q:14) Other (Skip to Q:9)
9	Please specify delay reasons	Open Ended (Recorded)	
10	What are reasons for the owner delay?	Multiple Choice	Delay in inspection or testing (Skip to Q:14) Differing site conditions (Skip to Q:14) Other (Skip to Q:11)
11	Please specify delay reasons	Open Ended (Recorded)	
12	What are reasons for the third-party delay?	Multiple Choice	Bad weather (Skip to Q:14) Other (Skip to Q:13)
13	Please specify delay reasons	Open Ended (Recorded)	
14	Were there any quality control issues?	Yes/No	Yes (Skip to Q:15) No (Skip to Q:16)
15	Please identify the Q/C issues during this period	Open Ended (Recorded)	
16	Is a Request for information/action needed?	Yes/No	Yes (Skip to Q:17) No (Skip to Q:18)
17	Please Record required information.	Open Ended (Recorded)	
18	Thank you for your information	Prompt Only	

Figure 5.1: IVR Call-Flow Diagram Application

Using such activity-specific and structured call-flow diagrams ultimately minimizes time wasted dealing with unnecessary questions and also facilitates bidirectional communication between site personnel and head office.

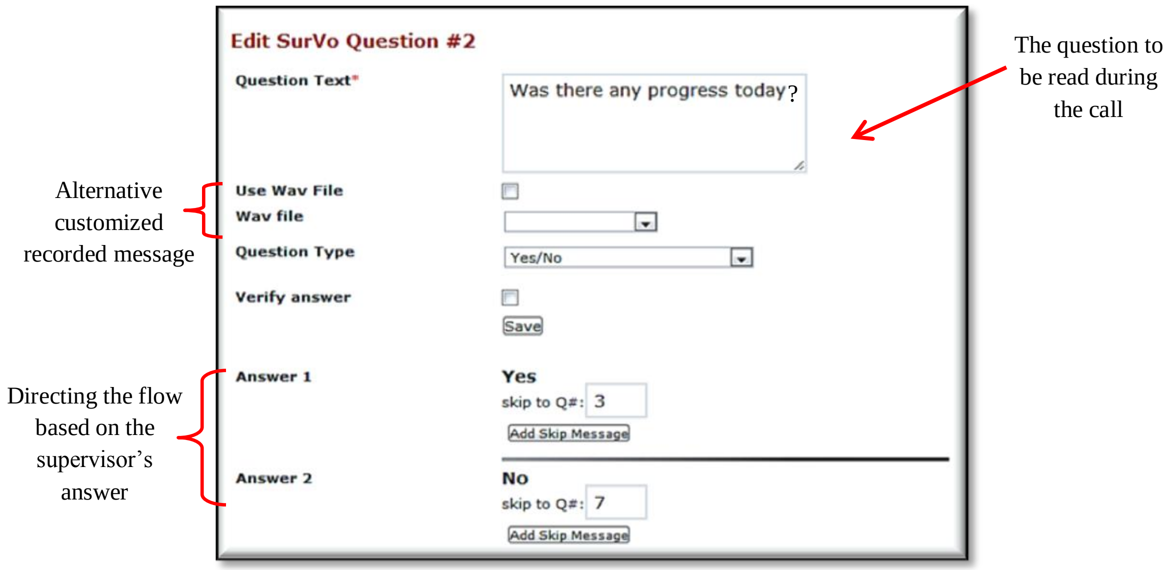


Figure 5.2: Setup for Question 2

5.3 Experimentation: Case Study 2

For demonstration purposes, the developed prototype system was applied to the same case study discussed in Chapter 4. The developed prototype (Abdel-Monem and Hegazy 2013) allows the user to modify the communication list, start the IVR data collection session, read the as-built responses received, check for any RFIs, update the traditional MS project schedule using cumulative percentage-complete values, and generate a time-segment-based as-built report with all progress events shown on the schedule. The prototype was developed as a modified version of the email system presented in Chapter 4. It integrates MS Excel, MS Outlook, MS Project, and ifbyphone. Visual Basic Application (VBA) language has been used so that the IVR cloud service can be controlled from within the application, which works as an add-on to MS Project. The communication list used in the prototype was changed to incorporate the phone numbers of the supervisors. Activities were also associated with unique IVR call-flow diagrams, rather than with email forms. The process for the tracking of as-built information, as it applies to the IVR case study, is shown in Figure 5.3.

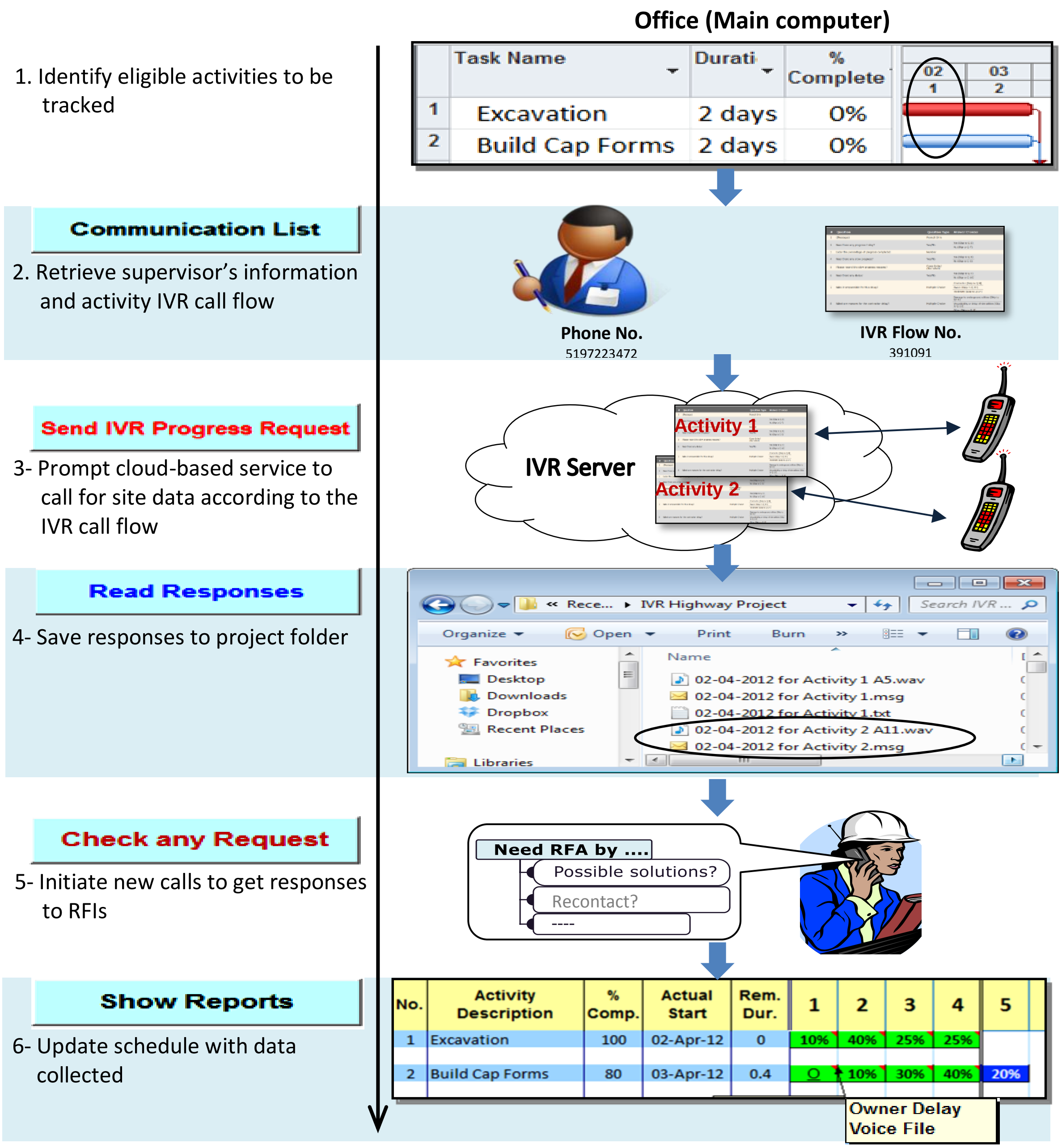


Figure 5.3: IVR-Based As-Built Tracking Process

The step-by-step details are as follows:

1. Identify activities that are eligible for progress tracking, these are either continuing activities or activities whose predecessors have been completed by the current progress date. In the case study, activities 1 and 2 are start on the first day of the project.

2. After identifying the eligible activities, the system retrieves the project communication list and loads the supervisors' phone contacts and index numbers to the related IVR call-flow for the eligible activities, as shown in Figure 5.4.

Project Communication List

No.	Activity Description	Supervisor Contacts		Responsible Contacts	Associated IVR Call-Flow
		Primary Phone No.	Secondary Phone No.		
1	Excavation	5197223472	5198889364	2266000695	391061
2	Build Cap Forms	5197223472	5198889364	2266000695	391091
3	Drive piles	5197223472	5198889364	2266000695	391091
4	Fine Grade	5197223472	5198889364	2266000695	391071
5	Place Forms	5197223472	5198889364	2266000695	391091
6	Place Rebar	5197223472	5198889364	2266000695	391091
7	pour/Cure Concrete	5197223472	5198889364	2266000695	391091
8	Strip Forms	5197223472	5198889364	2266000695	391091

Associated IVR flow diagrams; details in Figure 5.1

Figure 5.4: Project Communication List for the IVR Prototype

3. The system, then, automatically sends a request to the IVR cloud-based service to initiate phone calls to the supervisors of eligible activities, according to the set of questions in the associated IVR call-flow diagrams.

4. Once the supervisors have replied to the phone calls, their responses and any attachments (e.g., voice notes) are collected by the cloud-based service, which sends these responses as email files

to the project email account, as shown in Figure 5.5. The system then loads the latest email responses and saves the information into the project database along with other documents, such as voice notes (step 3 in Figure 5.3).

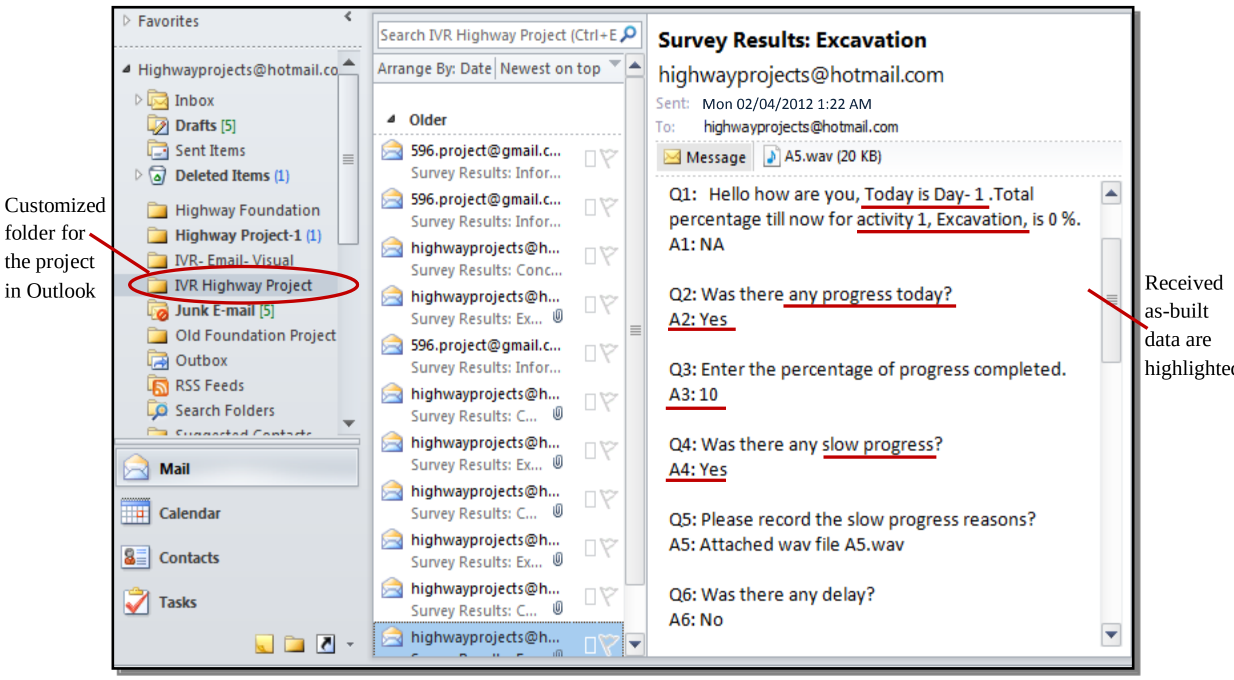


Figure 5.5: Responses Received Are Saved in the Project Email Account

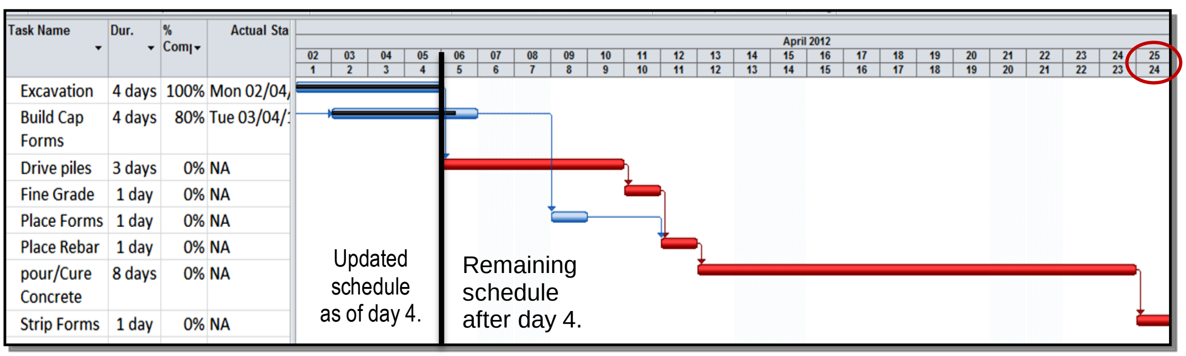
5. After reading the new as-built information, the system automatically updates the project schedule and saves all site events related to each activity, along with any attached files, in a log of all communications (Figure 5.6a). In addition to the detailed log, two important reports are generated automatically by the system: an automated update to the MS Project file for the project, which shows the cumulative percentage complete for each activity adjusted according to the latest information (Figure 5.6b), and a detailed CPS report of the schedule with the evolution of all as-built events, including all details shown as comments on the associated activity days (Figure 5.6c). Both reports show that the project duration has been extended to 24 days (two-day

delay). The MS Project schedule report can show only bars of completed and on-going tasks being extended, without any progress details. The CPS report, on the other hand, provides all of the daily details, with additional information shown as comments on the relevant days.

a) Partial log of email resposes received

	Activity No.	Description	Date	Progress Today %	Detailed File	Q/C Issues	Owner Delays	Contractor Delays	External Delays	Request For Information	Comments
Day 3	1	Excavation	04/04/2012	25	Detailed File					Phone Information Request	Slow Progress
	2	Build Cap Forms	04/04/2012	30	Detailed File						Slow Progress
	1	Excavation	03/04/2012	40	Detailed File	Q/C File					
	2	Build Cap Forms	03/04/2012	10	Detailed File						Slow Progress
	1	Excavation	02/04/2012	10	Detailed File						Slow Progress
Day1	2	Build Cap Forms	02/04/2012	0	Detailed File		Voice File				

b) MS Project schedule update



c) As-buit evolution report (CPS format)

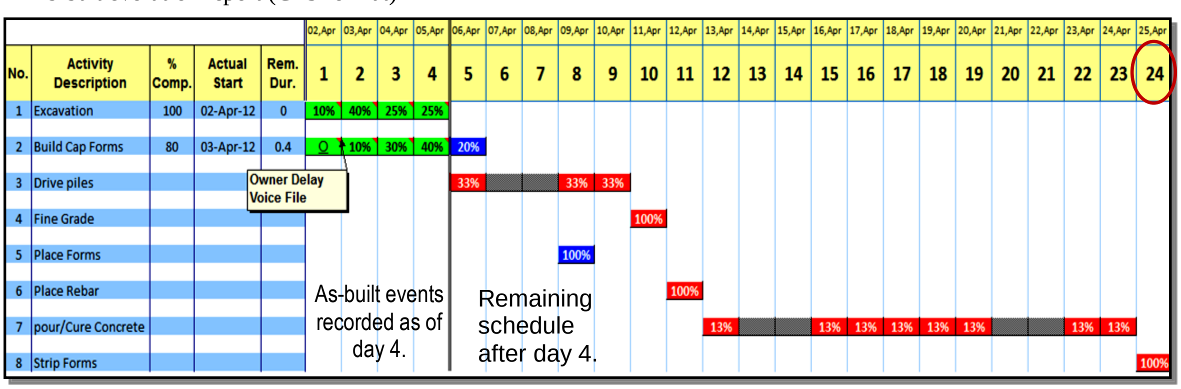


Figure 5.6: Log of IVR Communications and Progress Reports

At the end of day 1 (April 2nd), for example, the status for the "Excavation" and "Build Cap Forms" activities have been updated to show that Excavation involved slow progress. The reason for the slow progress was documented as an attached voice file (in the IVR log and on the as-built schedule), which states that the delay was the responsibility of the contractor. On the same day, the Build Cap Forms activity shows zero percent complete due to owner delay, as noted in an attached voice file. The CPS report, therefore, is more informative and more appropriate for facilitating schedule analysis and the planning of corrective action.

6. Once the project schedule has been updated with the information received, the system automatically checks to determine the presence of any requests for information (RFIs) or quality control issues and then automatically forwards the RFI voice messages to the phone of the person responsible to respond, based on the communication list. The response to an RFI is then automatically sent back to the initiating supervisor. For example, the system received an RFI from the Excavation supervisor (Top right-hand section of Figure 5.6a) on April 4th (day 3), and this RFI has been automatically forwarded to the person responsible for responding and taking action.

The received site events and progress information that are recorded directly on the associated time segments facilitate accurate forensic analysis of the schedule to analyze the responsibility for the two-day project delay. For example, based on the data collected as of day 4, the project is expected to be delayed by two days. The analysis of the current schedule starting from day 1 shows that the owner's work stop (O) for the "Build Cap Forms" activity on day 1 did not cause a delay in the project because it affected only a non-critical path. However, the contractor's slow progress (10 % as opposed to the planned progress of 50 %) for the "Excavation" activity is expected to cause the project to be delayed by one day. Therefore, because of the events on day 1, the project is delayed by one day, which is attributed to the contractor.

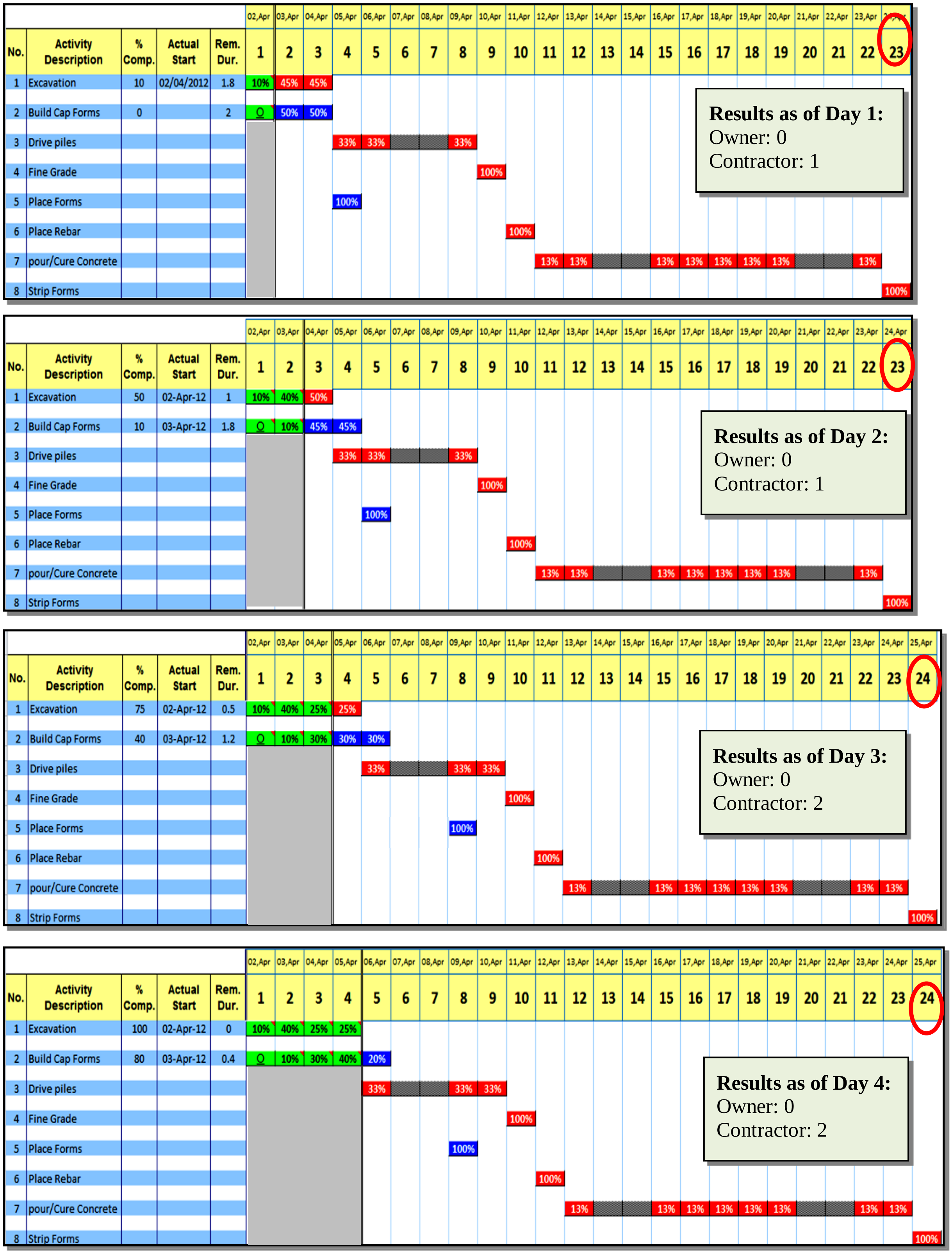


Figure 5.7: Delay Analysis: Days 1 to 4

As this process continues, the events of each day are analyzed and the responsibility is accumulated, as shown in Figure 5.7. Since the events of days 2 to 4 are all attributable to the contractor, the conclusion of the schedule analysis at the end of day 4 is an expected project delay of two days, apportioned as two days attributable to contractor events.

5.4 Large-Scale Experimentation: Case Study 3

The small case study presented in subsection 5.3 served as verification and error-free implementation of the framework and all of its components. To test the system in a large-scale situation in which many activities run in parallel, a more realistic case study was conducted as an academic class exercise (Hegazy et al. 2013). This case study was assigned at the University of Waterloo through the Civil and Environmental Engineering Department as part of the winter 2012 CIVE 596 construction management course. The case study entailed the collection of real-time project progress information by telephone (IVR) from a variety of groups simultaneously, followed by immediate updates to the project schedule that were displayed on a screen. The course involved 100 senior undergraduate and master's students divided into 20 groups. The case study was a part of a hands-on exercise, the goal of which was to build a model of the CN Tower in half an hour. The model design and parts assigned to each group are shown in Figure 5.8. All groups were to share the construction of a large 12.5 ft model of the CN Tower using foam paper, wooden popsicle sticks, and glue. Each of the 20 groups was responsible for designing, planning, and building one part and then assembling the whole final model, all within a strict deadline, adhering to budget constraints, and using zero waste construction. The exercise emphasized the importance of automation and the potential of existing low-cost technologies such as cellular phones and IVR systems to facilitate as-built tracking and corrective-action planning.

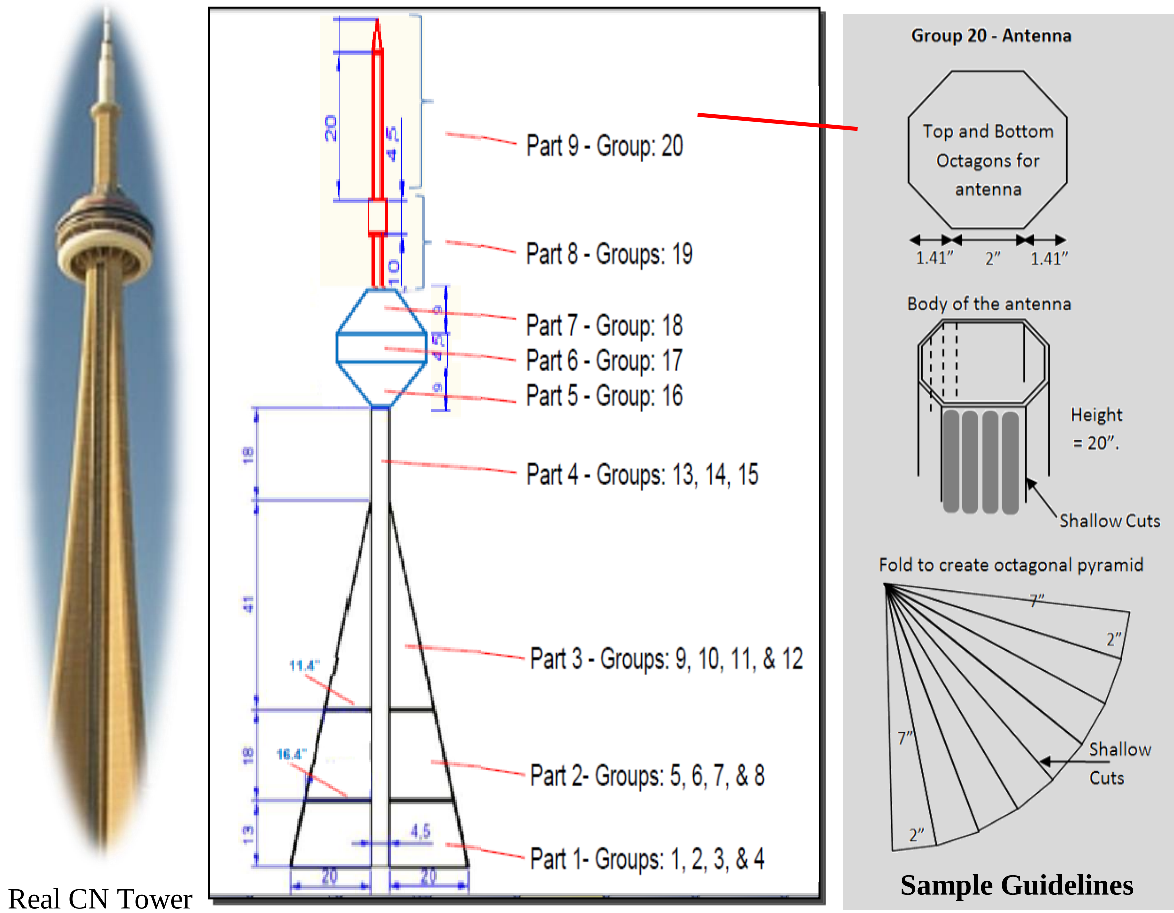


Figure 5.8: CN Tower Model Design, Group Assignments, and Sample Guidelines

Before starting the hands-on exercise, all groups submitted their detailed schedule for finishing their part of the project in 30 minutes, and a master plan for all 20 group projects was then developed based on the individual plans, as shown in Figure 5.9.

The phone numbers of the group project managers (PM's) were also input into the prototype of the framework, and ifbyphone was set up with a standard call-flow diagram. The prototype components are shown in Figure 5.10. Like many young professionals, the students are technology savvy and were able to provide valuable feedback about the performance and usability of the system.

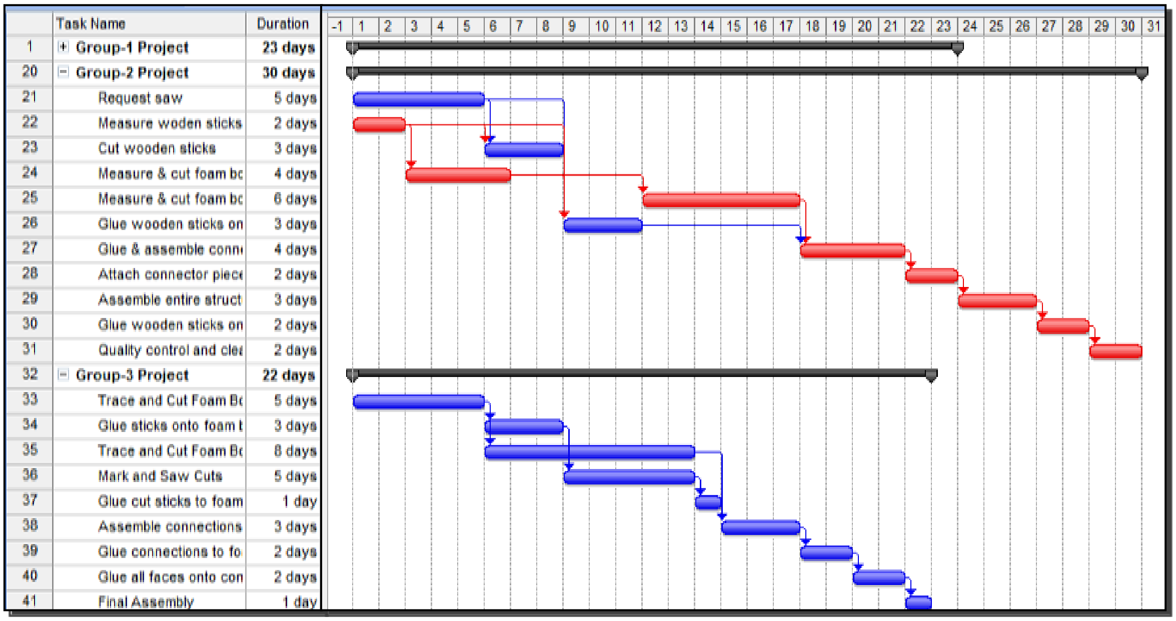


Figure 5.9: Portion of the MS Project Master Schedule for All Groups

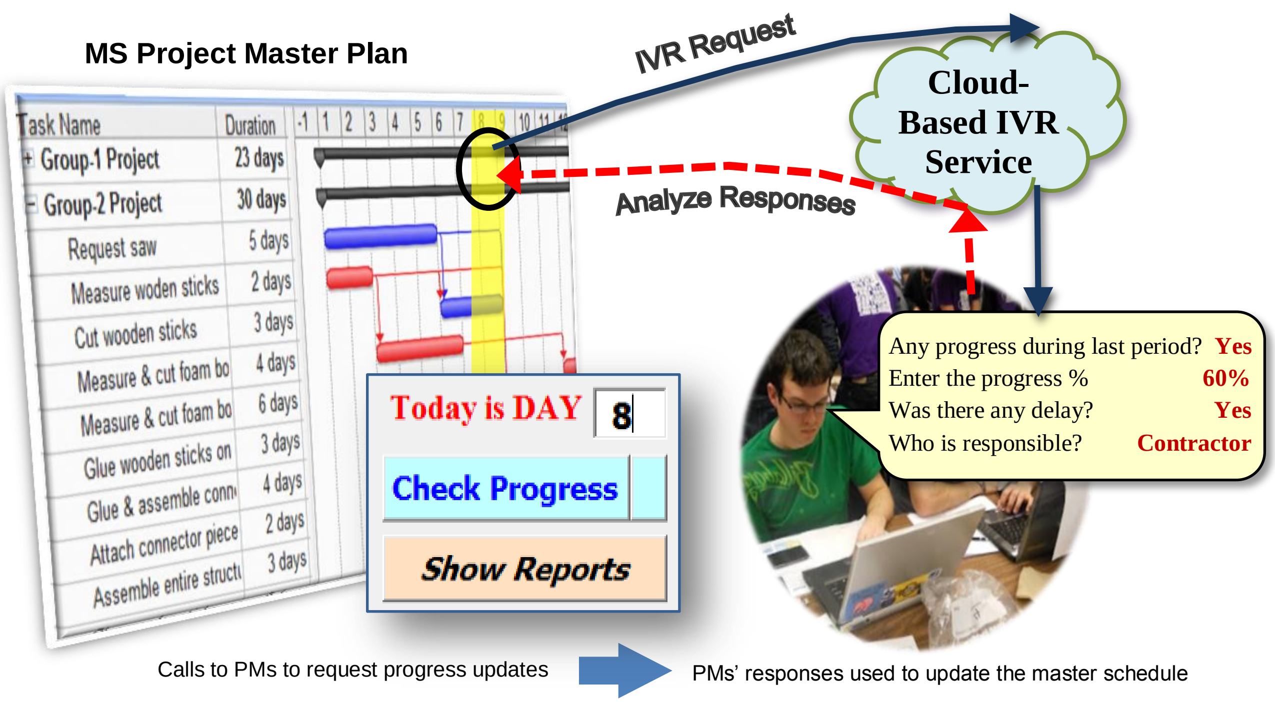


Figure 5.10: Components of the Voice-Based As-Built Tracking Prototype

During the execution of this hands-on exercise, the classroom environment was very similar to conditions at a real site: high noise level, congestion, work interruptions, rework, strict timing plans, and limited resources. In this type of environment, the groups found it challenging to finish their work on time. Each group consisted of four students who performed the actual construction and one project manager (PM) responsible for collecting data every two minutes, for updating the project schedule on the group's laptop computer, for ordering additional materials, and for responding by phone to any progress requests. To update the progress of an activity, the prototype system initiated a phone call to the group PMs every few minutes and asked a set of interactive questions (e.g., push 1 for progress; push 2 for delay) according to the call-flow diagram shown in Figure 5.11.

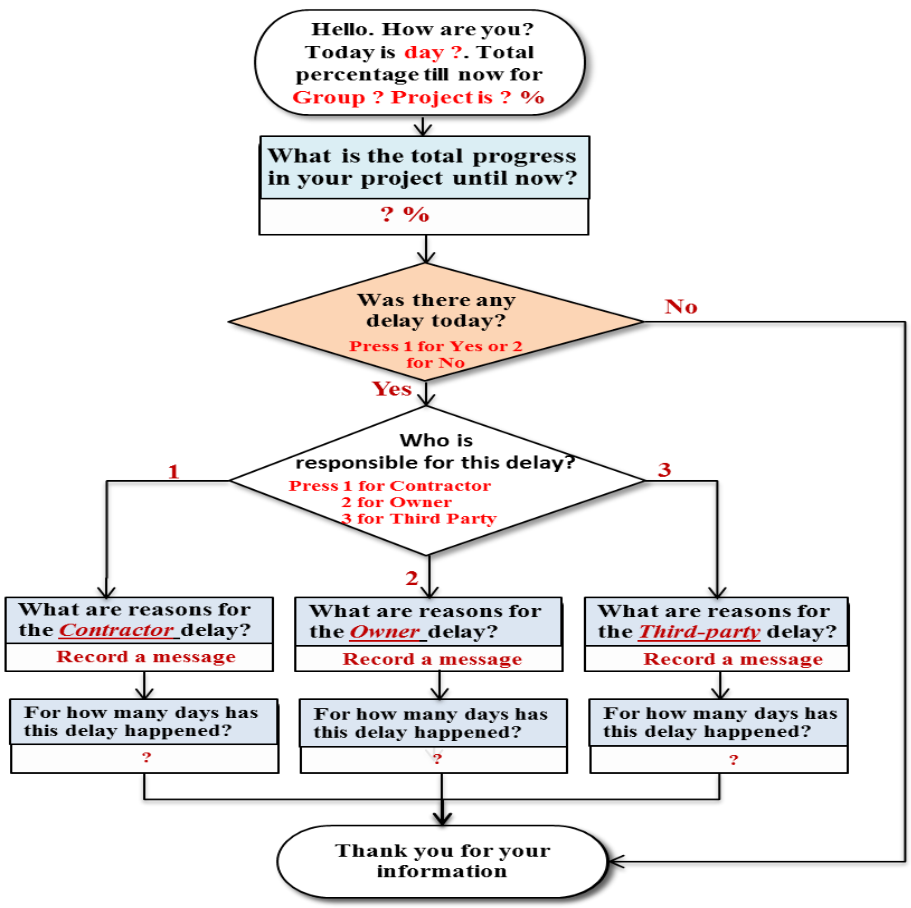


Figure 5.11: IVR Call Flow Diagram Applied During the Hands-On Exercise

Overall, the construction of the model proceeded very well, and the CN Tower replica was assembled in an open area with a high ceiling for viewing by students and colleagues. All progress tracking was performed using the IVR prototype system, and the master schedule was updated accordingly on the screen, as shown in the top left-hand photo in Figure 5.12.

Other Photos: https://picasaweb.google.com/106082500275579763138/596Project2012

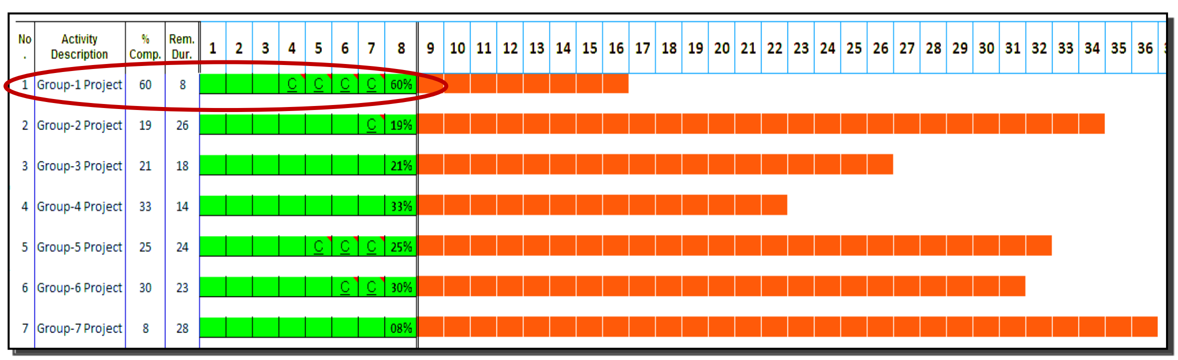
Figure 5.12: Photographs of the Construction and Assembly

During the progress tracking, the system automatically updates the project schedule and saves all site events related to each group in a log of all communications (Figure 5.13a). The time units for the class project were measured in minutes; however, the figure is a screen capture from the system, which indicates time in days, as would be the case for a construction project. Each row of the log represents a response received, including all data and hyperlinks to all attached files. In addition to the detailed log, a detailed as-built schedule was generated, which displays the evolution of all events on a daily basis, with all details shown as comments accompanying their associated times (Figure 5.13b). The CPS-format report shows that after 8 min from the starting point, the project duration is extended to 36 min and that the groups being delayed are identified. The reason for that delay was received as a voice file and automatically attached to the relevant minute for each group.

a) Log of Responses Received

Activity No.	Description	Day	* Date	Progress %	Detailed File	Owner Delays	No. of Days	Contractor Delays	No. of Days	ThirdParty Delays	No. of Days
1	Group-1 Project	8	12-03-16	60	Detailed Response			Voice File	4.00		
2	Group-2 Project	8	12-03-16	19	Detailed Response			Voice File	1.00		
3	Group-3 Project	8	12-03-16	21	Detailed Response						
4	Group-4 Project	8	12-03-16	33	Detailed Response						
5	Group-5 Project	8	12-03-16	25	Detailed Response			Voice File	3.00		

b) Detailed Progress Report



* Each minute represented as one day

Figure 5.13: As-Built Schedule and Log of Responses Received as of Min 8

All groups worked excitedly to complete their part of the project within their 30 min deadline. Fifteen of the 20 groups completed their parts within 35 min, three groups finished within 45 min, and two groups had to repeat parts of their work due to incorrect initial measurements but managed to finalize their parts in one hour. Despite the effort expended on the design and preparation for the exercise, the construction process nonetheless included both surprises and lessons to be learned. The students were very interested in the use of cellular phones for collecting progress data from the groups, and the technique worked very well, with the exception of a few communication difficulties. Given the fast pace of events, however, several students recommended using a combination of email/text messages and IVR to allow enough response time. A sample of the students' comments and suggestions for improvement are provided in Table 5.2.

Table 5.2: Sample of Students' Overall Comments about the Exercise

Comments by Students
- Exercise was a great experience and working under the given timeline gave us the feel of a real job pressure.
- It will be better if we have bigger space to work, got more details about the group organizations previously, and communication and sharing information with similar groups.
- The IVR system could also be improved by sending out emails simultaneously along with the cell phone call giving users the option of using either method as suitable.
- The IVR system was able to track numerous projects at the same time.
- Rather than having a system calls all groups at once, groups could call a number to provide progress information.
- Using a phone to update the schedule in real time is a very good idea; however, it is recommended that the request be conducted in text format through either a text message or a smart phone application.
- The exercise was easy to understand and follow, also easy to implement.
- Sharing ideas in the feedback session help us explore the varying perspectives to tackle similar problems.
- The IVR tool was very helpful for project managers to monitor the progress of different sections/fields.
- Any deviations from the initial schedule can be identified beforehand and addressed immediately.
- We learned how to do project control and deal with teamwork, also appreciate the importance of planning for successful project management.
- Groups were close to each other, so sometimes the noise made communications difficult.

5.5 Conclusion

This chapter has discussed the utilization of IVR for tracking and documenting as-built information from a number of project managers simultaneously. Compared to lengthy emails, the IVR sessions are more interactive, minimize the number of questions asked, and allow supervisors to specify site events as well as any requests for information. Responses are also received instantaneously so that the schedule can be updated and a visual representation of the latest as-built information can be added directly on the daily segments of a schedule. The developed IVR system can be configured so that it can operate either by receiving calls from supervisors at any time or by configuring eligible activities for the automatic initiation of calls to the appropriate supervisors. The IVR case study emphasizes the importance of automation and the potential for existing low-cost technologies such as cellular phones and IVR systems to facilitate as-built tracking and corrective-action planning. Based on the feedback received, email, IVR, and visual progress markup technologies were combined in order to enhance the tracking and documenting of as-built details, as explained in the next chapter.

Chapter 6
Combining Email, IVR, and Visual Tools

This chapter describes the combination of email, interactive voice response (IVR), and visual marking technologies as a means of enhancing both the tracking of site information and the inclusion of as-built documentation on the schedule. The first section discusses the implementation of a visual marking technique that permits the inclusion of a visual representation of work progress on drawing files. A further application case study is then presented in order to demonstrate the effectiveness and value of the enhanced system for automatically tracking all daily site events and for enabling the visualization of the evolution of activity progress.

6.1 Visual Marking Implementation

In addition to IVR communication, the visual presentation of construction site information offers another effective method of monitoring progress (Golparvar-Fard et al. 2009) and of enhancing the understanding of complex construction situations. Better visualization of site information enables project managers to have a better awareness of progress status so that they can then take informed corrective action. Previous research at the University of Waterloo (Hegazy et al. 2008) incorporated visualization through a portable handheld device with a built-in camera for visually recording building inspection information. In that study, a spreadsheet system included CAD drawing of floor plans as background images, overlaid by inspection markings linked to the building system being checked.

The framework developed in the research for this thesis relies on a similar visualization approach for the visual recording of the progress details on an image. Each activity in the project schedule is first associated with the appropriate CAD or image files that represent the location and extent of the activity (step 1 in Figure 6.1). This effective approach allows supervisors to indicate the elements that have been completed to date and to record pictures, sound, etc., during the data collection process (step 2 in Figure 6.1).

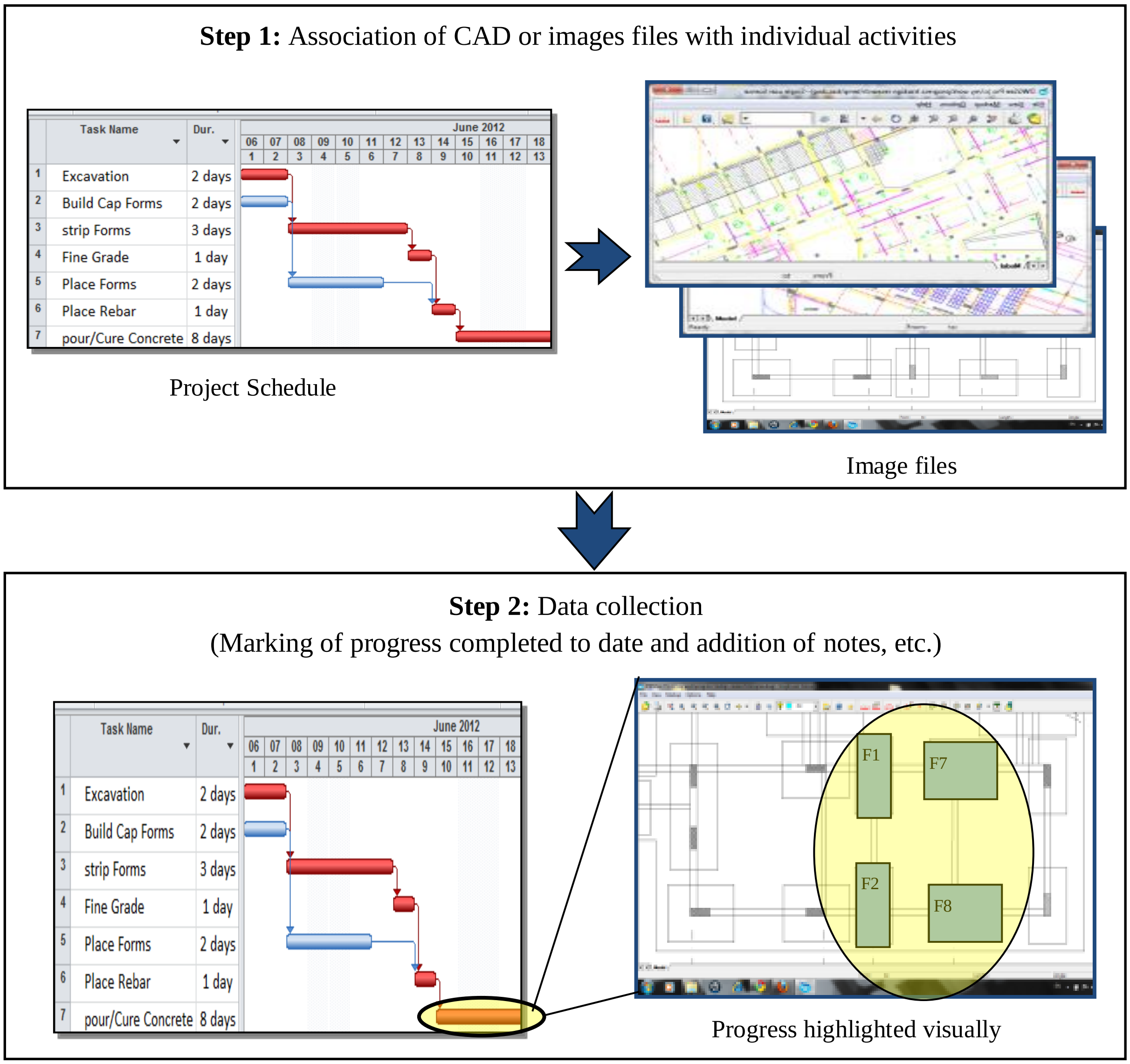
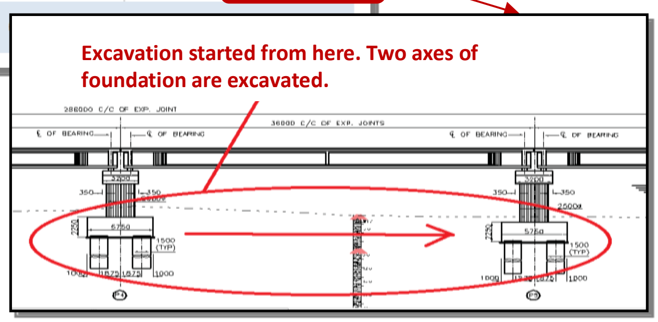


Figure 6.1: Schematic of the Visual Progress Tracking Approach

The system for the bidirectional communication of the visual files was designed so that all files received are automatically linked to associated activities for specific dates, as shown in Figure 6.2. Such a visual method of recording progress helps project participants easily understand the work completed to date and enables the evolution of the work progress to be documented.

Act. No.	Description	Date	Progress Today %	Visual File
2	Build Cap Forms	11-06-2012	40	
1	Excavation	11-06-2012	25	Visual File
2	Build Cap Forms	08-06-2012	30	
1	Excavation	08-06-2012	25	Visual File
2	Build Cap Forms	07-06-2012	10	
1	Excavation	07-06-2012	40	Visual File
1	Excavation	06-06-2012	10	Visual File
2	Build Cap Forms			



Visual progress file received is linked to associated activity on specific date

Figure 6.2: Linking of Visual File Received to the Associated Activity

To integrate all the framework components, the email-based system framework discussed in Chapter 4 was expanded to include both IVR and visual marking features, and a prototype of the enhanced framework was developed. For each activity, the system initiates the automatic calling or emailing of the corresponding supervisors with requests for as-built information updates, analyzes the responses received, updates the project schedule accordingly, and generates detailed as-built reports. To illustrate the procedure for the collection of site data, the following section describes a demonstration case study.

6.2 Experimentation: Case Study 4

For demonstration purposes, the developed prototype system was applied to the same case study discussed in Chapter 4: the bridge-pier construction project. In this case, it is assumed that the project is planned to start on June 6th, 2012, and is expected to take 16 working days (22 days including weekends). The main system options allow the modification of the communication list, start the collection of site data using email or IVR, read the responses received, check for any requests for information (RFIs), update the schedule, and generate full as-built reports. The process of tracking the as-built information, as it applies to the case study, can be summarized as shown in Figure 6.3. The detailed step-by-step process is explained below.

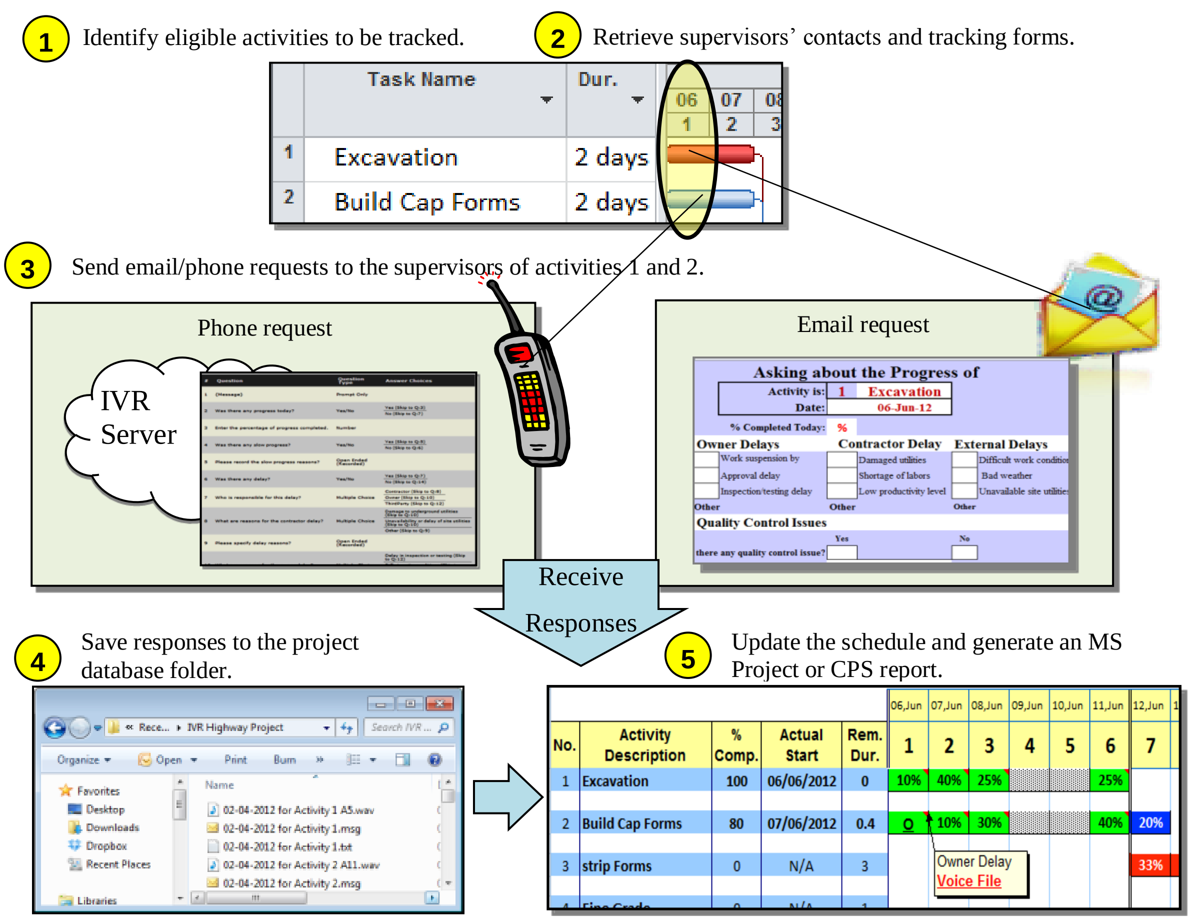


Figure 6.3: As-Built Information Tracking Process

- **Identify Eligible Activities and Retrieve Communication List:** The as-built documentation process starts with the automatic identification of activities that are planned to start on the current progress date, ones whose predecessors have been completed, or ones that are still not completed. In the case study, activities 1 and 2 are to start on the first day of the project. Once the eligible activities have been identified, the system retrieves the predefined project communication list and loads the supervisors' contacts (email and phone numbers), the index number related to the IVR call flow in case of a telephone progress request, the email form in case of an email progress request, and the associated visual files, as shown in Figure 6.4.

Save Received Responses to: IVR- Email- Visual

Project Communication List

Email-Forms Folder | Visual-Files Folder

No.	Activity Description	Supervisor Contacts		Preference	Responsible Contacts		Associated-Forms/Files		
		1- Primary Email Address	2- Primary Phone No.		Email	Phone	Associated Email-Form	Associated IVR-Form	Associated Visual-File
1	Excavation	Highwayprojects@hotmail.com	2266000695	1	m_shawky_s@yahoo.com	5198889364	Excavation.x	461471	General Lay
2	Build Cap Forms	Highwayprojects@hotmail.com	2266000695	2	Highwayprojects@hotmail.com	5198889364	Concreting.x	461561	Pile Cap.jpg
3	Drive piles	Highwayprojects@hotmail.com	5197223472	2	Highwayprojects@hotmail.com	5198889364	Concreting.x	461561	Pile Details.j
4	Fine Grade	Highwayprojects@hotmail.com	5197223472	2	Highwayprojects@hotmail.com	5198889364	Base & Sub-	461481	General Lay
5	Place Forms	Highwayprojects@hotmail.com	5197223472	1	Highwayprojects@hotmail.com	5198889364	Concreting.x	461561	Pile Cap.jpg
6	Place Rebar	Highwayprojects@hotmail.com	5197223472	1	Highwayprojects@hotmail.com	5198889364	Concreting.x	461561	Pile Cap.jpg
7	pour/Cure Concre	Highwayprojects@hotmail.com	5197223472	2	Highwayprojects@hotmail.com	5198889364	Concreting.x	461561	Pile Cap.jpg
8	Strip Forms	Highwayprojects@hotmail.com	5197223472	1	Highwayprojects@hotmail.com	5198889364	Concreting.x	461561	Pile Cap.jpg

Contact information for activity supervisors

Contact information for persons to respond to RFIs

Email, IVR, and visual forms

Figure 6.4: Enhanced Communication List That Includes Links to IVR and Drawing Files

- **Request a Progress Report:** The system then automatically sends a request to the relevant supervisors. For example, in the case of a progress request by phone (as with activity 2 "Build Cap Forms"), the system automatically contacts the IVR cloud-based service to initiate a phone call to the supervisor of activity 2 and follows the logical set of questions shown in Figure 5.1. If progress is reported, the supervisor is asked to enter the amount of the actual progress completed and to indicate any slow progress encountered. In the case of a delay, the supervisor will be asked to select the responsible party (owner, contractor, or third party) and the reasons for the delay. Next, the supervisor will be asked whether any quality control issues exist and, if so, to record the issue. At the end of the IVR session, the supervisor will be asked for any RFIs or other inquiries, and based on the contact information retrieved from the project, the request will automatically be forwarded to the person responsible, who will respond. In the case of progress information requested by email (e.g., activity 1 "Excavation"), the system sends an email message with the activity-specific form associated with the "Excavation" activity as the body of the message, as shown in Figure 6.5.

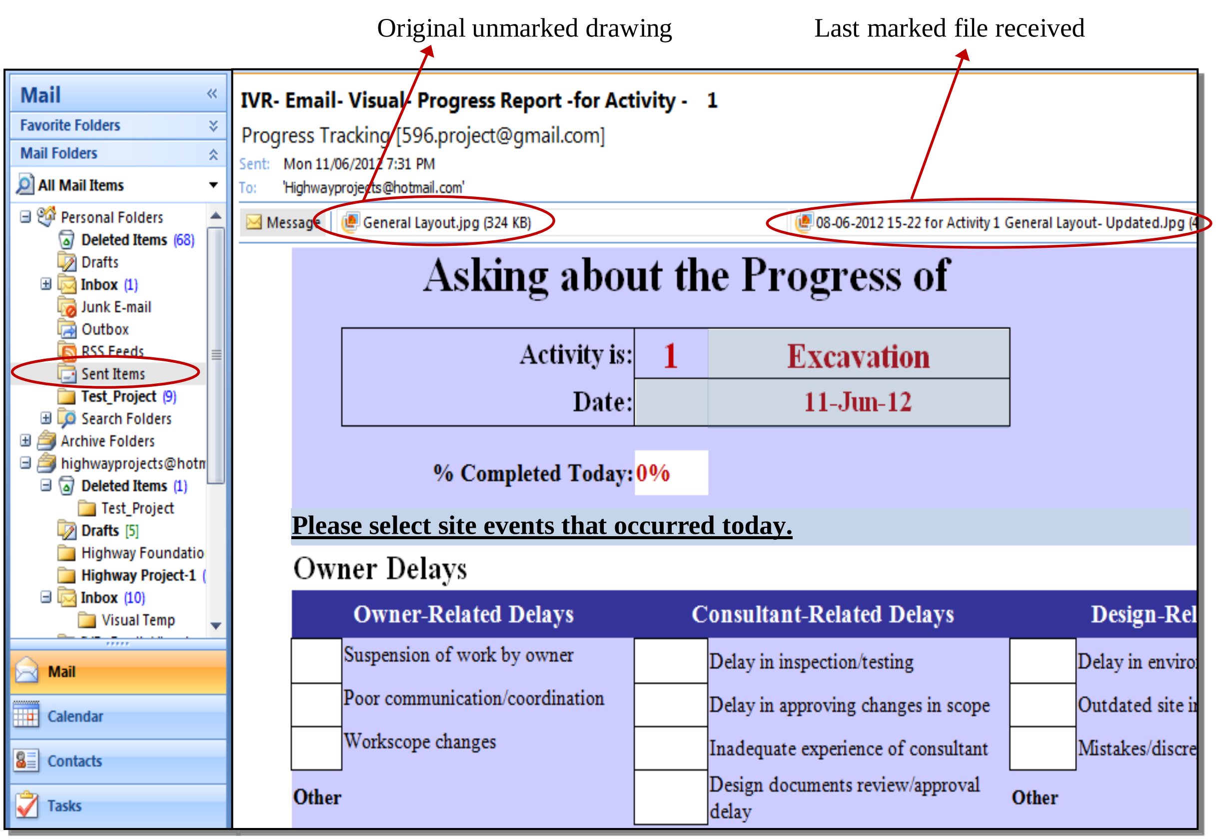


Figure 6.5: Progress Request Sent by Email.

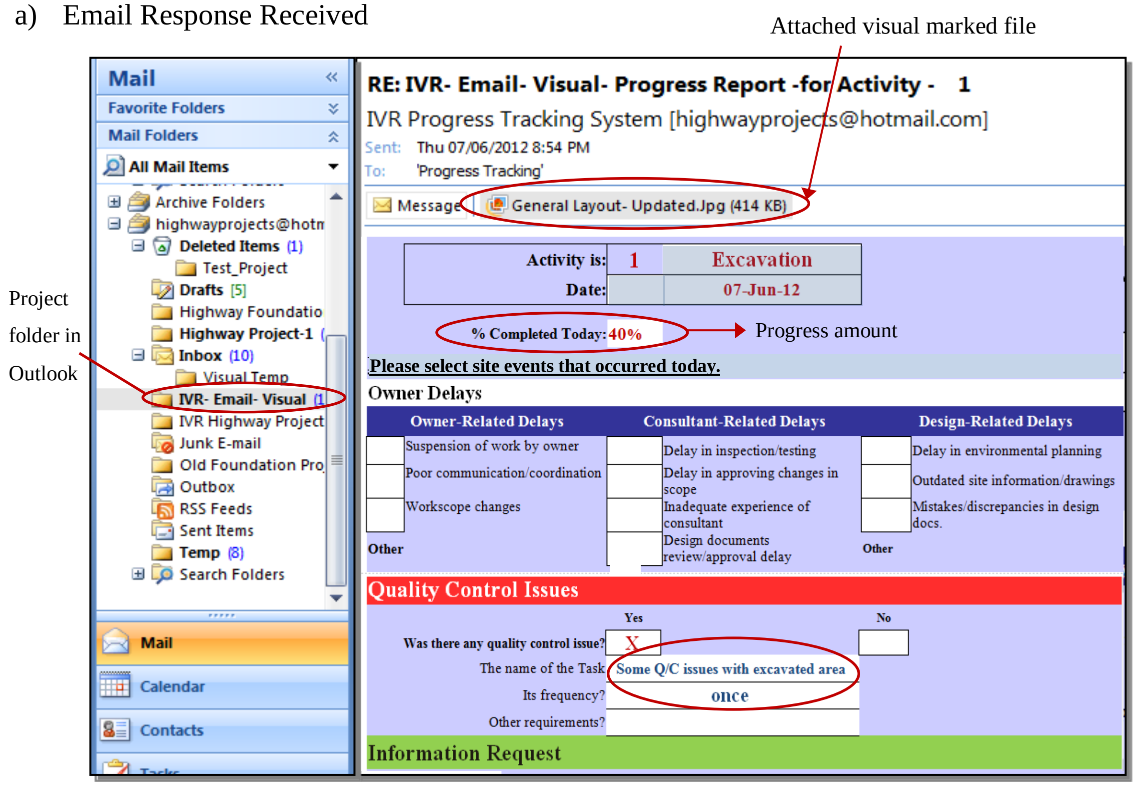
The system also attaches the related drawing files (the original unmarked drawing file and the last-marked file received from the supervisor) as shown at the top of Figure 6.5. The as-built details can be clearly documented by the supervisor, who can easily highlight the new progress visually on the attached drawing files and can add any comments or modifications.

- **Read Responses:** Once the supervisors reply to the phone calls, for example, their responses and any attachments are collected by the cloud-based service and then sent as email files to the project email account, as shown in Figure 6.6. The system then loads the latest email responses received and saves the information into the project database, along with other documents such as voice recordings, visual progress files, and other attachments.

  For example, for Excavation, progress of 40 % was reported on day 2 (June, 7) (Figure 6.6a), and a related quality control issue was also documented. The supervisor marked the progress visually on the visual file, as shown in Figure 6.7, in addition to adding a note that indicates the location associated with the quality control issue. On the same day, the system also received a progress report for the “Build Cap Forms” activity, which indicates slow progress of 10 %, with the reason attached as an audio file (A5.wav), as shown in Figure 6.6b. In this step, the system also automatically checks for any RFIs.

- **Respond to RFIs**: Upon receipt of an RFI, the system automatically forwards it to the phone or email of the responsible person, as identified in the project communication list. For example, the supervisor of the “Excavation” activity requested additional information about the exact depth of the excavation area, and the request has been sent to the person responsible for providing the missing information.

a) Email Response Received



b) IVR Response Received

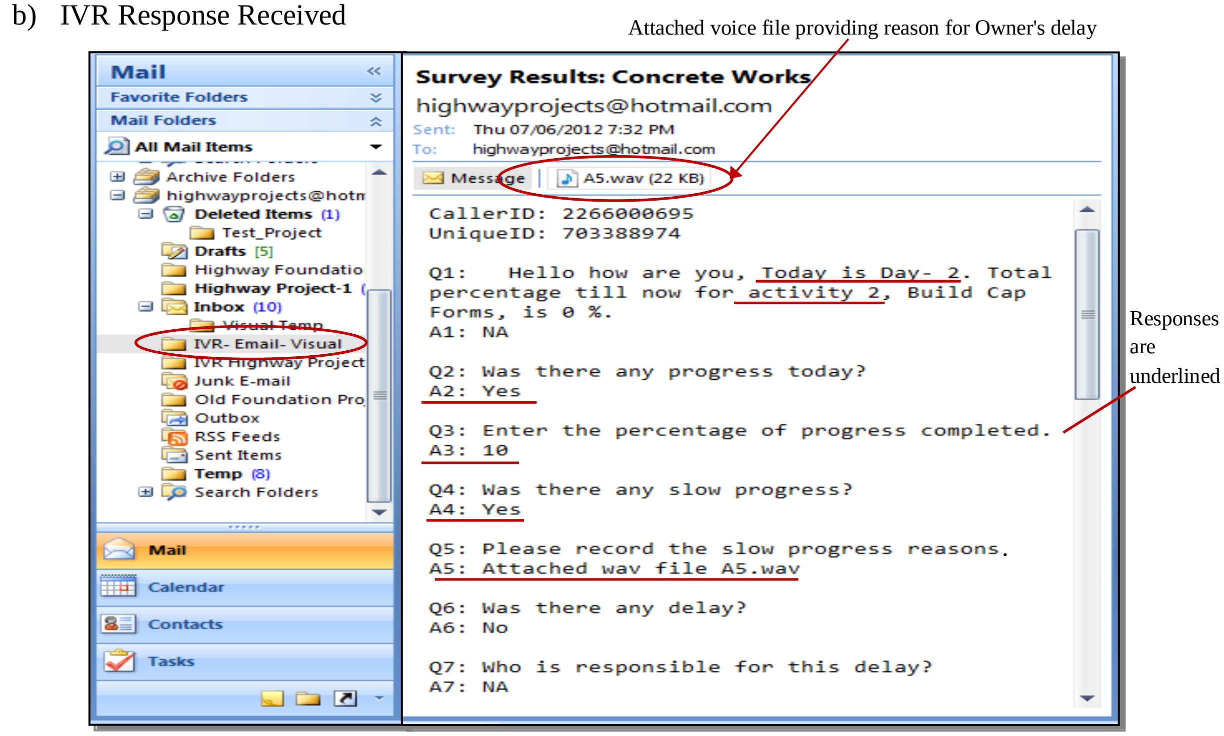


Figure 6.6: Responses Received and Saved in the Project Email Folder

The answers to the RFI are then automatically sent back to the supervisor. This bidirectional communication between the site and head office helps decision makers address the site issues raised as soon as they occur.

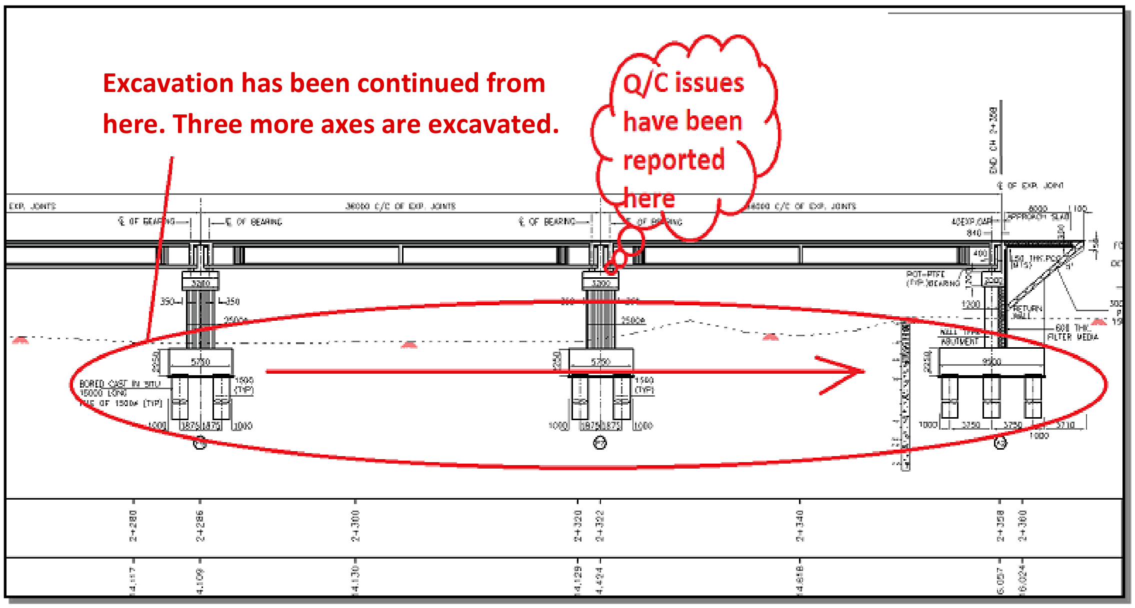


Figure 6.7: Visual Progress Marking for Excavation on Day 2

- **Update Project Information:** Upon reading the new as-built information, the system automatically updates the project schedule and, in a log of all communications, saves all information about the site events related to each activity, along with any attached files (Figure 6.8a). The MS Project file is updated with the cumulative percentage complete for each activity, adjusted according to the latest information received (Figure 6.8b), and a detailed CPS report is generated, which includes the evolution of all as-built events for each activity, as shown in Figure 6.8c. According to the updated schedule, the project duration is extended to 24 days (a delay of 2 days). At the end of day 1 (June 6th) the status of the "Excavation" and "Build Cap Forms" activities has been updated to show that "Excavation" entailed slow progress (10 % on day 1, as opposed to 50 % per the planned two-day duration). The reason for the slow progress was documented in the log of responses received and on the as-built schedule as "Shortage of labour" which is a contractor responsibility.

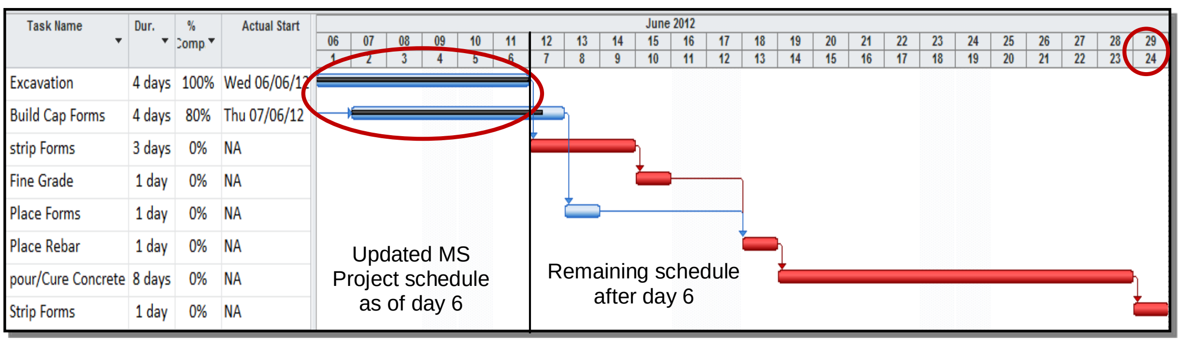
a) Partial Log of Resposes Received

Day 6

Act. No.	Description	Date	Progress Today %	Detailed File	Q/C Issues	Owner Delays	Contractor Delays	External Delays	Request For Information	Visual File	Comments	Accident Issues
2	Build Cap Forms	11/06/2012	40	Detailed File								
1	Excavation	11/06/2012	25	Detailed File						Visual File		
2	Build Cap Forms	08/06/2012	30	Detailed File							Slow Progress	
1	Excavation	08/06/2012	25	Detailed File					Excavation depth is unclear	Visual File	Slow Progress (1) Shortage of	
2	Build Cap Forms	07/06/2012	10	Detailed File							Slow Progress	
1	Excavation	07/06/2012	40	Detailed File	Q/C issues with excavated area					Visual File		
1	Excavation	06/06/2012	10	Detailed File						Visual File	Slow Progress (1) Shortage of	
2	Build Cap Forms	06/06/2012	0	Detailed File		Voice File						

Day1

b) Updated MS Project Schedule



c) As-Buit Evolution Report (CPS format)

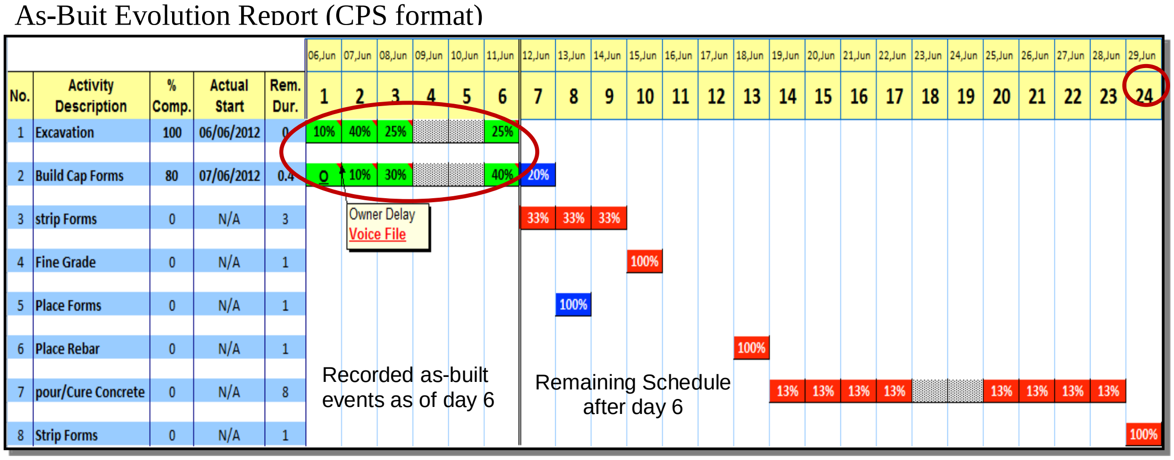


Figure 6.8: Log of Daily Site Information Received and Updated Schedule Reports

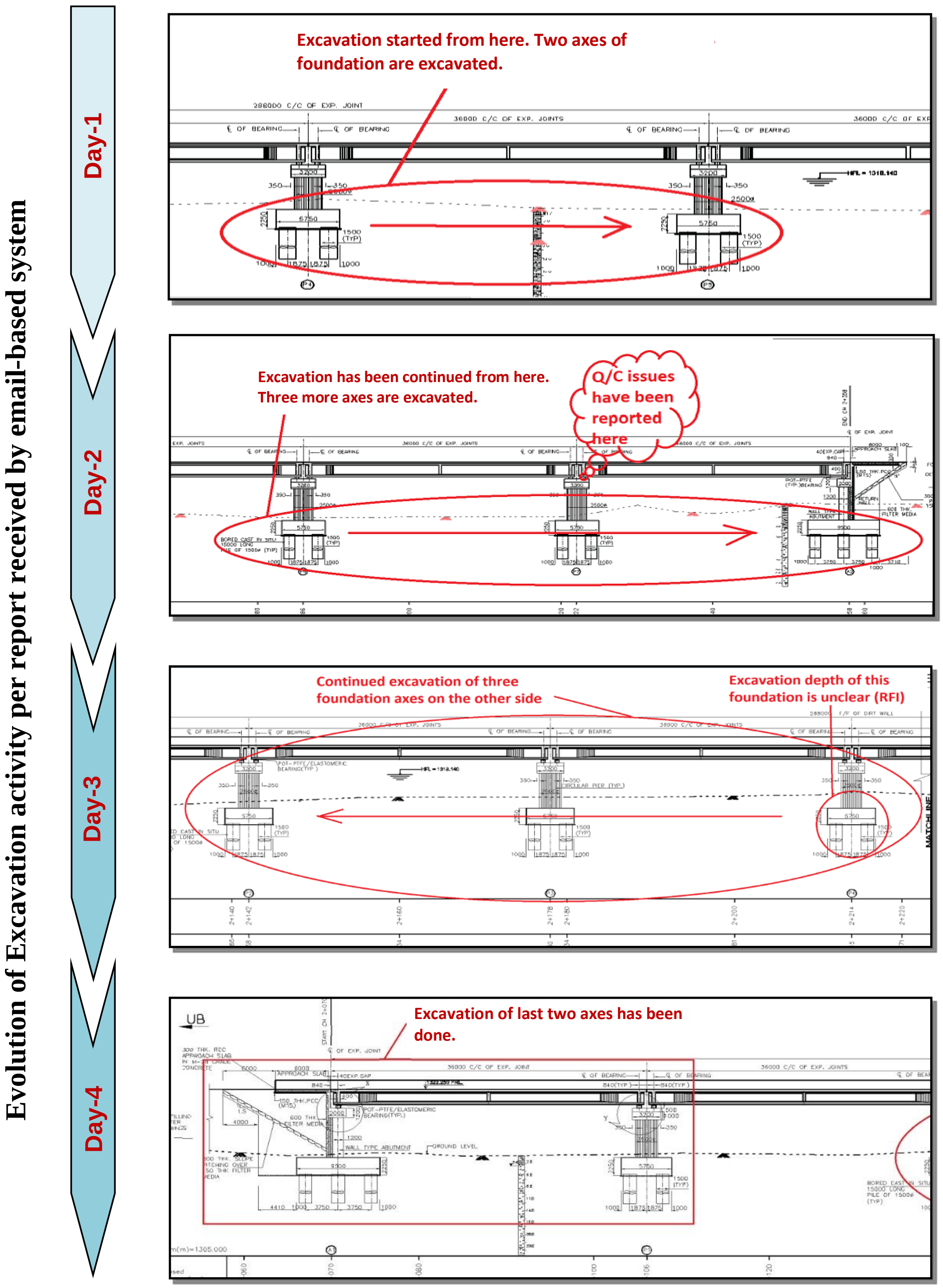


Figure 6.9: Visual Progress Evolution Report

6.3 System Performance

The prototype system for as-built documentation has been applied to a number of case studies in order to test its functionality and to determine potential improvements. The results are very promising with respect to collecting site information, updating the project schedule immediately, and visually representing all information received on annotated segments of each activity, all of which will greatly facilitate site data collection and save time for supervisors and head office staff.

The prototype has also been introduced to experts from three construction/consulting companies, in cooperation with the Waterloo Commercialization Office (WatCo). Three demonstration sessions were held so that the system could be explained to the industry professionals. They confirmed the potential of the system, and one company representative expressed interest in applying the system for a project in China.

The initial experiments showed that the system provides the expected benefits that derive from its structure and its implementation as an add-on to existing project management tools: the system can access resources such as the wide array of built-in features in MS Project as well as other easy-to-use procedures for defining activities and their relationships, for leveling project resources, and for handling large-size projects. The telephone component enables the use of a simple, widely available technology that expedites quick responses from the supervisors. Project activities have been programmed to include information about their progress status so that the progress tracking process can be initiated automatically, with bidirectional communication that facilitates fast responses to any RFIs. The system then automatically updates the schedule in MS Project and also generates a full as-built schedule report in CPS format.

The automated IVR system proved to be more interactive than static email and restricts the communication to only the relevant questions. Email, on the other hand, allows sufficient time for supervisors to consider their responses, rather than having to answer a phone call immediately. Integrating voice and email features thus combines the benefits of both and allows supervisors to select their preferred choice.

An additional advantage of the developed system is its inherently low costs, which involve only the expense of deploying the system in any organization at the beginning of a project plus the monthly subscription to the IVR cloud service, which is typically a reasonable amount of about $100 per month. No special equipment is needed for the supervisors since they use their own cellular phones. The benefits include the time saved by the elimination of manual data collection, the high quality and timeliness of the as-built information obtained, and the ability to respond quickly to urgent requests. Although the framework showed very promising results based on the benefits demonstrated through the case studies, it nevertheless should be assessed in actual site conditions in order to test its long-term performance in real-life environments.

The developed system setup and features can be summarized as follows:

- The framework can be implemented at head office as an automated system that does not require staffing at any time.
- The system can be configured so that the supervisor can call/email the head office system at any time at his/her convenience (e.g., after hours) in order to complete a daily progress update or to request information.
- The system can be configured so that the information associated with the activities themselves automatically triggers the initiation of calls/emails to multiple supervisors simultaneously.
- As soon as the IVR/email progress tracking session has been completed by the supervisor, all responses and supporting documents are automatically read by the system, and the schedule is then updated at head office.

- If the supervisor asks for information, the request is sent to the appropriate party, and the responses are then sent back to the supervisor.
- The visual marking system works bidirectionally and is linked to both the activities and the time segments.
- A complete log of all communications is kept on file.
- The schedule is always updated, with legible representation of the as-built information received so that timely corrective action can be determined.

6.4 Conclusion

This chapter has discussed a combination of email, IVR, and visual marking for the development of an enhanced framework for the automated collection of site data. This combination has proven to have significant potential for minimizing the time and costs associated with the collection of site data. The enhanced prototype has been applied as an add-on to MS Project so that the system identifies eligible activities for progress tracking and triggers emails/calls for progress, receives data, updates the schedule, and links all data received directly to the annotated daily segments for each activity. Combining email and IVR allows supervisors to choose their preferred contact method and to enter visual representations of the completed work by marking the elements accomplished for each activity, along with their location. The visual progress files received indicate the evolution of the progress of the activities, which helps project participants easily form a complete picture of the finished work to date. In addition, all as-built details received (e.g., work percentage completed, site events, visual progress files, and other comments) are saved automatically in a communication log report and attached to the relevant daily segments for each activity in order to provide full as-built documentation that can facilitate accurate schedule and delay analysis.

Chapter 7
Conclusion

7.1 Conclusion

The research presented in this thesis represents an effort to automate the documentation of construction as-built progress and the site events associated with all parties involved in the day-to-day execution of construction projects. The research has provided a structured systems approach to the utilization of a variety of low-cost communication tools commonly used by individuals (e.g., phone and email) in order to provide a project-wide interactive bidirectional communication system between site personnel and head office. The first step was an analysis of the challenges associated with manual as-built tracking and a determination of the level of detail required for documenting as-built data on the schedule. An additional requirement was a detailed understanding of site information, tracking needs, and possible site events related to a variety of activities. With a focus on highway projects, sample daily as-built forms were collected and analyzed and the related literature was analyzed. Based on this background, activity-specific site events related to the owner, contractor, and third party; measurement units; and construction considerations were identified for each activity. This information was used for the design of activity-specific tracking forms that facilitate the collection of as-built details using email or IVR. These forms were then refined based on input from construction experts. Activity call-flow diagrams were developed accordingly, including a logical sequence of questions related to each activity so that as-built information (progress amounts, site events, quality control issues, RFIs, etc.) can be tracked by telephone, with a minimum number of questions, thus facilitating the simple and quick collection of as-built information.

For practical reasons and so that the system would be applicable for any project, a prototype framework was designed and implemented as an add-on to Microsoft Project software. The first version of the prototype utilized only email technology for automating the data collection. The framework was then modified so that IVR alone was used for bidirectional communication between the site and head office, which enables the documentation of as-built details directly on the schedule. Compared with lengthy email messages, IVR sessions are interactive and omit irrelevant questions. Based on the user's answer, the system dynamically triggers the appropriate branch in the call-flow diagram so that the IVR sessions are dynamically responsive to the user's answers, which saves data collection time. In the final version of the prototype, email, IVR, and visual marking tools were combined in order to enhance the automation of the as-built documentation, to combine the benefits of all of the tools, and to allow supervisors to choose their preferred contact method. The ability to highlight progress visually helps project participants to easily understand the amount of work completed to date, to take better-informed corrective action, and to record the evolution of all as-built information associated with the project. The developed automated system eliminates the need for site personnel to be trained, automatically documents activity progress and site events, and links the most recent updates directly to the relevant time segment on the schedule.

The prototype of the as-built documentation system was applied for a number of case studies as a means of testing its functionality and determining potential improvements. The initial experiments showed that the system offers a number of benefits related to its structure and its implementation as an add-on to existing project management tools. The full functional prototype was also demonstrated to a number of professionals in the construction industry, who confirmed its ease of use and substantial potential for providing time and cost savings.

While existing commercial project management software offers tools for the collection of site data, the information recorded by these systems is saved in separate isolated forms and does not appear directly on the schedule. They thus fail to provide timely schedule updates or legible schedule reports that indicate a total picture of the evolution of the work progress for decision makers. They are also often unable to provide immediate bidirectional communication between site personnel and head office so that urgent RFIs can be answered quickly. This research has addressed these limitations through the development of an integrated framework that utilizes low-cost tools for providing interactive documentation and visual representation of the evolution of as-built details dynamically on a legible representation of the schedule. The framework has been uniquely designed for bidirectional voice/email communication. It allows the eligible activities on the office server to automatically initiate requests for progress reports from the appropriate supervisors but can also be configured to enable the supervisors to initiate the calls/emails in order to provide progress updates.

7.2 Research Contributions

This research has the potential to minimize the substantial time and costs associated with the collection of site information, the updating of the project schedule, the accurate analysis of progress information, and the facilitation of corrective action. This research automates the process of superimposing variety of as-built details, directly on the schedule, with their accurate timings. In essence, this research has made the following specific contributions:

- **Enhancement of the understanding of as-built tracking needs:** This research has provided an in-depth review of the challenges associated with the documentation of as-built details, the level of detail required for documenting as-built data on the schedule, and the site information categories that must be tracked. The study focused on the tracking needs for highway construction projects. Based on this analysis, activity-specific tracking forms were created that will dynamically guide the data collection process.
- **Development of activity-specific dynamic flow diagrams:** This research has provided activity-specific call-flow diagrams that direct the collection of site data by telephone. These flow diagrams include a logical and dynamic sequence of questions related to each activity so that

complete as-built information (progress amounts, site events, quality control issues, RFIs, etc.) can be tracked simply and quickly.

- **Use of the schedule as a basis for communication and as-built documentation:** This research provides a new approach that uses the schedule not as a static report but as a visualization and decision-support tool for collecting and representing site information. For eligible activities, the customized scheduling engine initiates requests for progress updates, receives data, and updates the schedule, with all data linked directly to the annotated daily segments for each activity.

- **Documentation of site events and their timing directly on the schedule:** The developed framework automatically generates as-built reports that employ CPS representation to clearly show the evolution of all as-built events and their accurate timing on the daily segments for each activity. Such information-rich representation helps decision makers easily follow the progress of the project and greatly facilitates accurate schedule forensics and delay analysis.

- **Automation of as-built documentation through the integration of voice, email, and visual marking:** This research has developed a cost-effective approach for integrating email, IVR, and visual marking for the automatic capture of complete and timely as-built details.

- **Development of a central depository/log of as-built documentation:** The framework provides decision makers with a complete daily log of all as-built details received for associated activities, including actual site events, attached files, hyperlinks to email response files, and visual progress files.

- **Automation of bidirectional communication:** The developed framework has the potential to immediately link site personnel with head office, provide timely information for decision makers, and furnish immediate responses to urgent needs or requests for information. This feature will increase project productivity and help prevent many of the problems associated with construction projects.

- **Enhancement of existing scheduling tools:** Compared to traditional methods, in which the schedule is merely a passive report that is often used for presentation purposes, the developed add-on framework converts the schedule into a rich medium for the enhancement of documentation, visualization, schedule analysis, and decision making.

7.3 Future Research

Several aspects of the developed system could be improved through further research. To upgrade the capabilities of the current system and enhance its practicality for real construction projects, the following areas are recommended for further study:

- Experiment with the developed system on real construction projects.
- Check the accuracy and usefulness of received information to help decision makers solve immediate construction problems and later for maintenance.
- Apply the system for other types of projects (e.g., building projects).
- Extend the functions to include the automatic documentation of the daily usage of all types of resources.
- Incorporate a provision for a variable frequency of progress-tracking (daily, weekly, etc.), which can be applied to different activities according to the specific associated needs and which will reduce the effort required for the daily collection of data.
- Extend the communication system by incorporating a supervisor follow-up and reminder system in order to avoid delays related to data collection.

- Extend the as-built documentation to include not only events that affect the schedule (as is currently the case) but also other important information, such as the changes related to dimensions, material properties, specifications, and operational parameters.
- Extend the activity-specific tracking forms to include additional site information categories, such as resource information and usage, safety issues, and accident reports.
- Integrate the system with other technologies such as GIS and resource-tracking tools such as RFID.
- Incorporate procedures for accurate schedule analysis and the optimization of corrective action (e.g., CPS analysis) in order to support decision makers for recovering delays and keeping projects on track.
- Incorporate detailed Earned Value (EV) analysis as a means of calculating activity progress and cost variances. In the case of a major variance, the system may automatically initiate an additional request to the activity supervisor asking for verification and reconfirmation of the schedule information.
- Expand the scheduling engine in order to address projects that involve linear and/or repetitive activities.

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Appendix A

Activity-Specific Email Forms

Asking about the Progress of

Activity is: 1 Survey & Stacking
Date: 20-Jul-11

% Completed Today: 0%

Please select site-events experinced today

Owner Delays

Owner-Related Delays	Consultant-Related Delays	Design-Related Delays
Poor communication/coordination	Delay in approving changes in scope	Delays in environmental planning
Suspension of work by owner	Design documents review/approval delay	Outdated site information/drawings
Workscope changes	Poor communication/coordination	Errors/discrepancies in design docs.
Other	Inadequate experience of consultant	Other
	Other	

Contractor Delays

Contractor-Related Delays	Material-Related Delays	Labor-Related Delays
Delay/error in benchmark setup	Delay in material delivery	Shortage of labors
Difficulties in site topograpy	Other	Unqualified workforce
Rework due to errors	**Equipment-Related Delays**	Low productivity level of labors
Poor site management/coordination	Shortage of equipment	Personal conflicts among labors
Unrealistic planning/scheduling	Lack of high-technology	Other
Difficulties in financing project	Delay in equipment delivery	
Other	Other	

External Delays

Diffuculities in site topography	Unavailability/Delay of site utilities
Differing site conditions	Traffic restrictions at job site
Accident during construction	Other
Bad weather	

Quality Control Issues

	Yes	No
Was there any quality control issue?		

The name of the Task
Its frequency?
Other requirements?

Information Request

	Yes	No
Is there any request for information?		

The required information ?
Other requirements?

Comments

Slow Progress	Accelaration

Reasons?
Reasons?
Other Comments

Site Information Tracking Form for "Survey & Stacking"

Asking about the Progress of

Activity is:	1	Moblization
Date:	20-Jul-11	

% Completed Today: 0%

Please select site-events experinced today

Owner Delays

Owner-Related Delays	Consultant-Related Delays	Design-Related Delays
Delay in site handover /access	Delay in inspection/testing	Insufficient site investigation prior design
Poor communication/coordination	Delay in approving changes in scope	Delays in environmental planning
Suspension of work by owner	Equip./material approval delay	Outdated site information/drawings
Workscope changes	Poor communication/coordination	Errors/discrepancies in design docs.
Other	Design documents review/approval delay	Other
	Inadequate experience of consultant	
	Other	

Contractor Delays

Contractor-Related Delays	Material-Related Delays	Labor-Related Delays
Poor site management/coordination	Delay in material delivery	Shortage of labors
Difficulties in financing project	Other	Unqualified workforce
Rework due to errors	Other	Low productivity level of labors
Unrealistic planning/scheduling	**Equipment-Related Delays**	Other
Poor qualification of technical staff	Shortage of equipment	
Poor safety management	Lack of high-technology	
Delay in site utitities	Delay in equipment delivery	
Other	Other	

External Delays

Objections from local residents	Effect of social and cultural factors
Delay in obtaining permits	Traffic restrictions at job site
Bad weather	Accident during construction
Unavailability/Delay of site utilities	Other

Quality Control Issues

	Yes	No
Was there any quality control issue?		
The name of the Task		
Its frequency?		
Other requirements?		

Information Request

	Yes	No
Is there any request for information?		
The required information ?		
Other requirements?		

Comments

	Slow Progress	Accelaration
Reasons?		
Reasons?		
Other Comments		

Site Information Tracking Form for "Mobilization"

Asking about the Progress of

Activity is:	2	Clearing & Grubbing
Date:	20-Jul-11	

% Completed Today: 0%

Please select site-events experinced today

Owner Delays

Owner-Related Delays	Consultant-Related Delays	Design-Related Delays
Late permits of ROW	Late approval	Delays in environmental planning
Poor communication/coordination	Poor communication/coordination	Outdated site information/drawings
Suspension of work by owner	Inadequate experience	Other
Workscope changes	Other	
Other		

Contractor Delays

Contractor-Related Delays	Equipment-Related Delays	Labor-Related Delays
Distant disposal area	Equipment breakdowns	Shortage of labors
Difficulties in financing project	Shortage of equipment	Unqualified workforce
Rework due to errors	Unskilled equipment-operators	Low productivity level of labors
Conflicts b/w contractor and others	Low productivity/efficiency	Other
Poor site management/coordination	Lack of high-technology	
Unrealistic planning/scheduling	Other	
Unappropriate location of stockpile		
Delays/errors by sub-contractors		
Other		

External Delays

Differing site conditions	Effect of social and cultural factors	Other
Accident during construction	Traffic restrictions at job site	
Bad weather	Unforssen events	

Quality Control Issues

	Yes	No
Was there any quality control issue?		
The name of the Task		
Its frequency?		
Other requirements?		

Information Request

	Yes	No
Is there any request for information?		
The required information ?		
Other requirements?		

Comments

	Slow Progress	Accelaration
Reasons?		
Reasons?		
Other Comments		

Site Information Tracking Form for "Clearing & Grubbing"

Asking about the Progress of

Activity is:	1	Excavation
Date:		05-Dec-11

% Completed Today: 0%

Please select site-events experinced today

Owner Delays

Owner-Related Delays	Consultant-Related Delays	Design-Related Delays
Suspension of work by owner	Delay in inspection/testing	Delay in environmental planning
Communication/coordination	Delay in approving changes in scope	Outdated information/drawings
Workscope changes	Inadequate experience of consultant	Mistakes in design docs.
Other	Design documents review/approval delay	Other
	Other	

Contractor Delays

Contractor-Related Delays

- Damage to underground utilities
- Distant disposal site
- Poor site layout
- Difficulties in financing project
- Rework due to errors
- Conflicts with others
- Site management/coordination
- Unrealistic planning/scheduling
- Qualification of technical staff

- Delay/errors by sub-contractors
- Other

Equipment-Related Delays

- Equipment breakdowns
- Shortage of equipment
- Low productivity/efficiency
- Lack of high-technology
- Other

Labor-Related Delays

- Shortage of labors
- Unqualified workforce
- Productivity level of labors
- Conflicts among labors
- Other

External Delays

- Objections from local residents
- Difficult work condition
- Bad weather
- Unavailability/Delay of site utilities
- Traffic restrictions at job site
- Accident during construction
- Other

Quality Control Issues

	Yes	No
Was there any quality control issue?		

The name of the Task

Its frequency?

Other requirements?

Information Request

	Yes	No
Is there any request for information?		

The required information ?

Other requirements?

Comments

Slow Progress	Acce-laration

Reasons?

Reasons?

Other Comments

Site Information Tracking Form for "Excavation"

Asking about the Progress of

Activity is:	6	Underground Utilities
Date:	20-Jul-11	

% Completed Today: 0%

Please select site-events experinced today

Owner Delays

Owner-Related Delays	Consultant-Related Delays	Design-Related Delays
Change orders by owner	Delay in inspection/testing	Delay in design
Late approval by owner	Delay in approving changes in scope	Outdated site information/drawings
Poor communication/coordination	conflict b/w consultant and designer	Mistakes/discrepancies in design docs.
Suspension of work by owner	Poor communication/coordination	Other
Workscope changes	Design documents review/approval delay	
Other	Inadequate experience of consultant	
	Other	

Contractor Delays

Contractor-Related Delays	Material-Related Delays	Labor-Related Delays
Utility is not protected as required	Delay in material delivery	Shortage of labors
Relocation for utilities	Shortage of suitable materials in market	Unqualified workforce
Difficulties in financing project	Changes in material specifications	Low productivity level of labors
Rework due to errors	Other	Other
Conflicts b/w contractor and others	**Equipment-Related Delays**	
Poor site management/coordination	Equipment breakdowns	
Delay/errors by sub-contractors	Shortage of equipment	
Unrealistic planning/scheduling	Unskilled equipment-operators	
Poor qualification of technical staff	Low productivity/efficiency	
Poor site layout	Lack of high-technology	
Other	Other	

External Delays

Traffic restrictions at job site	Unavailability/Delay of site utilities
Bad weather	Accident during construction
Unforseen site events	Other

Quality Control Issues

Yes No

Was there any quality control issue?

The name of the Task

Its frequency?

Other requirements?

Information Request

Yes No

Is there any request for information?

The required information ?

Other requirements?

Comments

Slow Progress Accelaration

Reasons?

Reasons?

Other Comments

Site Information Tracking Form for "Underground Utilities"

Asking about the Progress of

Activity is:	5	Grading
Date:	20-Jul-11	

% Completed Today: 0%

Please select site-events experinced today

Owner Delays

Owner-Related Delays	Consultant-Related Delays	Design-Related Delays
Change orders by owner	Delay in inspection/testing	Insufficient investigation prior design
Late approval by owner	Delay in approving changes in scope	Outdated site information/drawings
Poor communication/coordination	Inadequate experience of consultant	Mistakes/discrepancies in design docs.
Suspension of work by owner	Poor communication/coordination	Other
Workscope changes	Design documents review/approval delay	
Other	Other	

Contractor Delays

Contractor-Related Delays	Material-Related Delays	Equipment-Related Delays
Difficulties in financing project	Delay in material delivery	Equipment breakdowns
Rework due to errors	Shortage of suitable materials in market	Shortage of equipment
Delay/errors by sub-contractors	Changes in material specifications	Low productivity/efficiency
Poor site management/coordination	Other	Lack of high-technology
Unrealistic planning/scheduling	**Labor-Related Delays**	Other
Poor qualification of technical staff	Shortage of labors	
Other	Unqualified workforce	
	Low productivity level of labors	
	Other	

External Delays

Traffic restrictions at job site	Accident during construction
Differing site condition	Other
Bad weather	

Quality Control Issues

	Yes	No
Was there any quality control issue?		
The name of the Task		
Its frequency?		
Other requirements?		

Information Request

	Yes	No
Is there any request for information?		
The required information ?		
Other requirements?		

Comments

	Slow Progress	Accelaration
Reasons?		
Reasons?		
Other Comments		

Site Information Tracking Form for "Base or Sub-base"

Asking about the Progress of

Activity is:	9	Noise Barriars
Date:		20-Jul-11

% Completed Today: 0%

Please select site-events experinced today

Owner Delays

Owner-Related Delays	Consultant-Related Delays	Design-Related Delays
Change orders by owner	Delay in inspection/testing	Delay in design
Late approval by owner	Delay in approving changes in scope	Outdated site information/drawings
Poor communication/coordination	Inflexibility (rigidity) of consultant	Errors or discrepancies in design docs.
Suspension of work by owner	Poor communication/coordination	Other
Change in decision making authority	Design documents review/approval delay	
Workscope changes	conflict b/w consultant and designer	
Other	Inadequate experience of consultant	
	Other	

Contractor Delays

Contractor-Related Delays	Material-Related Delays	Labor-Related Delays
Difficulties in financing project	Delay in material delivery	Shortage of labors
Rework due to errors	Shortage of suitable materials in market	Unqualified workforce
Poor qualification of technical staff	Changes in material specifications	Low productivity level of labors
Delay/errors by sub-contractors	Other	Personal conflicts among labors
Poor site management/coordination	**Equipment-Related Delays**	Other
Unrealistic planning/scheduling	Equipment breakdowns	
Poor site layout	Shortage of equipment	
Other	Low productivity/efficiency	
	Lack of high-technology	
	Other	

External Delays

Objections from local residents	Effect of social and cultural factors
Delay in obtaining permits	Traffic restrictions at job site
Bad weather	Accident during construction
Unavailability/Delay of site utilities	Other

Quality Control Issues

	Yes	No
Was there any quality control issue?		
The name of the Task		
Its frequency?		
Other requirements?		

Information Request

	Yes	No
Is there any request for information?		
The required information ?		
Other requirements?		

Comments

	Slow Progress	Accelaration
Reasons?		
Reasons?		
Other Comments		

Site Information Tracking Form for "Noise Barriers"

Asking about the Progress of

Activity is:	8	Concrete Works
Date:		20-Jul-11

% Completed Today: 0%

Please select site-events experinced today

Owner Delays

Owner-Related Delays	Consultant-Related Delays	Design-Related Delays
Late approval by owner	Delay in inspection/testing	Delay in design
Workscope changes	Delay in approving changes in scope	Outdated site information/drawings
Poor communication/coordination	Poor communication/coordination	Errors/discrepancies in design docs.
Suspension of work by owner	Design documents review/approval delay	Other
Change in decision making authority	Inadequate experience of consultant	
Other	Other	

Contractor Delays

Contractor-Related Delays	Material-Related Delays	Equipment-Related Delays
Bad-surface preparation for paving	Delay in material delivery	Asphalt paver breakdowns
Difficulties in financing project	Shortage of suitable materials in market	Shortage of equipment
Rework due to errors	Changes in material specifications	Low productivity/efficiency
Poor site management/coordination	Other	Lack of high-technology
Unrealistic planning/scheduling	**Labor-Related Delays**	Other
Poor qualification of technical staff	Shortage of labors	
Delay/errors by sub-contractors	Unqualified workforce	
Other	Low productivity level of labors	
	Other	

External Delays

Traffic restrictions at job site	Objections from local residents
Bad weather	Accident during construction
Other	

Quality Control Issues

	Yes	No
Was there any quality control issue?		
The name of the Task		
Its frequency?		
Other requirements?		

Information Request

	Yes	No
Is there any request for information?		
The required information ?		
Other requirements?		

Comments

	Slow Progress	Acce-laration
Reasons?		
Reasons?		
Other Comments		

Site Information Tracking Form for "Concrete Works"

Asking about the Progress of

Activity is: 7 **Paving**

Date:

% Completed Today: 0%

Please select site-events experinced today

Owner Delays

Owner-Related Delays	Consultant-Related Delays	Design-Related Delays
Late approval by owner	Delay in inspection/testing	Delay in design
Workscope changes	Delay in approving changes in scope	Outdated site information/drawings
Poor communication/coordination	Poor communication/coordination	Errors/discrepancies in design docs.
Suspension of work by owner	Design documents review/approval delay	**Other**
Change in decision making authority	Inadequate experience of consultant	
Other	**Other**	

Contractor Delays

Contractor-Related Delays	Material-Related Delays	Labor-Related Delays
Bad-surface preparation for paving	Delay in material delivery	Shortage of labors
Difficulties in financing project	Shortage of suitable materials in market	Unqualified workforce
Rework due to errors	Changes in material specifications	Low productivity level of labors
Poor site management/coordination	**Other**	**Other**
Unrealistic planning/scheduling	**Equipment-Related Delays**	
Poor qualification of technical staff	Asphalt paver breakdowns	
Delay/errors by sub-contractors	Shortage of equipment	
Other	Low productivity/efficiency	
	Lack of high-technology	
	Other	

External Delays

Traffic restrictions at job site	Objections from local residents
Bad weather	Accident during construction
Other	

Quality Control Issues

	Yes	No
Was there any quality control issue?		
The name of the Task		
Its frequency?		
Other requirements?		

Information Request

	Yes	No
Is there any request for information?		
The required information ?		
Other requirements?		

Comments

	Slow Progress	Accelaration
Reasons?		
Reasons?		
Other Comments		

Site Information Tracking Form for "Paving Works"

Asking about the Progress of

Activity is:	9	Signage
Date:		20-Jul-11

% Completed Today: 0%

Please select site-events experinced today

Owner Delays

Owner-Related Delays	Consultant-Related Delays	Design-Related Delays
Change orders by owner	Delay in inspection/testing	Delay in design
Late approval by owner	Delay in approving changes in scope	Outdated site information/drawings
Poor communication/coordination	Poor communication/coordination	Errors/discrepancies in design docs.
Suspension of work by owner	Design documents review/approval delay	**Other**
Change in decision making authority	conflict b/w consultant and designer	
Workscope changes	Inadequate experience of consultant	
Other	**Other**	

Contractor Delays

Contractor-Related Delays	Material-Related Delays	Equipment-Related Delays
Sign works Error	Delay in material delivery	Equipment breakdowns
Rework due to errors	Shortage of suitable materials in market	Shortage of equipment
Poor site management/coordination	Changes in material specifications	Low productivity/efficiency
Ineffective planning/scheduling	**Other**	Lack of high-technology
Poor qualification of technical staff	**Labor-Related Delays**	**Other**
Delay/errors by sub-contractors	Shortage of labors	
Difficulties in financing project	Unqualified workforce	
Other	Low productivity level of labors	
	Other	

External Delays

Traffic restrictions at job site	Bad weather	**Other**
Accident during construction	Unforseen site events	

Quality Control Issues

	Yes	No
Was there any quality control issue?		
The name of the Task		
Its frequency?		
Other requirements?		

Information Request

	Yes	No
Is there any request for information?		
The required information ?		
Other requirements?		

Comments

	Slow Progress	Accelaration
Reasons?		
Reasons?		
Other Comments		

Site Information Tracking Form for "Electrical & Signage"

Asking about the Progress of

Activity is:	10	Landscaping
Date:	20-Jul-11	

% Completed Today: 0%

Please select site-events experinced today

Owner Delays

Owner-Related Delays	Consultant-Related Delays	Design-Related Delays
Change orders by owner	Delay in inspection/testing	Delay in design
Late approval by owner	Delay in approving changes in scope	Outdated site information/drawings
Poor communication/coordination	Poor communication/coordination	Mistakes/discrepancies in design docs.
Suspension of work by owner	Design documents review/approval delay	**Other**
Workscope changes	Inadequate experience of consultant	
Other	**Other**	

Contractor Delays

Contractor-Related Delays	Material-Related Delays	Labor-Related Delays
Difficulties in financing project	Delay in material delivery	Shortage of labors
Rework due to errors	Shortage of suitable materials in market	Unqualified workforce
Poor site management/coordination	Changes in material specifications	Low productivity level of labors
Unrealistic planning/scheduling	**Other**	Personal conflicts among labors
Poor qualification of technical staff	**Equipment-Related Delays**	**Other**
Delay/errors by sub-contractors	Equipment breakdowns	
Other	Shortage of equipment	
	Low productivity/efficiency	
	Lack of high-technology	
	Other	

External Delays

Delay in obtaining permits	Traffic restrictions at job site
Bad weather	Accident during construction
Effect of social and cultural factors	**Other**

Quality Control Issues

	Yes	No
Was there any quality control issue?		
The name of the Task		
Its frequency?		
Other requirements?		

Information Request

	Yes	No
Is there any request for information?		
The required information ?		
Other requirements?		

Comments

	Slow Progress	Accelaration
Reasons?		
Reasons?		
Other Comments		

Site Information Tracking Form for "Landscaping"

Bituminous Pavement Construction Inspection Checklist

New Pavement

Yes	No	N/A	
			(1) Has the subgrade been constructed to the proper lines and grades?
			(2) Has the subgrade been proof-rolled?
			(3) Did the dump truck used to proof-roll the subgrade weigh at least 37 tons?
			(4) Was excessive rutting or deflection observed during the proof-roll?
			(5) Have soft or wet areas in the subgrade been observed?
			(6) Have soft areas and areas that rutted during proof-rolling been stabilized?
			(7) Do the Contract Documents specify construction of subbase?
			(8) Is cement modification or lime stabilization of the subgrade required?
			(9) If cement modification or lime stabilization of the subgrade is required, have the revised Proctor curves and lime/cement application rates been submitted?
			(10) Has the Contractor submitted the required material certifications, aggregate sieve analysis, and asphalt mix formulas?
			(11) Have the appropriate approvals been received for the above submittals?
			(12) Is the granular base course being properly placed and compacted?
			(13) Is the DGA at the proper moisture content during placement and compaction?
			(14) Have "No Parking" signs been erected at least 24 hours prior to paving?
			(15) Prior to placing the surface course, is the asphalt base course being cleaned and treated with tack coat?
			(16) Is the tack coat allowed to "break" prior to placing the surface course?
			(17) Are the asphalt base and surface courses being placed with equipment and machinery meeting the requirements of the Contract Documents?
			(18) Is the asphalt mix being properly rolled so that it is compacted to the required thickness?
			(19) Does all asphalt mix delivered to the site appear to be acceptable with respect to color, texture, asphalt content, and temperature?

Existing Pavement

Yes	No	NA	
			(1) Are all areas of pavement repair being cut back properly in straight lines so that joints between existing and new pavements will be smooth and continuous?
			(2) Do the pavement cut-backs conform to the Contract Documents and the LFUCG Standard Drawings?
			(3) Is the pavement being cut with a pavement saw?
			(4) Within the area of the cut-back, has the pavement been replaced in accordance with the Contract Documents and the LFUCG Standard Drawings?
			(5) In areas to be completely resurfaced, are edge keys properly constructed where old and new pavements are joined?
			(6) If required, have all manholes, storm sewer inlets, and catch basins been adjusted to the proper elevation?
			(7) If necessary, have wedges or leveling courses been placed properly?
			(8) Have all requirements of the Contract Documents been met regarding the placement of the driveway wedges and adjustment to pavement shoulders?

Bituminous Pavement Construction Check List

Appendix B

Activity-Specific Call-Flow Diagrams

#	Question	Question Type	Answer Choices
1	{Message}	Prompt Only	
2	Was there any progress today?	Yes/No	Yes (Skip to Q:3) No (Skip to Q:7)
3	Enter the percentage of progress completed.	Number	
4	Was there any slow progress?	Yes/No	Yes (Skip to Q:5) No (Skip to Q:6)
5	Please record the slow progress reasons?	Open Ended (Recorded)	
6	Was there any delay?	Yes/No	Yes (Skip to Q:7) No (Skip to Q:14)
7	Who is responsible for this delay?	Multiple Choice	Contractor (Skip to Q:8) Owner (Skip to Q:10) ThirdParty (Skip to Q:12)
8	What are reasons for the contractor delay?	Multiple Choice	Error in benchmarking (Skip to Q:14) Unqualified workforce (Skip to Q:14) Other (Skip to Q:9)
9	Please specify delay reasons?	Open Ended (Recorded)	
10	What are reasons for the owner delay?	Multiple Choice	Approval delay (Skip to Q:14) Modifications in drawings or specifications (Skip to Q:14) Other (Skip to Q:11)
11	Please specify delay reasons?	Open Ended (Recorded)	
12	What are reasons for the third-party delay?	Multiple Choice	Bad weather (Skip to Q:14) Other (Skip to Q:13)
13	Please specify delay reasons?	Open Ended (Recorded)	
14	Were there any quality control issues?	Yes/No	Yes (Skip to Q:15) No (Skip to Q:16)
15	Please identify the Q/C issues during this period	Open Ended (Recorded)	
16	Is a Request for information/action needed?	Yes/No	Yes (Skip to Q:17) No (Skip to Q:18)
17	Please Record required information, then will be transferred to the responsible person.	Open Ended (Recorded)	
18	Thank you for your information	Prompt Only	

Site Information Tracking Form for "Survey & Stacking"

#	Question	Question Type	Answer Choices
1	{Message}	Prompt Only	
2	Was there any progress today?	Yes/No	Yes (Skip to Q:3) No (Skip to Q:7)
3	Enter the percentage of progress completed.	Number	
4	Was there any slow progress?	Yes/No	Yes (Skip to Q:5) No (Skip to Q:6)
5	Please record the slow progress reasons?	Open Ended (Recorded)	
6	Was there any delay?	Yes/No	Yes (Skip to Q:7) No (Skip to Q:14)
7	Who is responsible for this delay?	Multiple Choice	Contractor (Skip to Q:8) Owner (Skip to Q:10) ThirdParty (Skip to Q:12)
8	What are reasons for the contractor delay?	Multiple Choice	Delay in material or equipment delivery (Skip to Q:14) Delay in obtaining permits (Skip to Q:14) Other (Skip to Q:9)
9	Please specify delay reasons?	Open Ended (Recorded)	
10	What are reasons for the owner delay?	Multiple Choice	Delay in site handover or access (Skip to Q:14) Differing site conditions (Skip to Q:14) Other (Skip to Q:11)
11	Please specify delay reasons?	Open Ended (Recorded)	
12	What are reasons for the third-party delay?	Multiple Choice	Bad weather (Skip to Q:14) Other (Skip to Q:13)
13	Please specify delay reasons?	Open Ended (Recorded)	
14	Were there any quality control issues?	Yes/No	Yes (Skip to Q:15) No (Skip to Q:16)
15	Please identify the Q/C issues during this period	Open Ended (Recorded)	
16	Is a Request for information/action needed?	Yes/No	Yes (Skip to Q:17) No (Skip to Q:18)
17	Please Record required information, then will be transferred to the responsible person.	Open Ended (Recorded)	
18	Thank you for your information	Prompt Only	

IVR Call Flow Diagram for "Mobilization"

#	Question	Question Type	Answer Choices
1	{Message}	Prompt Only	
2	Was there any progress today?	Yes/No	Yes (Skip to Q:3) No (Skip to Q:7)
3	Enter the percentage of progress completed.	Number	
4	Was there any slow progress?	Yes/No	Yes (Skip to Q:5) No (Skip to Q:6)
5	Please record the slow progress reasons?	Open Ended (Recorded)	
6	Was there any delay?	Yes/No	Yes (Skip to Q:7) No (Skip to Q:14)
7	Who is responsible for this delay?	Multiple Choice	Contractor (Skip to Q:8) Owner (Skip to Q:10) ThirdParty (Skip to Q:12)
8	What are reasons for the contractor delay?	Multiple Choice	Distant disposal area (Skip to Q:14) Shortage or equipment breakdowns (Skip to Q:14) Other (Skip to Q:9)
9	Please specify delay reasons?	Open Ended (Recorded)	
10	What are reasons for the owner delay?	Multiple Choice	Late permits of right of the way (Skip to Q:14) Work scope changes (Skip to Q:14) Other (Skip to Q:11)
11	Please specify delay reasons?	Open Ended (Recorded)	
12	What are reasons for the third-party delay?	Multiple Choice	Bad weather (Skip to Q:14) Other (Skip to Q:13)
13	Please specify delay reasons?	Open Ended (Recorded)	
14	Were there any quality control issues?	Yes/No	Yes (Skip to Q:15) No (Skip to Q:16)
15	Please identify the Q/C issues during this period	Open Ended (Recorded)	
16	Is a Request for information/action needed?	Yes/No	Yes (Skip to Q:17) No (Skip to Q:18)
17	Please Record required information, then will be transferred to the responsible person.	Open Ended (Recorded)	
18	Thank you for your information	Prompt Only	

IVR Call Flow Diagram for “Clearing & Grubbing”

#	Question	Question Type	Answer Choices
1	{Message}	Prompt Only	
2	Was there any progress today?	Yes/No	Yes (Skip to Q:3) No (Skip to Q:7)
3	Enter the percentage of progress completed.	Number	
4	Was there any slow progress?	Yes/No	Yes (Skip to Q:5) No (Skip to Q:6)
5	Please record the slow progress reasons?	Open Ended (Recorded)	
6	Was there any delay?	Yes/No	Yes (Skip to Q:7) No (Skip to Q:16)
7	Who is responsible for this delay?	Multiple Choice	Contractor (Skip to Q:8) Owner (Skip to Q:10) ThirdParty (Skip to Q:12)
8	What are reasons for the contractor delay?	Multiple Choice	Damage to underground utilities (Skip to Q:14) Unavailability or delay of site utilities (Skip to Q:14) Other (Skip to Q:9)
9	Please specify delay reasons?	Open Ended (Recorded)	
10	What are reasons for the owner delay?	Multiple Choice	Delay in inspection or testing (Skip to Q:14) Differing site conditions (Skip to Q:14) Other (Skip to Q:11)
11	Please specify delay reasons?	Open Ended (Recorded)	
12	What are reasons for the third-party delay?	Multiple Choice	Bad weather (Skip to Q:14) Other (Skip to Q:13)
13	Please specify delay reasons?	Open Ended (Recorded)	
14	Were there any quality control issues?	Yes/No	Yes (Skip to Q:15) No (Skip to Q:16)
15	Please identify the Q/C issues during this period	Open Ended (Recorded)	
16	Is a Request for information/action needed?	Yes/No	Yes (Skip to Q:17) No (Skip to Q:18)
17	Please Record required information.	Open Ended (Recorded)	
18	Thank you for your information	Prompt Only	

IVR Call Flow Diagram for “Excavation”

#	Question	Question Type	Answer Choices
1	{Message}	Prompt Only	
2	Was there any progress today?	Yes/No	Yes (Skip to Q:3) No (Skip to Q:7)
3	Enter the percentage of progress completed.	Number	
4	Was there any slow progress?	Yes/No	Yes (Skip to Q:5) No (Skip to Q:6)
5	Please record the slow progress reasons?	Open Ended (Recorded)	
6	Was there any delay?	Yes/No	Yes (Skip to Q:7) No (Skip to Q:14)
7	Who is responsible for this delay?	Multiple Choice	Contractor (Skip to Q:8) Owner (Skip to Q:10) ThirdParty (Skip to Q:12)
8	What are reasons for the contractor delay?	Multiple Choice	Utility is not protected as required (Skip to Q:14) Relocation for utilities (Skip to Q:14) Other (Skip to Q:9)
9	Please specify delay reasons?	Open Ended (Recorded)	
10	What are reasons for the owner delay?	Multiple Choice	Delay in inspec4tion or testing (Skip to Q:14) Work scope changes (Skip to Q:14) Other (Skip to Q:11)
11	Please specify delay reasons?	Open Ended (Recorded)	
12	What are reasons for the third-party delay?	Multiple Choice	Bad weather (Skip to Q:14) Other (Skip to Q:13)
13	Please specify delay reasons?	Open Ended (Recorded)	
14	Were there any quality control issues?	Yes/No	Yes (Skip to Q:15) No (Skip to Q:16)
15	Please identify the Q/C issues during this period	Open Ended (Recorded)	
16	Is a Request for information/action needed?	Yes/No	Yes (Skip to Q:17) No (Skip to Q:18)
17	Please Record required information, then will be transferred to the responsible person.	Open Ended (Recorded)	
18	Thank you for your information	Prompt Only	

IVR Call Flow Diagram for "Underground Utilities"

#	Question	Question Type	Answer Choices
1	{Message}	Prompt Only	
2	Was there any progress today?	Yes/No	Yes (Skip to Q:3) No (Skip to Q:7)
3	Enter the percentage of progress completed.	Number	
4	Was there any slow progress?	Yes/No	Yes (Skip to Q:5) No (Skip to Q:6)
5	Please record the slow progress reasons?	Open Ended (Recorded)	
6	Was there any delay?	Yes/No	Yes (Skip to Q:7) No (Skip to Q:14)
7	Who is responsible for this delay?	Multiple Choice	Contractor (Skip to Q:8) Owner (Skip to Q:10) ThirdParty (Skip to Q:12)
8	What are reasons for the contractor delay?	Multiple Choice	Delay in material or equipment delivery (Skip to Q:14) Equipment shortage or breakdowns (Skip to Q:14) Other (Skip to Q:9)
9	Please specify delay reasons?	Open Ended (Recorded)	
10	What are reasons for the owner delay?	Multiple Choice	Delay in inspection or testing (Skip to Q:14) Other (Skip to Q:11)
11	Please specify delay reasons?	Open Ended (Recorded)	
12	What are reasons for the third-party delay?	Multiple Choice	Bad weather (Skip to Q:14) Other (Skip to Q:13)
13	Please specify delay reasons?	Open Ended (Recorded)	
14	Were there any quality control issues?	Yes/No	Yes (Skip to Q:15) No (Skip to Q:16)
15	Please identify the Q/C issues during this period	Open Ended (Recorded)	
16	Is a Request for information/action needed?	Yes/No	Yes (Skip to Q:17) No (Skip to Q:18)
17	Please Record required information, then will be transferred to the responsible person.	Open Ended (Recorded)	
18	Thank you for your information	Prompt Only	

IVR Call Flow Diagram for "Base or Sub-base"

#	Question	Question Type	Answer Choices
1	{Message}	Prompt Only	
2	Was there any progress today?	Yes/No	Yes (Skip to Q:3) No (Skip to Q:7)
3	Enter the percentage of progress completed.	Number	
4	Was there any slow progress?	Yes/No	Yes (Skip to Q:5) No (Skip to Q:6)
5	Please record the slow progress reasons?	Open Ended (Recorded)	
6	Was there any delay?	Yes/No	Yes (Skip to Q:7) No (Skip to Q:14)
7	Who is responsible for this delay?	Multiple Choice	Contractor (Skip to Q:8) Owner (Skip to Q:10) ThirdParty (Skip to Q:12)
8	What are reasons for the contractor delay?	Multiple Choice	Delay in resources delivery (Skip to Q:14) Rework due to errors (Skip to Q:14) Other (Skip to Q:9)
9	Please specify delay reasons?	Open Ended (Recorded)	
10	What are reasons for the owner delay?	Multiple Choice	Delay in inspection or testing (Skip to Q:14) Errors or Modifications in drawings and specs (Skip to Q:14) Other (Skip to Q:11)
11	Please specify delay reasons?	Open Ended (Recorded)	
12	What are reasons for the third-party delay?	Multiple Choice	Bad weather (Skip to Q:14) Other (Skip to Q:13)
13	Please specify delay reasons?	Open Ended (Recorded)	
14	Were there any quality control issues?	Yes/No	Yes (Skip to Q:15) No (Skip to Q:16)
15	Please identify the Q/C issues during this period	Open Ended (Recorded)	
16	Is a Request for information/action needed?	Yes/No	Yes (Skip to Q:17) No (Skip to Q:18)
17	Please Record required information, then will be transferred to the responsible person.	Open Ended (Recorded)	
18	Thank you for your information	Prompt Only	

IVR Call Flow Diagram for "Noise Barriers"

#	Question	Question Type	Answer Choices
1	{Message}	Prompt Only	
2	Was there any progress today?	Yes/No	Yes (Skip to Q:3) No (Skip to Q:7)
3	Enter the percentage of progress completed.	Number	
4	Was there any slow progress?	Yes/No	Yes (Skip to Q:5) No (Skip to Q:6)
5	Please record the slow progress reasons?	Open Ended (Recorded)	
6	Was there any delay?	Yes/No	Yes (Skip to Q:7) No (Skip to Q:14)
7	Who is responsible for this delay?	Multiple Choice	Contractor (Skip to Q:8) Owner (Skip to Q:10) ThirdParty (Skip to Q:12)
8	What are reasons for the contractor delay?	Multiple Choice	Delay in material delivery (Skip to Q:14) Delay or errors by subcontractors (Skip to Q:14) Other (Skip to Q:9)
9	Please specify delay reasons?	Open Ended (Recorded)	
10	What are reasons for the owner delay?	Multiple Choice	Delay in inspection or testing (Skip to Q:14) Errors or discrepancies in design documents (Skip to Q:14) Other (Skip to Q:11)
11	Please specify delay reasons?	Open Ended (Recorded)	
12	What are reasons for the third-party delay?	Multiple Choice	Bad weather (Skip to Q:14) Other (Skip to Q:13)
13	Please specify delay reasons?	Open Ended (Recorded)	
14	Were there any quality control issues?	Yes/No	Yes (Skip to Q:15) No (Skip to Q:16)
15	Please identify the Q/C issues during this period	Open Ended (Recorded)	
16	Is a Request for information/action needed?	Yes/No	Yes (Skip to Q:17) No (Skip to Q:18)
17	Please Record required information, then will be transferred to the responsible person.	Open Ended (Recorded)	
18	Thank you for your information	Prompt Only	

IVR Call Flow Diagram for “Concrete Works”

#	Question	Question Type	Answer Choices
1	{Message}	Prompt Only	
2	Was there any progress today?	Yes/No	Yes (Skip to Q:3) No (Skip to Q:7)
3	Enter the percentage of progress completed.	Number	
4	Was there any slow progress?	Yes/No	Yes (Skip to Q:5) No (Skip to Q:6)
5	Please record the slow progress reasons?	Open Ended (Recorded)	
6	Was there any delay?	Yes/No	Yes (Skip to Q:7) No (Skip to Q:14)
7	Who is responsible for this delay?	Multiple Choice	Contractor (Skip to Q:8) Owner (Skip to Q:10) ThirdParty (Skip to Q:12)
8	What are reasons for the contractor delay?	Multiple Choice	Bad surface preparation (Skip to Q:14) Paver breakdowns (Skip to Q:14) Other (Skip to Q:9)
9	Please specify delay reasons?	Open Ended (Recorded)	
10	What are reasons for the owner delay?	Multiple Choice	Delay in inspection or testing (Skip to Q:14) Errors or discrepancies in design documents (Skip to Q:14) Other (Skip to Q:11)
11	Please specify delay reasons?	Open Ended (Recorded)	
12	What are reasons for the third-party delay?	Multiple Choice	Bad weather (Skip to Q:14) Other (Skip to Q:13)
13	Please specify delay reasons?	Open Ended (Recorded)	
14	Were there any quality control issues?	Yes/No	Yes (Skip to Q:15) No (Skip to Q:16)
15	Please identify the Q/C issues during this period	Open Ended (Recorded)	
16	Is a Request for information/action needed?	Yes/No	Yes (Skip to Q:17) No (Skip to Q:18)
17	Please Record required information, then will be transferred to the responsible person.	Open Ended (Recorded)	
18	Thank you for your information	Prompt Only	

IVR Call Flow Diagram for "Paving Works"

#	Question	Question Type	Answer Choices
1	{Message}	Prompt Only	
2	Was there any progress today?	Yes/No	Yes (Skip to Q:3) No (Skip to Q:7)
3	Enter the percentage of progress completed.	Number	
4	Was there any slow progress?	Yes/No	Yes (Skip to Q:5) No (Skip to Q:6)
5	Please record the slow progress reasons?	Open Ended (Recorded)	
6	Was there any delay?	Yes/No	Yes (Skip to Q:7) No (Skip to Q:14)
7	Who is responsible for this delay?	Multiple Choice	Contractor (Skip to Q:8) Owner (Skip to Q:10) ThirdParty (Skip to Q:12)
8	What are reasons for the contractor delay?	Multiple Choice	Error in sign work (Skip to Q:14) Shortage or low productivity of labors (Skip to Q:14) Other (Skip to Q:9)
9	Please specify delay reasons?	Open Ended (Recorded)	
10	What are reasons for the owner delay?	Multiple Choice	Late approval (Skip to Q:14) Errors or Modifications in drawings and specs (Skip to Q:14) Other (Skip to Q:11)
11	Please specify delay reasons?	Open Ended (Recorded)	
12	What are reasons for the third-party delay?	Multiple Choice	Bad weather (Skip to Q:14) Other (Skip to Q:13)
13	Please specify delay reasons?	Open Ended (Recorded)	
14	Were there any quality control issues?	Yes/No	Yes (Skip to Q:15) No (Skip to Q:16)
15	Please identify the Q/C issues during this period	Open Ended (Recorded)	
16	Is a Request for information/action needed?	Yes/No	Yes (Skip to Q:17) No (Skip to Q:18)
17	Please Record required information, then will be transferred to the responsible person.	Open Ended (Recorded)	
18	Thank you for your information	Prompt Only	

IVR Call Flow Diagram for "Electrical & Signage"

#	Question	Question Type	Answer Choices
1	{Message}	Prompt Only	
2	Was there any progress today?	Yes/No	Yes (Skip to Q:3) No (Skip to Q:7)
3	Enter the percentage of progress completed.	Number	
4	Was there any slow progress?	Yes/No	Yes (Skip to Q:5) No (Skip to Q:6)
5	Please record the slow progress reasons?	Open Ended (Recorded)	
6	Was there any delay?	Yes/No	Yes (Skip to Q:7) No (Skip to Q:14)
7	Who is responsible for this delay?	Multiple Choice	Contractor (Skip to Q:8) Owner (Skip to Q:10) ThirdParty (Skip to Q:12)
8	What are reasons for the contractor delay?	Multiple Choice	Subcontractor delay (Skip to Q:14) Delay in material delivery (Skip to Q:14) Other (Skip to Q:9)
9	Please specify delay reasons?	Open Ended (Recorded)	
10	What are reasons for the owner delay?	Multiple Choice	Delay in inspection or testing (Skip to Q:14) Approval delay (Skip to Q:14) Other (Skip to Q:11)
11	Please specify delay reasons?	Open Ended (Recorded)	
12	What are reasons for the third-party delay?	Multiple Choice	Bad weather (Skip to Q:14) Other (Skip to Q:13)
13	Please specify delay reasons?	Open Ended (Recorded)	
14	Were there any quality control issues?	Yes/No	Yes (Skip to Q:15) No (Skip to Q:16)
15	Please identify the Q/C issues during this period	Open Ended (Recorded)	
16	Is a Request for information/action needed?	Yes/No	Yes (Skip to Q:17) No (Skip to Q:18)
17	Please Record required information, then will be transferred to the responsible person.	Open Ended (Recorded)	
18	Thank you for your information	Prompt Only	

IVR Call Flow Diagram for “Landscaping”