

Investigating the Feasibility of Using Quick Response Codes in Highway Construction for Document Control

FINAL PROJECT REPORT

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16. Abstract Highway construction takes place in remote locations, making document control challenging. Frequent changes in a project can cause errors, reworks, and schedule delays due to the time taken to disseminate these changes to the field or due to using outdated documents. With the advancement of mobile devices, Quick Response (QR) codes can now provide project teams rapid and reliable access to information and documents required for field operations. The use of QR codes can also allow for checking document versions, reduce the need for travelling or meeting for document revisions, and reduce the amount of hardcopy documents and storage spaces. Despite the potential for significant benefits, there have been little to no studies aimed at assessing the feasibility of using QR codes in highway construction. In response, this study aimed at investigating the benefits of and barriers of using QR codes in highway construction for document control. First, an online survey was conducted to determine the status quo of highway construction in terms of document control and mobile information technology (IT). The survey results indicated that hardcopy documentation is still the most prevalent form of document control in highway construction, and hence there is an opportunity for implementing QR codes in conjunction with mobile IT. Further, a time study using a real-world infrastructure project was conducted based on three activities: detail look up, specification check, and version check. A statistical analysis of the time study data showed that using QR codes can significantly save time, indicating a benefit cost ratio of 1.70. In conclusion, the report presents a guideline that state transportation agencies can use to implement QR codes in their document control practices.			
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Table of Contents

Executive Summary.....	v
CHAPTER 1 INTRODUCTION	1
CHAPTER 2 BACKGROUND	3
2.1 QR Codes – Two Dimensional Barcodes	3
2.2 Application of Barcodes in Construction Industry	4
2.3 Benefits from Using QR Codes	5
2.4 Costs of Using QR Codes	6
2.5 Limitations and Barriers	6
2.6 Method for Embedding QR Codes in Documents	7
CHAPTER 3 SURVEY STUDY	9
3.1 Survey Structure.....	9
3.1.1 Part 1: Background Information	9
3.1.2 Part 2: Current Trend of Sharing Data	9
3.1.3 Part 3: Industry Perception of QR Codes and Mobile IT.....	10
3.2 Survey Distribution.....	10
3.3 Survey Findings	10
3.3.1 General Information.....	10
3.3.2 Onsite Construction Document Control.....	11
3.3.3 Document Revision Notification	11
3.3.4 Mobile Devices	12
3.3.5 QR Codes	13
CHAPTER 4 TIME STUDY	17
4.1 Time Study Structure	17
4.2 Time Study Results	19
4.3 Benefit Cost Analysis	23

4.3.1 Benefits Analysis	23
4.3.2 Cost Analysis	25
4.3.3 Benefit Cost Ratio.....	26
4.4 Barriers Identified	27
CHAPTER 5 IMPLEMENTATION GUIDELINE	29
5.1 Introduction.....	29
5.2 Implementation Steps.....	29
5.2.1 Step 1	30
5.2.2 Step 2	30
5.2.3 On-site Access	32
CHAPTER 6 CONCLUSION	35
REFERENCES	37
APPENDIX A – ONLINE SURVEY	39
APPENDIX B –SURVEY BEFORE TIME STUDY	46
APPENDIX C – TIME STUDY DOCUMENTS	47

List of Figures

Figure 3.1 Observed duration for document revision notifications.....	12
Figure 3.2 Experience with QR codes.....	14
Figure 3.3 Benefits of using QR codes for document control.....	14
Figure 4.1 Time study process.....	18
Figure 4.2 Characteristics of time study participants.....	20
Figure 4.3 Mean time for each category (time in seconds).....	22
Figure 4.4 Results of time study in box plots (time in seconds).....	23
Figure 5.1 QR code workflow.....	33
Figure C.2 QR Code Embedded Drawing Example 2.....	48
Figure C.3 QR Code Embedded Drawing Example 3.....	48
Figure C.4 Screenshots of Database Developed for Time Study Analysis.....	49

List of Tables

Table 3.1 Smartphone Users in Highway Construction.....	13
Table 4.1 Results of Wilcoxon Sign Test.....	20
Table 4.2 Benefit Calculation for Using QR Codes.....	24
Table 4.3 Costs for Implementing QR codes.....	26

Executive Summary

Highway construction can take place in remote locations. Due to the dynamic environment of construction activities, the document control of highway construction can lead to increased difficulties in disseminating or notifying field personnel of updated document versions, increasing the chance of schedule delays or field reworks. In turn, highway construction provides an opportunity to incorporate or utilize information technologies (IT) that would help project teams close physical gaps between team members when sharing critical project information. For example, IT such as mobile devices and wireless networks enable rapid and reliable transfer and distribution of information from one source to another, consequently enhancing the efficiency of the document control process of highway construction.

However, according to the survey of this study, hardcopy documentation is still the most prevalent medium for sharing project information in highway construction. One of the main disadvantages of using hardcopy documents is its lack of responsiveness to changes that happen as the project progresses. This can cause errors and confusion that may reduce the chances for project success.

In response, this study aims at investigating the benefits of and barriers in implementing Quick Response (QR) codes into the document control process of highway construction. The study involved (1) performing a literature review and an online survey to identify the barriers; (2) conducting a time study analysis to validate the benefits in terms of time saving; and (3) performing benefit cost analysis. As a result of the analyses, this report concludes with a guideline that state transportation agencies (STA's) can use to implement QR codes in their document control practices.

Chapter 1 Introduction

Construction projects are dynamic in nature, as they always have to cope with changes. Particularly with highway construction, document control brings a great deal of challenges because changes have to be distributed on time to field personnel that are likely be in remote locations. Document control in such remote locations may require a considerable amount of time and cost, and untimely dissemination of documents to the field can lead to errors resulting in reworks.

Over the past few years, the industry has experienced the advancement of information technology (IT), and its increased application contributes to the quality and productivity of work. Therefore, highway construction can benefit from using IT to improve the efficiency and productivity of document control by providing and managing electronic versions of documents. Electronic document control can enhance the effectiveness of information management centered on a database that effectively stores, updates, and disseminates information (Wallace 2011). The effectiveness of electronic document control can be augmented by the use of mobile devices. Tserng et al. (2005) found that the use of mobile devices and other wireless technology to access an online project database would enhance the flow of information on the field involving different project participants. The use of mobile devices in a construction site is also found to improve the productivity and quality of work (Haas et al 2002), and it contributes to the efficiency of coordination between team members by providing timely information for project members in remote locations (Venkatraman et al. 2007). Consequently, the availability of and access to electronic documents in the field contributes to effective communication among team members (Venkatraman and Yoong 2009).

With the incorporation of electronic document management systems, the construction industry has observed the reduced use of hardcopy documentation in recent years. However, highway construction lags behind other construction sectors as far as electronic document management is concerned. A survey conducted as part of this study revealed that hardcopy documentation is still the most dominant form of document control in highway construction.

In response, this study aims at investigating the feasibility of using Quick Response (QR) codes in terms of barriers and benefits. This study was developed based on the premise that electronic document management systems provide a rapid and reliable way to disseminate up-to-date documents to the field. Mobile devices that are capable of scanning QR codes can provide field personnel with an easy access to electronic documents stored in a database.

This report is structured as follows: Chapter 2 presents background information on the use of QR codes in the construction industry. Chapter 3 summarizes findings from an online survey that aimed to identify the status quo of the highway construction sector in terms of IT. Chapter 4 presents the results of time study analysis and benefit cost analysis based on time saving from using QR codes. Lastly, Chapter 5 presents a guideline that state transportation agencies (STA's) can use when they implement QR codes in their document control practices.

Chapter 2 Background

2.1 QR Codes – Two Dimensional Barcodes

Over the past few decades, document management systems have significantly improved in the construction industry. These systems enable project teams to manage and access project information effectively and efficiently. It has been suggested that combining the use of barcodes with management systems can increase reliability and ease of access. The use of barcodes has proved to be one of the most reliable tools to access and retrieve information from offsite. Barcodes are represented in the form of unique black and white patterns which—when scanned by laser or digital camera—allow rapid access to the information stored in them (Shehab and Moselhi 2005).

Barcodes have been extensively used in the retail and manufacturing industries to keep track of inventories. Barcodes are used as an error-free input of data into the systems, making the data entry and transfer reliable (McCullouch and Lueprasert 1994; Bell and McCullouch 1988; Blakey 1990). The use of barcodes in the construction industry is also known to result in significant time saving for data entry (McCullouch and Lueprasert 1994). However, one-dimensional barcodes started being replaced with two-dimensional barcodes that offer high storage capacity (McCullouch and Lueprasert 1994).

QR codes are most widely used two-dimensional barcodes that consist of several unique black and white pixels and are square in shape. The high capacity of QR codes makes them suitable to store data of larger size (Trajan et al. 2011). After they were first successfully implemented by the Toyota automobile manufacturer in Japan for tracking their inventories during the manufacturing process (Friedman 2012), QR codes have been used by retailers and manufacturers to provide more information about their products to their customers.

The commercial use of QR codes has led to the increased awareness of public users. In particular, the availability of smartphones and tablets has enabled these users to access the data encoded in QR codes using applications, providing access to the digital world from the physical world (Friedman 2012).

2.2 Application of Barcodes in Construction Industry

In the past few decades, barcodes have been successfully used in the construction industry for improving the accessibility of information for field personnel and also for the management of inventories on the field. The use of barcodes has supported the industry involving a tremendous amount of data that has to be coordinated and shared among project members.

A study done by Bell and McCullouch (1988) reported the following applications of barcodes in the construction industry: quantity takeoff, field material control, warehouse inventory and maintenance, tool and consumable material issue, timekeeping and cost engineering, purchasing and accounting, and document control and office operations. Similarly, QR codes can be applied to the following (McCullouch and Lueprasert 1994): identification cards, maintenance management, shipping processes, processing equipment repair, and on material safety data sheets. The various existing applications of QR codes in the industry indicate the potential for its use in document control.

There have been previous efforts to use QR codes in construction document control mainly for version checking. A system called 'isOKTM' attempted to use QR codes to enable quick access to revised documents (Dougherty 2011). The system proved to be effective in

reducing the number of reworks by providing access to the latest version of the drawings (NCE Editorial 2012).

It is important that field personnel have an easy access to project documents and that they are immediately notified of any changes to avoid errors and further complication in the process. This provides an opportunity to implement QR codes combined with mobile devices. For example, QR codes can be embedded in drawings and specifications, which can be effectively and efficiently done using online tools for free. Alternatively, the QR code plug-in in Autodesk's AutoCAD allows for encoding plain texts, web addresses, contact information, and geographic coordinates (Autodesk 2014).

2.3 Benefits from Using QR Codes

Highway construction, due to its geographically dispersed nature, makes it difficult for project members to exchange up-to-date project information in the field, home office, and engineering office. This physical gap in document control can be overcome by utilizing mobile devices and electronic documents. Mitchell et al. (2006) and Haas et al. (2002) recognized that the availability of information on the field using mobile IT can reduce the time consumed for travelling and communication. However, using this technology is feasible only when having a reliable wireless network on the field, which allows for the rapid retrieval of electronic documents on their respective devices, thus mitigating the spatial differences and the extra time otherwise required to access the documents (Tserng et al. 2005).

During the construction process, frequent referencing to project documents is helpful for field personnel to achieve the desired outcome of the process. In addition, it is important to notify field personnel of any changes in drawings and specifications. The recent advancement of

Internet and mobile technology has enabled designers and architects to quickly notify project teams of changes. In particular, using mobile devices for scanning QR codes can allow for accessing data quickly in the field. As a result, one can achieve cost effective management practices, as the time and space requirements for hardcopy documents are reduced considerably (Sardroud 2012).

2.4 Costs of Using QR Codes

The infrastructure cost for implementing QR codes would be considerably low. Most contractors and STA's already have existing databases for document control, making the process of linking QR codes to the database cost effective. Moreover, the development of these codes does not require much time or cost as they can be generated using various websites that provide free QR code generators or through QR plug-ins from AutoCAD, as stated earlier.

QR codes are primarily scanned by using mobile devices such as smartphones or tablets. Therefore, smartphones or tablets must be available for field personnel, yet most construction employees are already equipped with them; so there is a minimum level of cost expected for purchasing mobile devices.

2.5 Limitations and Barriers

Highway construction can extend up to several miles in rural areas. Due to the unique nature of highway construction, using QR codes for document control of highway construction may face a number of barriers.

First, rapid and reliable access to electronic documents relies on a good Internet connectivity (Mitchell et al. 2006), which might not be guaranteed in remote geographical locations.

Second, acceptance of new technologies in the construction industry is challenging due to various internal and external factors. Haas et al. (2002) found that the concern of construction firms as well as individual opinions regarding the uncertainty of new technologies act as a barrier. Similarly, a study done by Venkatraman and Yoong (2009) found that some project participants were reluctant and felt uncomfortable using mobile technology in the field as they were concerned about the outcomes. In particular, Probst (2012) reported that the user's interest in downloading and using a QR code application depends on the user's belief that QR codes are worth using.

Third, the capability of field personnel to use and scan QR codes can be another barrier. Probst (2012) found that the knowledge of users on QR codes is a key to realizing intended benefits.

Lastly, the deterioration of QR codes on paper can limit the implementation. Damage to hardcopy documents in which QR codes are embedded might prevent QR code applications from scanning as the pixels of QR codes may be significantly distorted.

2.6 Method for Embedding QR Codes in Documents

A QR code can generally be developed in two different ways: Using websites that allow generating QR codes or using the AutoCAD's QR plug-ins. First, some websites allow for a quick generation of QR codes. In doing so, one must be careful about which data source (e.g., web addresses) has to be converted. The websites typically require the web addresses of source

documents to be entered in a specific space. Then, an image of the QR code is generated in one click. The image must be stored by the user for its further use—embedding in target documents.

Another way to generate a QR code is to use AutoCAD. The QR plug-in provided by AutoCAD enables a quick converting of any types of texts into QR codes. The plug-in is included in AutoCAD and codes can be generated free of charge.

Linking a QR code is one of the crucial steps in the implementation of QR codes. The QR code image saved by the user can be embedded into drawings or any types of documents. One must ensure that the image size of the QR code be large enough for mobile devices to scan.

Between the two ways, using the plug-in in AutoCAD is found to be more convenient because codes and drawings can be developed simultaneously.

Chapter 3 Survey Study

The study involved performing an online survey that aimed at investigating the benefits of and barriers to using QR codes in highway construction for document control. This chapter presents the survey structure and its results. Screenshots of the online survey are provided in Appendix A.

3.1 Survey Structure

The survey questions mainly aimed at identifying (1) the existing document control methods or procedure currently used by the survey participants and their organizations, (2) the extent to which mobile IT has been incorporated in the highway industry, and (3) the knowledge levels for mobile IT and QR codes. The survey consisted of 26 questions; it also provided an optional comment space for the participants to provide their inputs regarding the study. Overall, the survey was threefold as follows:

3.1.1 Part 1: Background Information

The first part of the survey asked about the general information of the participants, related to their projects and their organizations. This was mainly to gather data about the participant's experience with projects and the adaptation level of mobile IT in the current highway construction.

3.1.2 Part 2: Current Trend of Sharing Data

The second part of the survey focused on identifying the current methods of data sharing between onsite and offsite offices in highway construction. Given that the construction industry

traditionally relies on hardcopy documents for communicating or sharing information between project parties, this part targeted on identifying the adaptation level of electronic documents in the industry.

3.1.3 Part 3: Industry Perception of QR Codes and Mobile IT

The last part of the survey aimed to obtain and understand the participant's view on implementing QR codes in the industry by asking questions that sought comments and feedback from the individuals.

3.2 Survey Distribution

This survey was hosted and administrated via Google Drive™ for approximately 50 days. As the survey intended to investigate the status quo of the highway construction industry, it was mainly distributed to highway construction professionals. This was done by posting a link to the online survey on the blog of Associated General Contractors – Oregon Columbia Chapter (<http://www.agc-oregon.org/osu-needs-your-input-2014-05-06/>). Also, the link to the survey was forwarded to other professionals in the industry benefiting from the industry connections of the School of Civil and Construction at Oregon State University.

3.3 Survey Findings

3.3.1 General Information

The survey results revealed that the participants were currently working in states including California, Idaho, Nevada, Oregon, and Washington. Their roles in the projects range

from project managers (34.6%), project engineers (23.1%), estimators (23.1%), field engineers (7.7%), an area manager (3.8%), to an executive (3.8%). Further, the participants were involved in different types of highway construction projects, including new construction (36.96%), reconstruction (23.91%), resurfacing (15.22%), rehabilitation, and restoring of highways (15.22%). The remaining 8.7% of the responses were from non-highway projects. It was also found that 77% of the participants indicated 5 years or more of professional experience.

3.3.2 Onsite Construction Document Control

The survey participants indicated that they visited the field multiple times every day and typically carried hardcopies of plans, specifications, estimates, and other construction documents. In short, the survey found that field personnel in highway construction still rely on hardcopy documents for sharing and retrieving data. Consequently, the survey results implied that using mobile IT for document control in highway construction has the potential to benefit the industry.

3.3.3 Document Revision Notification

When asked about how revised documents were disseminated to the field, the participants indicated that emails (50%) were the most preferred method for document revision notifications, followed by meetings (18.75%) and phone calls (16.67%). Large projects tend to use software that provides automatic electronic notifications to field personnel. However, one participant mentioned that he/she still distributes the documents manually in the field.

Next, when asked about the frequency of being notified, 30.8% of the participants said they were notified multiple times a week, followed by at least once every other week (23.1%),

once every other week (23.1%), once a month (23.1%), and once a quarter (3.8%). Such a high frequency of revisions portrays that a quick access to the documents can be beneficial for field personnel.

Lastly, when asked about the time taken to disseminate revised documents, 35% of the participants said within in a day while 15% were notified of document revisions within two weeks from the day of revisions (Figure 3.1).

Q. How soon are the revised drawings generally notified in your project? (Speed of revision notifications)



Figure 3.1 Observed duration for document revision notifications

3.3.4 Mobile Devices

88.5% of the participants indicated that they are proficient with smartphones or tablets to view email conversations and view plans and specifications. Also, a few mentioned that they use mobile devices to browse the Internet to check maps or acquire information. Furthermore, it was found that the participants with 11 to 15 years of professional experience utilize their mobile devices relatively more than other groups (Table 3.1).

Table 3.1 Smartphone Users in Highway Construction

Construction Experience	Use Mobile Devices	Do Not Use Mobile Devices
0 to 5 Years	86%	14%
6 to 10 Years	80%	20%
11 to 15 Years	100%	-
16 Years and Above	83%	17%

When asked about the barriers to using mobile devices on site, the participants selected fast battery consumption (26.09%), small size of the screen (41.30%), poor network reception (26.09%), and difficulty in operating the device (6.52%).

When further asked about the reasons for not using mobile devices on the field (11.54% of the participants), the participants reported that mobile devices were not necessary for their scope of work, and their lack of knowledge with respect to how to use mobile devices.

3.3.5 QR Codes

When asked about the knowledge level regarding QR codes and its application, the survey results revealed that 19.2% of the participants did not have any knowledge about QR codes, whereas 23% know what QR codes are but were unaware of their application. Nonetheless, 39% have actually used/scanned QR codes at least once (see fig 3.2).

Q. Do you know how to use QR codes?

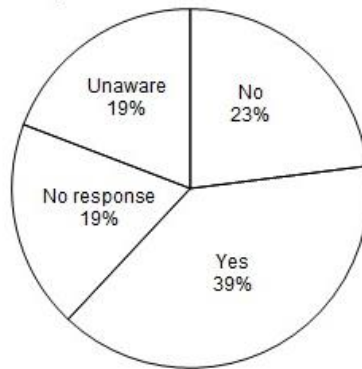


Figure 3.2 Experience with QR codes

The lack of knowledge or awareness of QR codes in the industry seems to be a significant barrier. In addition, 16.7% of the participants still expressed their hesitation in adapting such new technologies in their projects. However, it is important to note that 45.8% of the participants supported the implementation of QR codes for document control and provided positive feedback about their contribution to the industry (see fig 3.3).

Q. Do you think using QR codes to access documents on your smartphones/tablets while on site would be beneficial for document



Figure 3.3 Benefits of using QR codes for document control

A few participants mentioned that the use of QR codes can benefit the industry as they provide field personnel with rapid and reliable access to up-to-date documents using mobile devices. In particular, one participant emphasized that the opportunity to access information from a project database would help to manage and transfer important data without having any data loss during the process.

Chapter 4 Time Study

As identified in Chapter 3, the uniqueness of highway construction offers an opportunity for using QR codes for document control. This can support activities such as verifying versions of documents, and referring to project documents such as drawings, specifications, etc.

In order to further identify the benefits of and barriers to using the QR code for document control, time study analysis was performed based on the survey results. The analysis aimed at assessing the efficiency and effectiveness of using QR codes in comparison to the conventional methods of referencing drawings and documents for extracting the required information.

A real-world bridge replacement project (a project for the Oregon Department of Transportation) was selected as a case study. In addition to the contract documents including bidding plans, special provisions, addenda, the standard drawings belonging to roadwork (RD 700 series), and bridgework (100 and 300 series) were obtained from the Oregon Department of Transportation's website. Hereinafter, the bidding plans will be referred to as "primary documents" while documents such as standard specifications and standard drawings will be referred to as "secondary documents."

4.1 Time Study Structure

The time study was conducted at Oregon State University using a tablet (Nexus 10; a tablet computer co-developed by Google and Samsung Electronics, running the Android operating systems) with a QR code application. In preparation for the study, QR codes were embedded in the primary documents, which led testees to an online database where various

project information consisting mainly of drawings and specifications. An online database and webpages were established using Google Sites™ for the time study.

Adapting from the study of Yeh et al. (2012), this study involved three activities: (1) detail look up, (2) specification check, and (3) version check. The study participants were asked to find and report specific information that was asked in a questionnaire at the commencement of the study. Each of the three activities comprised of three cases: Cases A, B, and C, each requiring the participant to refer and report on information from the primary documents and subsequently locate a reference element from the corresponding secondary documents. Most importantly, the time taken for each process was measured—time taken from when starting to explore the primary documents started to when the required information was located in the secondary documents. Figure 4.1 illustrates the process.

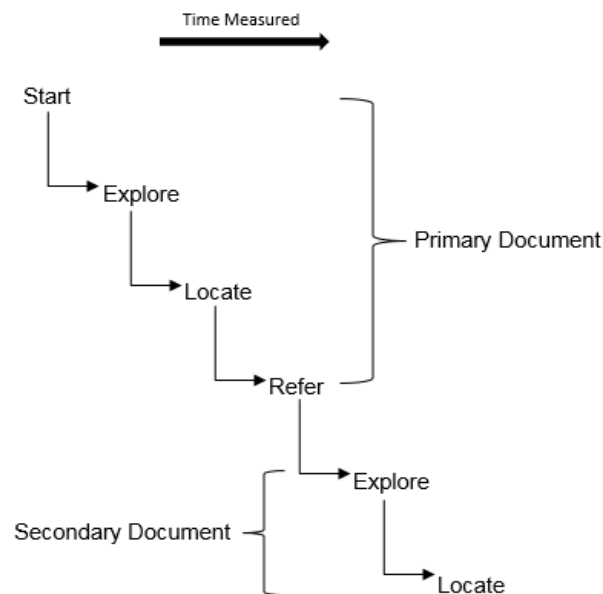


Figure 4.1 Time study process

The main objective of the time study was to compare the time taken by two methods, namely, with QR codes versus without QR codes. The without-QR-code method followed the steps typical of the industry to extract information from documents. This required a participant to answer the first question from the questionnaire by exploring and locating the answer from the primary documents and then to answer the second question by exploring and locating the answer from the secondary documents. For the with-QR-code method, identical activities were performed until the first question was answered, and then embedded QR codes were scanned to answer the second question by using the tablet to access the online database.

4.2 Time Study Results

25 students in the School of Civil and Construction Engineering at Oregon State University participated in the time study. At the start of the time study, a set of preliminary questions were asked to identify their construction experience, awareness on QR codes, efficiency with mobile technology, and efficiency with drawing reading (Appendix B). After answering the questions, the participants were briefed with the steps that they would follow to complete the activities required for the time study.

64% of the participants had 6 months or more of construction experience through part-time jobs or internships (see fig 4.2). They indicated different levels of experience in using drawings and specifications of a highway construction project. For example, 24% of participants indicated that they possess “good” efficiency in reading drawings based on their prior construction experience through internship and also through courses that involved reading construction drawings. Further, 84% of the participants said that they were familiar with using QR codes.

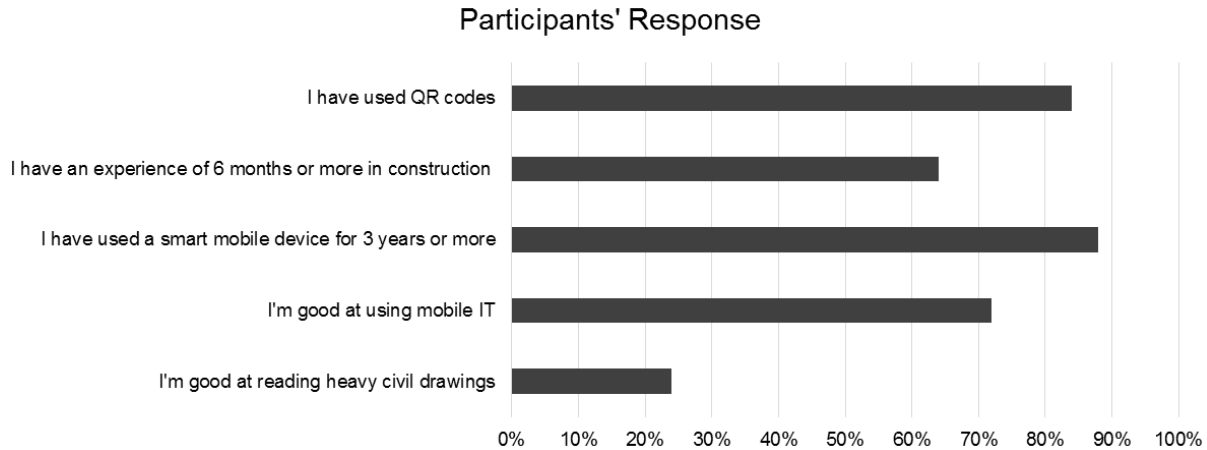


Figure 4.2 Characteristics of time study participants

The collected data was analyzed using a nonparametric Wilcoxon sign test to compare the differences in time taken between the activities that were performed with and without QR codes for each case (A, B, and C). The analysis was performed by using IBM's SPSS statistical software, and its results are summarized in Table 4.1.

Table 4.1 Results of Wilcoxon Sign Test

Detail Look Up	Z- test	p-value (2-tailed)	Specification Check	Z- test	p-value (2-tailed)	Version Check	Z- test	p-value (2-tailed)
DA - WDA	-3.027	0.002	SA - WSA	-3.888	0.000	VA - WVA	-1.719	0.086
DB - WDB	-3.162	0.002	SB - WSB	-3.969	0.000	VB - WVB	-0.067	0.946
DC - WDC	-2.973	0.003	SC - WSC	-4.077	0.000	VC - WVC	-2.731	0.006
Abbreviation List								
Detail Look Up			Specification Check			Version Check		
Case	With QR code	Without QR code	Case	With QR code	Without QR code	Case	With QR code	Without QR code
A	DA	WDA	A	SA	WSA	A	VA	WVA
B	DB	WDB	B	SB	WSB	B	VB	WVB
C	DC	WDC	C	SC	WSC	C	VC	WVC

The results of the Wilcoxon test indicated that the activities for design look up and specification check can be performed more efficiently using QR codes than without QR codes ($p\text{-value} < 0.05$ for all cases). As the data was skewed for multiple variables, the output indicated that the time taken by the with-QR-code method had scores significantly higher than the scores of the time taken by the without-QR-code method. However, the time difference was insignificant for version check ($p\text{-value} > 0.05$). This may be attributed to the limitation of the time study in replicating a real life situation for checking the versions of documents.

Figure 4.3 presents a bar chart representing the mean time taken in seconds for the three activities. It can be seen from the error bars that there exist significant differences between all the cases of detail look up and specification check. It is visually noticeable that the with-QR-code method resulted in significantly less time than the without-QR-code method in case of the detail look up and specification check, but not for the version check.

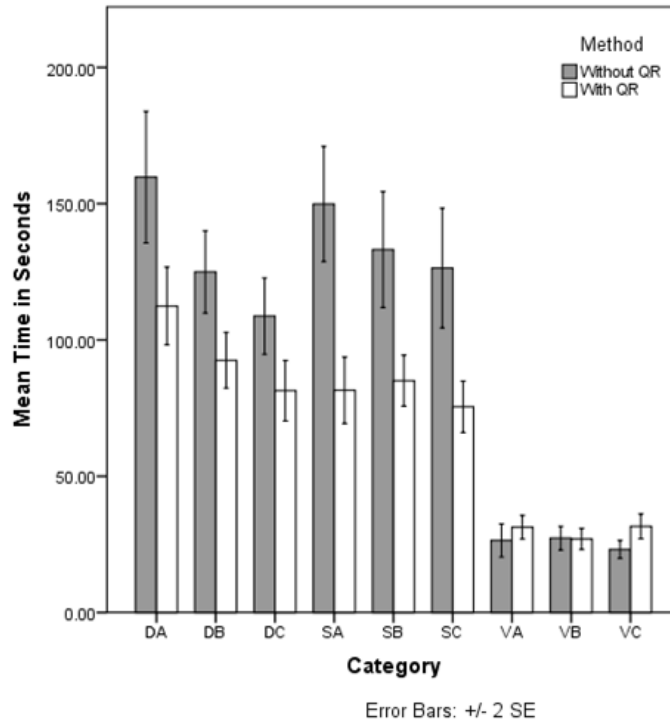


Figure 4.3 Mean time for each category (time in seconds)

Figure 4.4 shows box plots that were created to examine the spread and shrewdness of observations for each category. It is seen that the with-QR-code method resulted in not only shorter time but also more consistency in time than the without-QR-code method, confirming the benefit of using QR codes for document control.

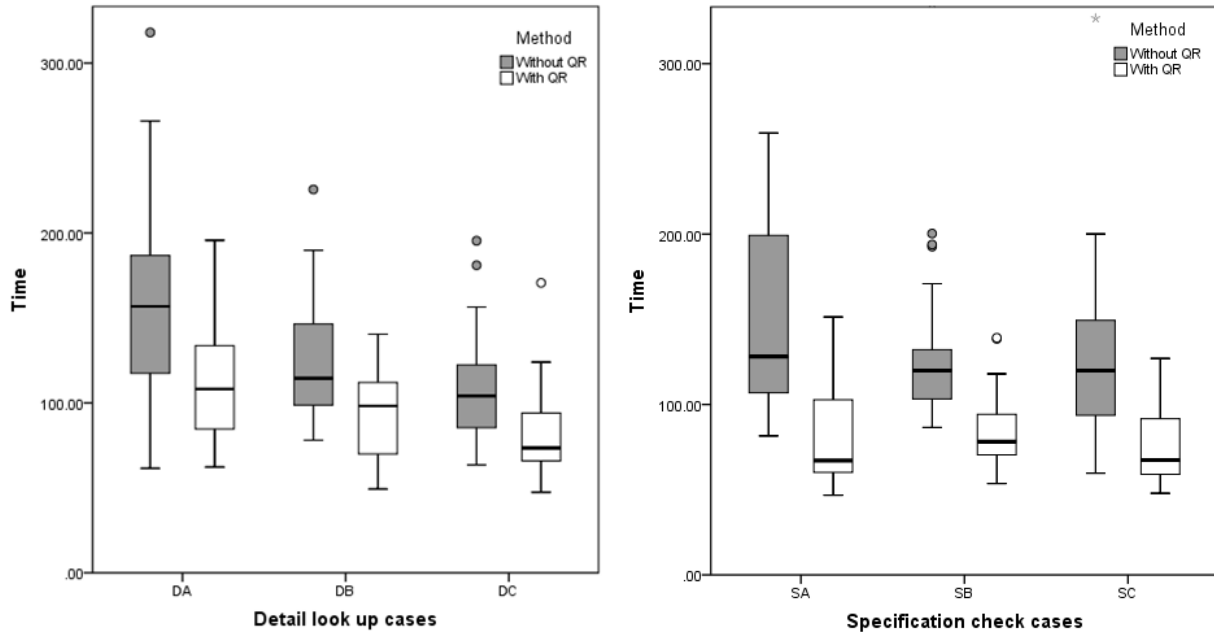


Figure 4.4 Results of time study in box plots (time in seconds)

4.3 Benefit Cost Analysis

Based on the results of the time study analysis, this section presents the results of benefit cost analysis that aimed at assessing the costs and benefits of using QR codes for document control. The determination of the benefits was based on the two activities: *detail look up* and *specification check*, because the time differences between the two methods for *version check* were not statistically significant. Thus, *version check* was not included for the benefit cost analysis. However, it should be noted that version checking can still be indirectly beneficial by helping avoid errors and resulting reworks due to using outdated documents.

4.3.1 Benefits Analysis

The mean time taken to complete all three cases for design look up (mean = 1.8 minutes) and specification checks (mean = 2.7 minutes) for 25 members was determined to be the main

benefit of using QR codes for the benefit cost analysis. The total benefits were calculated using Equation 4.1 to convert the time saved into a monetary value:

$$Total\ Benefit = U \times T \times N \times W \quad (4.1)$$

Where U is the number of users in the project; T is the time saved after implementing QR codes, and N is the number of times that the activity n is performed in one day by an individual; and W is the hourly wage of the individual in dollars per hour.

Further, the following assumptions were made for the analysis:

- Each activity is performed 10 times a day per person on average.
- The cost saving of using QR codes is calculated based on hourly wages.
- Average time saved is identical for each person.
- There are a total of 10 members in a project.
- An average hourly wage of \$40 is assumed based on \$39.8/hour according to Bureau of Labor Statistics (2012).

Based on the assumptions and Equation 4.1, Table 4.2 presents the total daily financial benefit from using QR codes for document control.

Table. 4.2 Benefit Calculation for Using QR Codes

Activity	Times	Time Saving (minutes)	Users	Total Time Saving (hours)	Hourly Wage	Daily Benefit
Design Look Up	10	1.8	10	1.5	\$40	\$120
Specification Check	10	2.7	10	2.25	\$40	\$180
Total		4.5				\$300

A study done by Jiang and Wu (2004) estimated the average duration of an average-sized new construction project to be 124 working days. Using the estimate, the total cost savings for one project is estimated at \$37,200 (124 working days times \$300 per day). Assuming 10 projects per year, the total financial benefit for an organization can sum up to \$372,000.

In addition to the direct financial benefits, it should be noted that QR codes can also benefit indirectly to a project, a contractor, or a STA, for the following reasons:

- Reduction in meeting time for communicating document revisions
- Reduction in travelling time for checking document revisions
- Reduction in hardcopy documents (less paper and less storage space)
- Increased efficiency in organizing documents during construction

4.3.2 Cost Analysis

Implementing QR codes requires one-time and recurring costs. One-time costs include purchasing a server and developing a database in the early stage of implementation, while recurring costs are mainly to support maintenance-related activities. However, it is likely that organizations in the construction industry have an existing online database for sharing information. Thus, assuming that an organization has an existing database for QR codes, the additional cost items required for implementing QR codes include, but are not limited to:

- Costs to maintain the server and database
- Costs to secure wireless network in remote locations
- Costs to purchase tablets or smartphones if not already available
- Costs to provide introductory training on how to embed and/or scan QR codes

Primarily, costs to embed QR codes are ignored because it can be done easily using websites or the QR code plug-in in AutoCAD free or charge. In addition, it is assumed that costs to use wireless networks are included in the existing communication costs (mobile service and internet service) of the project.

Assuming 124 working days, Table 4.3 summarizes the costs required to implement QR codes in a highway construction project. The total cost of implementing QR codes in a project of 124 working days is estimated at \$21,840. Assuming 10 projects per year, the total cost for an organization can be up to \$218,400. The costs presented in Table 4.3 may vary by location and by the types of technology used in a project.

Table 4.3 Costs for Implementing QR codes

Cost Items	Assumptions	Costs
Database management	A half-time document controller (\$40/hour) for keeping the database up-to-date	\$19,840
Mobile device purchases	5 devices (\$400 each), assuming the other 5 field engineers already have devices	\$2,000
Training	No training assumed	-
Total costs		\$21,840

4.3.3 Benefit Cost Ratio

Based on the benefits and costs estimated in the previous sections, a benefit cost ratio (BCR) is calculated as follows:

$$\text{Benefit Cost Ratio (BCR)} = \$37,200 / \$21,840 = 1.70$$

A BCR greater than 1 indicates that the benefits from using QR codes outweigh the implementation costs.

4.4 Barriers Identified

Confirming the discussions in the previous sections, the time study revealed that using QR codes may present barriers, including:

- Some participants were not familiar with smartphones and tablets.
- There were a few cases where Internet connection was lost.

Chapter 5 Implementation Guideline

To effectively deploy mobile IT in the construction industry in regards to cost, it is important to educate potential users about how to implement and use the technology so that they can use the target technology to the maximum potential. Therefore, this section presents a brief implementation guideline to support the implementation efforts of STA's that are interested in using QR codes for their document control practices.

5.1 Introduction

QR codes are square in shape consisting of black and white pixels. Codes can be generated using encoding applications. To generate a QR code, it is important to determine what information is encoded. Then, the generated QR code is embedded into the target document, providing a quick link to a certain document stored in a database. As QR codes can be linked to any online content or any data that provides vital real-time information for a project, it is suggested to embed these QR codes during the development of project documents.

5.2 Implementation Steps

QR codes can be generated using online sources or websites that generate and allow the user to download the codes in JPEG format from the website. Then, the generated QR codes can be embedded into any documents, i.e., the codes can be copied and pasted on documents. However, this method is relatively inefficient in that the generated codes will have to be saved from online sources for their use. Therefore, there is chance that QR codes will be embedded in incorrect documents, thereby, causing confusions, errors, or even reworks.

For those reasons, it is suggested that users generate QR codes using the AutoCAD's QR code plug-in, because it enables engineers or CAD detailers to instantly embed the codes in drawings, specifications, or any other project documents in a more convenient and reliable way. Thus, the following implementation steps are for using the AutoCAD's plug-in.

5.2.1 Step 1

First, it is important to establish an online database for the project, where all the relevant documents must be stored and maintained. If needed, multiple webpages can be created to categorize project information and increase the convenience of users. It is suggested that the database should at least contain the following information:

- Design details
- Technical specifications
- Standard drawings
- Other information such as environmental reports, permits, etc.

5.2.2 Step 2

Generating QR codes in AutoCAD requires the installation of the QR code plug-in, which is included free of charge. The plug-in allows for an easy conversion of texts, files, and designs/graphics into QR codes. The generated QR codes can then be embedded in documents that can later be printed out as needed. As stated earlier, this method appears to be more convenient than using online resources, based on the experience from the time study. Listed below are specific sub-steps that one can follow to create a QR code as hyperlink to a webpage:

1. Download and install the QR code plug-in from Autodesk website
<https://apps.exchange.autodesk.com/ACD/en/Detail/Index?id=appstore.exchange.autodesk.com:qrcodes:en>)
2. Create a design or a drawing that has to be linked to a specific webpage.
3. Select the QR Code Mtext option under “Plug-ins” menu to encode a multi-line text.
4. Select the area next to the relevant design or detail where a QR code is required, and define the textbox appropriately as a hyperlink to the webpage.
5. After entering the hyperlink in the textbox, click outside the textbox and then the text will appear as a QR code.
6. The generated QR code can be resized accordingly. It is strongly suggested that the size be 2.5 cm by 2.5 cm or larger for effective scanning. (QRStuff 2015)
7. The QR code plug-in provides an option to encode the design details using leader lines in the drawings. This is done by selecting the QR Code Leader option and following steps 4 through 6.

The AutoCAD commands for Mtext and Leader QR codes are QRTEXT and QRLEADER respectively. The official webpage of Autodesk <https://apps.exchange.autodesk.com/en> provides complete details regarding troubleshooting the QR code plug-in.

As the generated QR codes provide easy access to the online project database. This access might pose security concerns to the IT management, as the QR codes can be mishandled during or after the project. Such security concerns can be mitigated by adding a login feature to the database to provide secured access only to registered members or devices involved in the project.

5.2.3 On-site Access

To effectively use QR codes for document control, it is important to have a reliable onsite wireless network to access the project database. This is challenging in highway construction as this construction takes place in remote locations where mobile services are often limited.

Projects having reliable network coverage can easily rely on mobile data services such as 3G or 4G networks. This provides an opportunity for the project to avoid any additional costs brought on by the installation of Wi-Fi devices in the field. However, highway construction in remote locations might have limited mobile network services, which would require the installation of additional network devices in the field for implementing QR codes. Multiple hotspots or Wi-Fi boosters can be placed in strategic locations.

Satellite Internet is also an option to overcome poor mobile network coverage on the field. Various satellite Internet services are available in the market and have competitive pricing. More information regarding satellite Internet can be found at www.bestsatelliteproviders.com (Best Satellite Providers 2013).

In summary, figure 5.1 illustrates the overall workflow for QR code implementation.

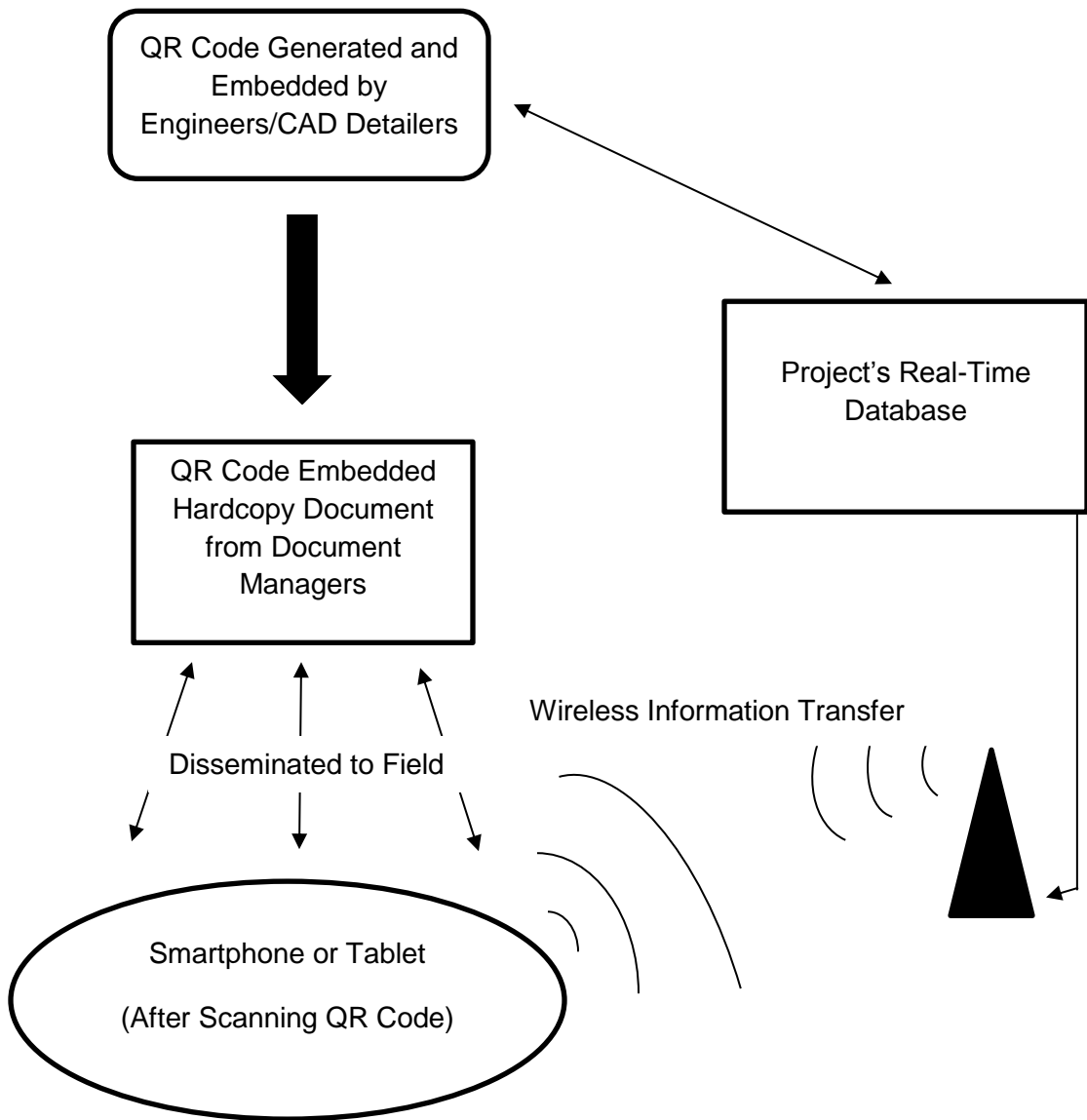


Figure 5.1 QR code workflow.

Chapter 6 Conclusion

Highway construction takes place in remote locations, making document control for these projects challenging. Frequent changes in a project can cause errors, reworks, and schedule delays due to the time taken to disseminate these changes to the field or due to using outdated documents. With the advancement of mobile devices, using QR codes can provide project teams rapid and reliable access to information and documents required to field operations. The use of QR codes can also allow for checking the versions of documents, reduce the need for travelling or meeting for document revisions, and reduce the amount of hardcopy documents and storage space. Despite the potential for significant benefits, there have been little to no studies aimed at assessing the feasibility of using QR codes in highway construction. In response, this study aimed at investigating the benefits of and barriers to using QR codes in highway construction for document control. The study involved performing online survey, time study, and benefit cost analysis.

The survey results indicated that professionals in highway construction agreed that there is a good opportunity for the implementation of QR codes for their document control practices. The time study then revealed that using QR codes can result in significant time savings for activities related to detail look up and specification check, yet no statistically significant time saving was found for version check. Based on the results of the time study, the benefit cost analysis reported that the benefits of using QR codes outweigh the implementation costs (BCR = 1.70). Assuming 124 working days on average for each project and 10 projects each year, an annual financial benefit from using QR codes is estimated at \$372,000. In conclusion, the report presented a brief guideline that STA's can follow to implement QR codes using the AutoCAD's QR code plug-in.

References

1. Autodesk, Inc (2014). "QR Codes", *apps exchange*, <<http://apps.exchange.autodesk.com/ACD/en/Detail/Index?id=appstore.exchange.autodesk.com%3aqr-codes%3aen>>, (14th March, 2014).
2. Bell, L. C., and McCullough, B. G. (1988) "Bar code applications in construction." *Journal of construction engineering and management*, 114(2) 263-278.
3. Best Satellite Providers. (2013). "Best Satellite Internet Providers in 2015". *Satellite Internet Providers*, < <http://www.bestsatelliteproviders.com/satellite-internet-providers/> >. (6th March, 2015).
4. Blakey, L. (1990). "Bar codes: Prescription for precision, performance, and productivity." *Journal of construction engineering and management*, 116(3), 468-479.
5. Bureau of Labor Statistics (January 8, 2014). "Occupational Outlook Handbook", *Bureau of Labor Statistics*, <<http://www.bls.gov/ooh/management/construction-managers.htm>>, (17th March 2015).
6. Dougherty, P. (2011), "isOK™ Revision control system" isOK™ Patent Pending Construction Document Revision Control System, <<http://promo.isok.us/isok-constructiondocument-revision-control-system/>>, (14th March, 2014).
7. Friedman, J. (2012). "QR Codes: Beyond the trend." QR Codes: Beyond the trend-Massar Corporation, <<http://massarcorporation.com/2012/09/qr-codes-beyond-the-trend/>>, (15th March, 2014).
8. Haas, C.T., Tucker, R.L., Saidi, K.S., and Balli, N. A. (2002). "The value of handheld computers in construction." *Center for Construction Industry Studies*, University of Texas, Austin.
9. Jiang, Y., Wu, H. (2004). "Determination of INDOT highway construction production rates and estimation of contract times", Joint Transportation Research Program, Purdue University, West Lafayette, Indiana.
10. NCE Editorial (2012), "Costain/Laing O'Rourke discover cunning use for QR codes in construction," Online News, *New Civil Engineer*, <<http://www.nce.co.uk/news/bim/costain/laing-orourke-discover-cunning-use-for-qr-codes-in-construction/8627885.article>> (16th March, 2014).
11. McCullough, B. G., and Lueprasert, K. (1994). "2D bar-code applications in construction." *Journal of Construction Engineering and Management*, 120(4), 739-752.
12. Mitchell, V., May, A., Bowden, S., and Thrope, T. (2006). "Using mobility as a conceptual framework for informing the design of mobile ICT for construction professionals." *Proceedings of the 8th conference on Human-computer interaction with mobile devices and services*. ACM, New York, USA, 45-48.

13. Probst, A. (2012). "The expectations of quick response (QR) codes in print media: An Empirical Data Research Anthology." *UW-L Journal of Undergraduate research XV*.
14. QRStuff.com (2015). "What size should a qr code be", *QRStuff.com*, <<http://www.qrstuff.com/blog/2011/01/18/what-size-should-a-qr-code-be>>, (17th March 2015).
15. Sardroud, J. M. (2012). "Influence of RFID technology on automated management of construction materials and components." *Scientia Iranica, Transactions A: Civil Engineering* 19(3), 381-392.
16. Shehab, T., and Moselhi, O. (2005). "An automated barcode system for tracking and control of engineering deliverables", *Construction Research Congress*, San Diego, C.A., 1-9.
17. Stukhart, G., and Cook, E. L. (1990). "Bar code standardization in industrial construction", *Journal of Construction Engineering and Management*, 116 (3), 416-431.
18. Tarjan, L., Senk, I., Kovac, R., Horvat, S., Ostojic, G., and Stankovski, S. (2011). "Automatic identification based on 2D barcodes." *International Journal of Industrial Engineering and Management*, 2(4), 151-157.
19. Tserng, H.P., Dzeng, R.J., Lin, Y.C., and Lin, S.T. (2005). "Mobile construction supply chain management using PDA and bar codes." *Computer-Aided Civil and Infrastructure Engineering*, Blackwell publishing, 20, 242-264.
20. Venkatraman, S., Hoehle, H., Scornavacca, E. and Yoong, P. (2007). "Developing and testing a mobile facsimile system: the case of CiliFax." *Proceedings of LA Global Mobility Roundtable, Los Angeles, USA*, 1-2 June.
21. Venkatraman, S. and Yoong, P. (2009). "Role of mobile technology in the construction industry – a case study." *Int. J. Business Information Systems*, Vol 4, No. 2, 195-209.
22. Wallace, P. (2011). "The use of QR codes for document management in safety critical industries." *M.Eng. Project Report, University of Bath, Bath, U.K.*
23. Yeh, K. C., Tsai, M. H., and Kang, S. C., (2012). "On-site building information retrieval by using projection- based augmented reality." *Journal of Computing in Civil Engineering*, 26(3), 342-355.

Appendix A – Online Survey

Investigating the Feasibility of Using Quick Response (QR) Codes for Construction Document Control in Highway Construction

INTRODUCTION

This survey is to identify the barriers to and the opportunities for embedding quick response (QR) codes in construction documents of highway construction. The study objectives are:

- (1) To determine the industry's readiness for the use of mobile devices in document controls,
- (1) To examine the applicability and method of embedding QR codes in drawings, and
- (2) To determine the type of information to be encoded in the codes.

This short survey is voluntary and confidential, and it will only take less than 5 minutes. Your valuable participation will help identify ways to improve document controls of highway construction. This research effort is led by a group of researchers including:

- H W Chris Lee, Assistant Professor, Construction Engineering Management at Oregon State University,
- Bharat Harapanahalli, Graduate Research Assistant, Construction Engineering Management at Oregon State University

If you have any questions regarding this survey, please feel free to contact Dr. Lee at 541-737-8539 or Bharat via email at harapanb@onid.orst.edu. Thanks for your participation.

** This research project is funded by PacTrans (depts.washington.edu/pactrans/) **

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu

* Required

General Information

1. Q1. Select your organization's role: *

Mark only one oval.

- Owner Agency (e.g. DOT)
- General Contractor
- Designer
- Subcontractor
- Other: _____

2. Q2. What states do you work in (e.g., California, Oregon)? *

Provide up to three

3. Q3. Select the job title that best describes what you do *

Choose one.

Mark only one oval.

- Project engineer
- Field engineer
- Project manager
- Design manager
- Estimator
- Design engineer
- Other: _____

4. Q4. Select the type of highway construction project you are currently working on *

Select all that apply.

Check all that apply.

- New construction
- Reconstruction
- Resurfacing, rehabilitation, and restoring
- Other: _____

5. Q5. How many years of industry experience do you have?

Onsite Construction Document Controls

6. Q6. How often do you go out to the project site? *

Choose one.

Mark only one oval per row.

	Multiple times a day	Once a day	Once every other day	Once every few days	Once a week
Frequency of going to the site	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

7. Q7. How often do you carry hard copy documents when you go to the site? *

Choose one.

Mark only one oval per row.

	Never	Rarely	Sometimes	Often	Always
Frequency of carrying hardcopies to the site	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

8. Q8. What type of hard copy documents are carried to the site?

Select all that apply.

Check all that apply.

- Design details
- Plans/Maps
- DOT specifications
- Permits and other legal documents
- Technical specifications (Equipment, materials, etc.)
- Estimates
- Other: _____

Document Revision Notifications

9. Q9. How are document revisions disseminated to field engineers?

Select all that apply.

Check all that apply.

- Meetings
- Phone calls
- Automatic electronic notifications via document control software (e.g. Prolog, Buzzsaw)
- Manual notifications via emails
- Other: _____

10. Q10. How often are you notified of construction document revisions (including plans and specs) in your project?

Choose one.

Mark only one oval per row.

	Multiple times a week	Once a week	Once every other week	Once a month	Once a quarter
Frequency of revision notifications	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

11. Q11. How soon are the revised drawings generally notified in your project?

Choose one.

Mark only one oval per row.

	Within a day	Within two days	Within three days	Within a week	Within two weeks
Speed of revision notifications	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Mobile Access and Use of Mobile Devices

12. Q12. Do you think mobile access to construction documents would be beneficial while on site? *

Mark only one oval.

- Yes *After the last question in this section, skip to question 6.*
- No

13. Q13. If no to Q12, why do you not think mobile access is beneficial?

Select all that apply.

Check all that apply.

- Documents are available in the field office
- They are not required on every site visit
- My job does not require frequent referral of detailed drawings and documents
- Other: _____

14. Q14. Do you use a smartphone/tablet for your job? *

Mark only one oval.

- Yes
- No *Skip to question 17.*

15. Q15. What purpose(s) does your smartphone/tablet serve for your job?

Select all that apply.

Check all that apply.

- To make phone calls and texts
- To make email conversations
- To view plans and specifications
- To browse web for information search
- To check maps and satellite images
- Other: _____

16. **Q16. What kind of problems do you face while using a smartphone/tablet on the site?**

Select all that apply.

Check all that apply.

- Fast battery consumption
- Small screen
- Difficulty in operating
- Poor network reception
- Other: _____

Skip to question 19.

17. **Q15. What are your reasons for not using a smartphone/tablet on the site?**

Select all that apply.

Check all that apply.

- It is too expensive.
- It is not needed for what I do.
- My organization discourages the use of mobile devices while on site.
- I don't know how to use a smartphone/tablet.
- I don't see a benefit of using it.
- Other: _____

18. **Q16. How likely do you think you will use a smartphone/tablet for your job in the future?**

Choose one.

Mark only one oval.

- Extremely unlikely
- Unlikely
- Neutral
- Likely
- Extremely likely
- Other: _____

Quick Response (QR) Codes

19. **Q17. Do you know what a Quick Response (QR) code is? ***

QR codes are a 2-dimensional barcode that can be easily scanned by using smartphones/tablets.

Check http://en.wikipedia.org/wiki/QR_code

Mark only one oval.

- Yes
- No Skip to question 25.

Quick Response (QR) Code Image



20. Q18. Do you know how to use QR codes? *

Mark only one oval.

- Yes
 No

21. Q19. Do you think using QR codes to access documents on your smartphones/tablets while on site would be beneficial for document control in your job? *

Mark only one oval.

- Yes
 No
 I don't know

22. Q20. If no to Q19, why?

23. Q21. To what extent do you agree or disagree with each of the statements regarding the benefit of using QR codes? *

Mark only one oval per row.

	Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree
It can help to organize plans and specifications more efficiently	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
It can reduce chances for errors	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
It can reduce the time required for checking documents	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
It can reduce the cost of document controls	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

24. Please provide your comments on your above responses to Q21.

Follow-up Questions

25. If we are ok to contact you with follow-up questions, please provide your contact information. We appreciate your support!

Your participation is voluntary, and your contact information would be kept confidential.

Appendix B –Survey Before Time Study

Short Survey:

1. Rate your level of proficiency reading heavy civil drawings:
 - a) Very Good
 - b) Good
 - c) Neutral
 - d) Somewhat poor
 - e) Poor

2. Rate your level of proficiency using mobile IT (iPhone/iPads, Smartphones, Tablets, PDA, etc.)
 - a) Very Good
 - b) Good
 - c) Neutral
 - d) Somewhat poor
 - e) Poor

3. How many years of experience do you have with mobile IT (iPhones/iPads, Smartphones, Tablets, PDA, etc.)
_____ Years

4. Have you ever seen a QR Code?
 - Yes
 - No

5. If yes, do you know how to use them?
 - Yes
 - No



QR Code

Appendix C – Time Study Documents

Figures C.1 through C.3 are example drawings excerpted from the bidding plans that had QR codes embedded and were used for the time study. As seen from the figures, the time study involved testing activities related to detail look up, specification check, and version check.

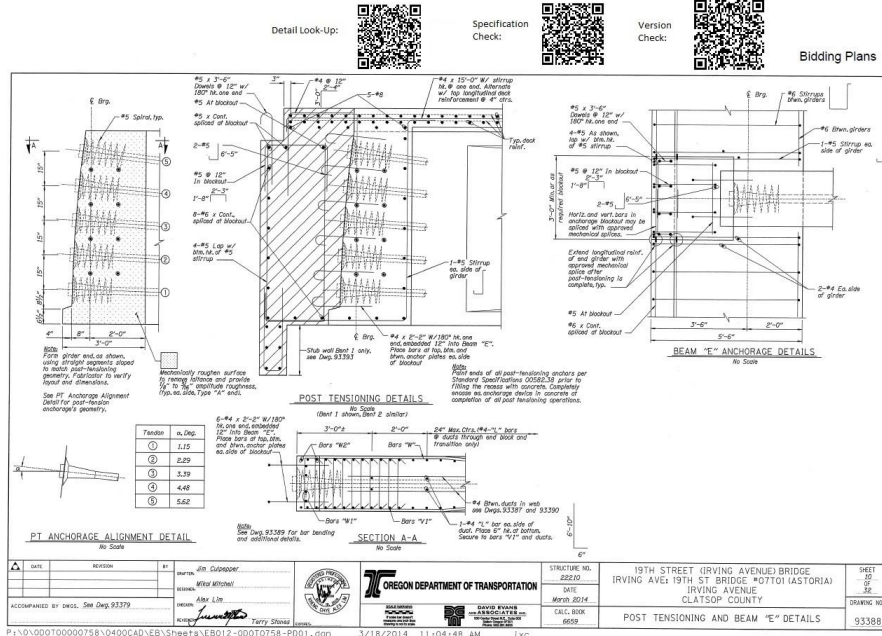


Figure C.1 QR Code Embedded Drawing Example 1

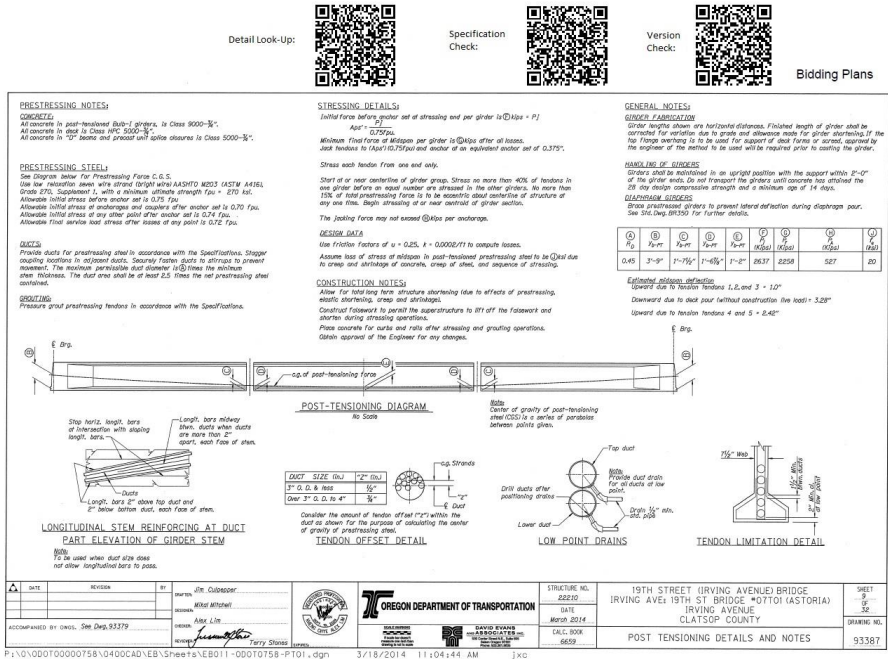


Figure C.2 QR Code Embedded Drawing Example 2

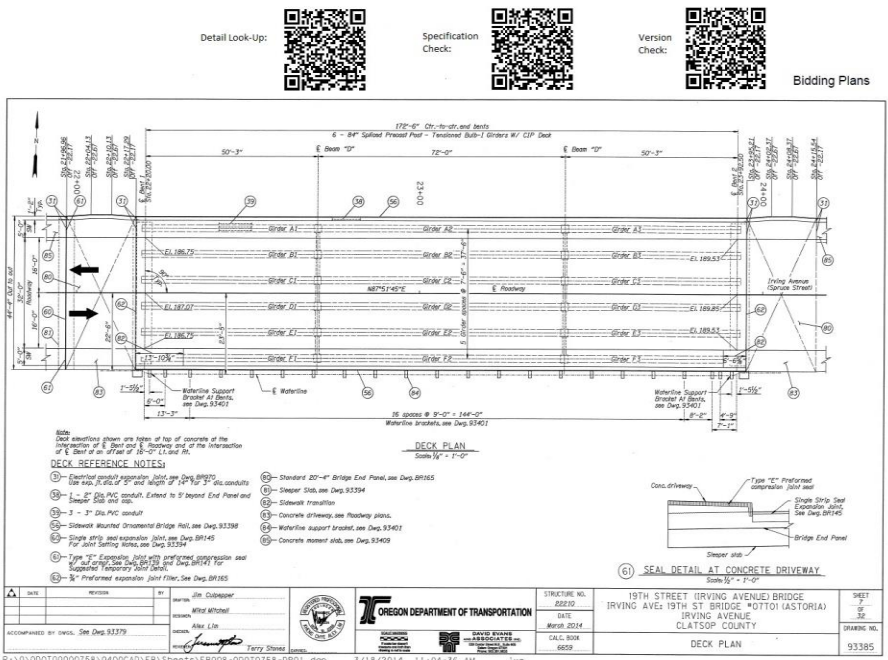


Figure C.3 QR Code Embedded Drawing Example 3

Figure C.4 presents two screenshots of the database and webpages that were developed for the time study (<https://sites.google.com/a/onid.oregonstate.edu/irving-ave-19st-bridge-07t01-astoria/>).

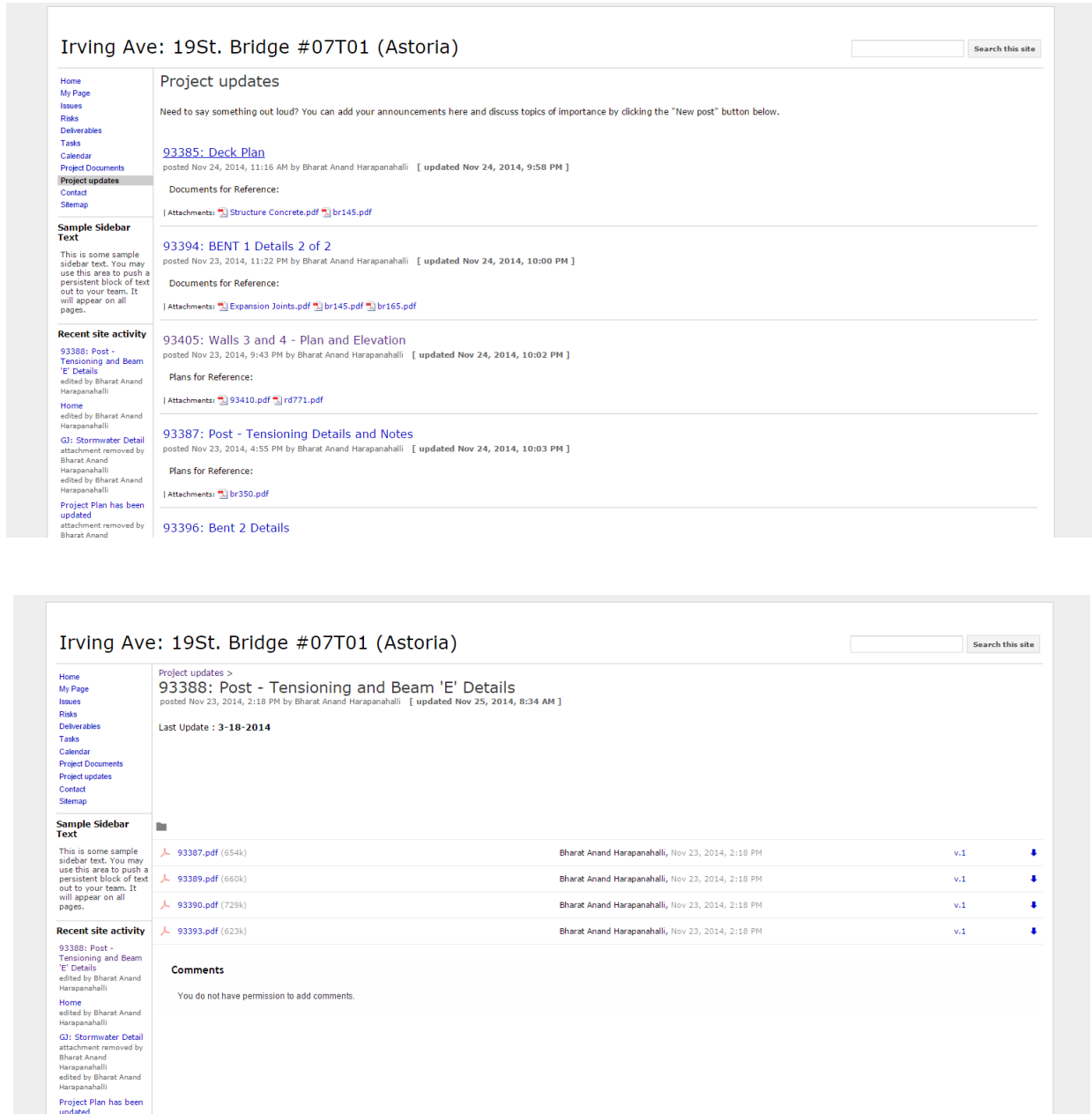


Figure C.4 Screenshots of Database Developed for Time Study Analysis