ABSTRACT

PARIKH, PRANAV SNEHAL. Process Modeling and Automation for Concrete Cylinder Testing. (Under the direction of Dr. John Baugh).

Concrete is used more than any other man-made material to make dams, parking lots, building structures, roads, pavements, and more. Deficiencies in concrete can lead inadequate performance of the constructed facility. As a result, concrete is tested for quality assurance with respect to many characteristics, and most importantly for its strength. When doing so, a compressive axial load is typically applied to molded concrete cylinders within a prescribed loading rate until failure occurs. The load at which this occurs is then divided by the cross-sectional area of the cylinder to calculate the compressive strength of the specimen. Within a concrete testing facility, the logistics of undertaking this process for hundreds and perhaps thousands of cylinders can become quite complex since typically a set of six cylinders is tested at 7 and 28 days for every 50 to 150 cubic yards of concrete produced. This thesis describes the process of cylinder testing at a concrete testing facility. Critical and repetitive activities are identified and an alternative process model is suggested with the use of RFID (Radio Frequency Identification Tags) and automation devices. The use of RFID reduces the risk of mixing up cylinders and improves the checking process at the laboratory, which is a critical activity. To eliminate the tedious and repetitive activity of measuring cylinder diameters, the development of a prototype device is proposed using a 68hc12 microcontroller and ultrasonic sensors, an approach which also reduces human error. A Java-based simulation program compares both current and proposed process models for time differences. Results show a reduction of total time for overall cylinder testing by more than half.

PROCESS MODELING AND AUTOMATION OF CONCRETE CYLINDER TESTING

by

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A thesis submitted to the graduate faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

CIVIL ENGINEERING

Raleigh, North Carolina

2006

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To my family and friends …

BIOGRAPHY

Pranav Parikh was born on September 8, 1983 in Ahmedabad, India. He graduated with a Bachelor of Engineering degree in Civil Engineering from Nirma Institute of Technology, Gujarat University, India, in June 2004. He joined the Masters of Science program in the Civil, Construction, and Environmental Engineering Department at North Carolina State University, USA with focus in Computer Aided Engineering in fall 2004.

ACKNOWLEDGMENTS

I would like to express my gratitude to my advisor, Dr. John Baugh, for his guidance, patience and hours he spent with me to help bring this thesis to the current form. I am grateful to my committee members, Dr. Michael Leming and Dr. David Johnston, and to Dr. Ram MK, for devoting time and providing valuable input.

I would like to thank Mr. James Smith, President of Advance Testing Company, Inc., for providing laboratory access and necessary equipment to conduct my study. I would also like to thank my colleagues, Daryl O'dell, Mark Clark, and Kevin Patton, for providing me with technical details of testing procedures.

I would like to thank my parents, Mr. Snehal Parikh and Mrs. Darshna Parikh, and my younger brother, Manan Parikh, for the love, care and encouragement they have given me throughout my life. I would also like to thank my teachers, Mrs. Dipti Shah, Mrs. Dewangi Shah, Mrs. Bhairavi Maniyar, Mr. Ravi Agrawal and Mrs. Nita Patel, for believing in me and their constant inspiration and guidance without which I would not have reach at this level of my life. I would like to thank my aunts, Mrs. Minal Shah and Mrs. Pragna Shah, for their support and words of wisdom.

I would also like to thank my friends Bhushan Bhatt, Vineet Sahijwani, Pritesh Patwa, Tara Sivamani, Khyati Ruparelia and Mitul Patel for being caring, understanding and supportive. My life as a graduate student would not have been the same without these friends.

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CHAPTER 1:INTRODUCTION

1.1 BACKGROUND

Concrete is a construction material that consists, in its most common form, of portland cement, aggregate, water and admixtures. Water reacts with cement in a chemical process known as hydration, bonding the other components together and eventually creating a stone-like material. Concrete is the most widely used construction material. It is used more than any other man-made material on the planet [Ref 6].

To assure the quality of concrete, the American Society for Testing and Materials (ASTM) committee, C09, Concrete and Concrete Aggregates, was formed in 1914. The scope of this committee is to develop standards for concrete and for the constituent materials of concrete. In 1958, committee C09 became a joint sponsor of the Cement Reference Laboratory (CRL), and later the name Cement and Concrete Reference Laboratory (CCRL) was adopted. CCRL provides an inspection process for testing laboratories with a comprehensive account of the testing procedures, practices, equipment, and facilities with respect to ASTM standards requirements. ASTM provides standards for concrete testing, and CCRL acts as an accreditation agency for testing laboratories in the United States.

Concrete has two distinct stages: (A) fresh concrete, and (B) hardened concrete. Both stages are tested for different characteristics. Most typically, fresh concrete is tested for consistency and hardened concrete is tested for strength. Engineers usually specify the required compressive strength of concrete, normally given as the 28-day compressive strength in megapascals (MPa) or pounds per square inch (psi). Twenty eight days is a long wait to determine whether the desired strength will be obtained, so three-day and seven-day strengths are also used to predict the ultimate 28-day compressive strength of concrete. A 25% strength gain between 7 and 28 days is often observed with 100% ordinary portland cement (OPC) mixtures.

Technicians performing concrete tests must be certified by the American Concrete Institute (ACI). Concrete is typically sampled while being placed, with testing protocols requiring that test samples be cured under laboratory conditions. Concrete tests can measure the "plastic" (un-hydrated) properties of concrete prior to and during placement. As these properties affect the hardened compressive strength and durability of concrete (resistance to freeze-thaw), the properties of slump (workability), temperature and density are monitored to ensure the production and placement of “quality” concrete. Compressive strength tests are conducted using an instrumented hydraulic ram to compress a cylindrical or cubic sample to failure. Tensile strength tests are conducted either by three-point bending of a prismatic beam specimen or by applying compression along the sides of a cylindrical specimen resulting in splitting tension.

1.2 OBJECTIVE

The objective of this research is to understand, document, and analyze an industry procedure for concrete cylinder testing from a perspective of operational efficiency. It is focused on the process and logistics of cylinder testing and not the technical specifications of the testing procedure. Specific objectives include understanding the current industry process of cylinder testing, documenting and modeling the details of the process, and analyzing the process so that possible improvements may be identified. Observing the industrial testing procedure and developing a simulation model are needed to meet these objectives. The simulation model can also be used to predict the effects of future improvements to the current process. These enhancements to the process model rely on the use of Radio Frequency Identification (RFID) tags for cylinders, as opposed to paper tags, and make use of automation technology for measuring the diameters of cylinders. Implementation and integration of these improvements into the current process are studied and explained. A simulation of the proposed process model is developed so that performance comparisons can be made between both approaches. This comparison leads to an analysis of the reduced effect of the number of cylinders on the testing procedure. This research investigates the use of the latest automation and communication technologies to improve the current concrete testing processes of the construction industry.

CHAPTER 2: CURRENT PROCESS MODEL

2.1 COMMERCIAL TESTING FACILITY

To achieve the objective of this study, an actual commercial testing facility is considered to better understand current industry practice. Advance Testing Company, Inc. is a consulting construction materials testing laboratory that has been providing testing services to its construction clients since 1984. Located at Campbell Hall, New York, Advance Testing provides both field inspection and laboratory analysis of all construction materials for commercial, private, and public organizations. The company has built a state-of-the-art laboratory with more than 15,000 sq. ft. of space to accommodate a wide variety of material testing in an open and clean environment. Advance Testing also maintains a quality assurance program in accordance with AASHTO and ASTM specifications.

Because concrete testing is at the core of the services they provide, all technicians are certified by ACI as Level I Concrete Field Technicians. With a moist curing room designed to hold over 4,000 standard concrete specimens (mainly cylinders), the company's concrete laboratory is AASHTO accredited and certified by the CCRL for major concrete testing procedures. The following is a list of the testing procedures that constitute the scope of this work:

- T 22 / C 39 Compressive Strength
- T 97 / C 278 Flexural Strength
- T 126 / C 192 Making and Curing Concrete Test Specimens in the Lab
- T 213 / C 617 Capping Cylinders

An opportunity to observe operations was afforded during a six-month internship experience at the Advance Testing Company as an Assistant Lab Manager, a position that enabled the author to participate in and document the processing procedures for concrete cylinder testing. Responsibilities included working with field technicians to cast cylinders on-site, helping laboratory technicians with testing procedures, and assisting managers in scheduling operations. Most importantly, being a part of all these day-to-day activities promoted a general understanding of the process model of cylinder testing in a commercial material testing facility.

The overall process of concrete cylinder testing for compressive strength test consists of two major processes: (A) field and office processes and (B) laboratory processes. The central office facilitates administrative activities like scheduling, data collection, and reporting to the client. Field work consists of sampling concrete material in the field and testing fresh concrete for workability and casting concrete cylinders. Laboratory processes are the most complex and time consuming, which consist of curing and testing cylinders.

2.2 FIELD AND OFFICE PROCESS

Figure 2.1 illustrates the flow of information for field, office, and laboratory processes. Clients call the scheduling department to request the testing of concrete placement. The total quantity of concrete to be placed, the specified strength of the concrete, and the location of the placement are collected by the scheduling department, and the request is generated in the system. A field technician is assigned to the request and the concrete placement details are transferred to technician.

From the given information, the technician identifies the number and type of the cylinders required to test the concrete. Typically, the technician casts 6 (2 for 7-day breaking, 2 for 28-day breaking, and 2 as back ups) 4 x 8 inch cylinders, for each 50 cubic yards of concrete. The size and numbers of the cylinders vary depending on the size of the aggregate and client's requirements. In the field, the technician performs the standard concrete field test for workability as per ASTM standard [Ref 3].

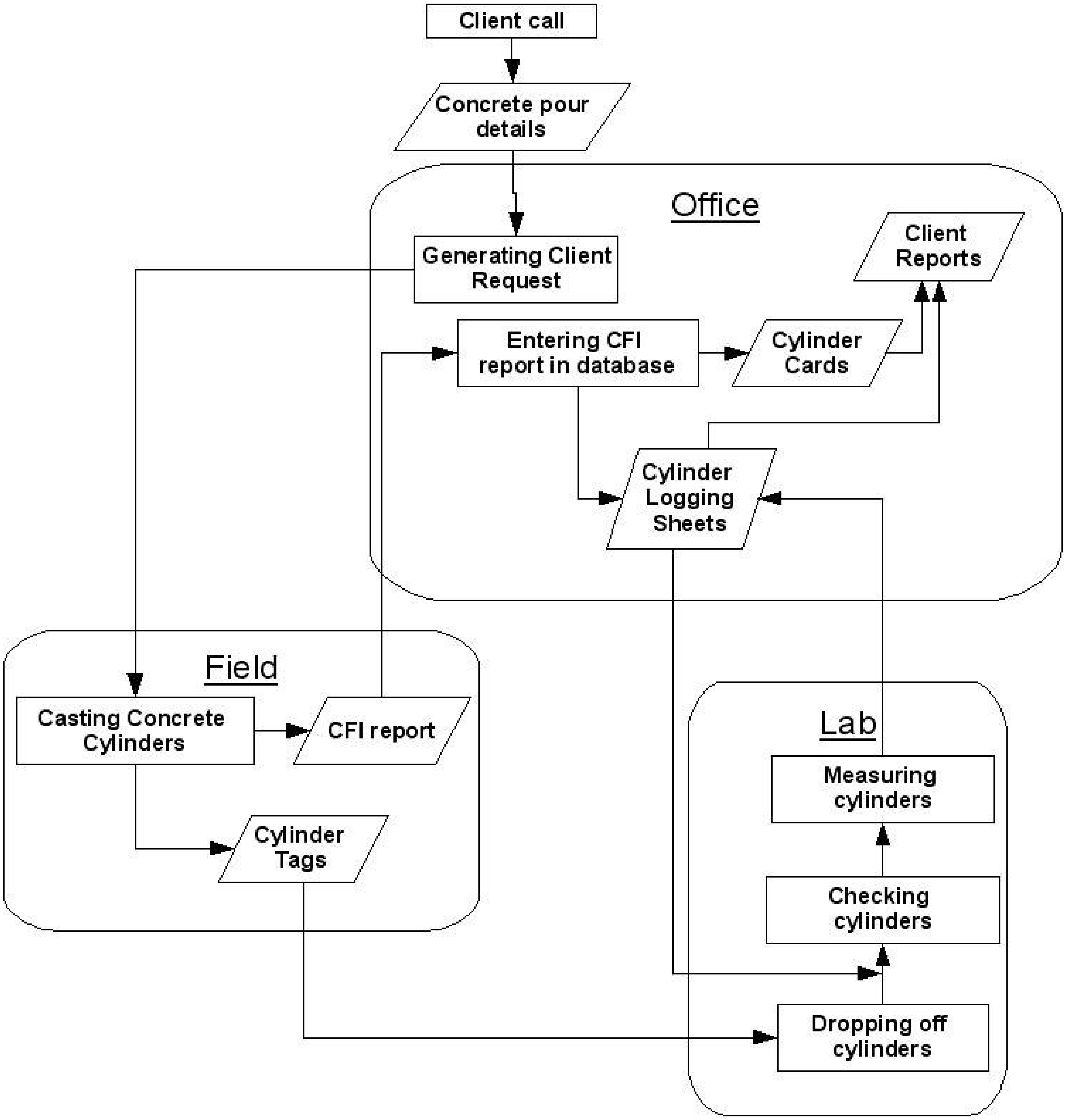


Figure 2.1 Flow of information in current process model

After initial tests, the technician casts concrete cylinders with standard procedure C31 [Ref 1]. This process generates information that is divided in two parts: Concrete Field Inspection (CFI) reports and cylinder tags. CFI reports contain individual test details and concrete cylinder properties. A cylinder tag contains the location, casting date, and set number, which are attached to the cylinders.

Details of the CFI report are transferred to the office and stored in digital format. From CFI reports, Concrete Cylinder Cards are generated. At this point, the lab manager assigns numbers to the cylinders. The Concrete Cylinder Card contains the physical properties of the cylinder as well as the testing results. These cards initially log all information. As the process continues, data are added to these cylinder cards. Cylinder Logging Sheets are generated from unfinished Cylinder cards. Cylinder Logging Sheets are then transferred to the laboratory to get the necessary information. Upon completion, finished logging sheets are transferred back to the office where Cylinder cards are completed by adding information from Cylinder Logging Sheets, and final reports are generated.

Cylinder pick-up is scheduled for each concrete placement for the next day. A technician picks up cylinders with cylinder tags and drops off the same at the laboratory. From this point, the laboratory technician takes care of any further cylinder processing.

2.3 LABORATORY PROCESS

Once the cylinders are placed in the laboratory by the field technician, they are put inside a storage area in sets. Each cylinder set is checked with Cylinder Logging sheets for the client details. Cylinder Logging Sheets are printed every morning, and they contain numbers for each cylinder. Figure 2.2 shows flow chart diagram of current laboratory process.

Cylinders are checked for any physical damage during the on-site storage or transportation. Cylinders are checked for perpendicularity to the axis which should not exceed 0.5° according to ASTM standards C39 [Ref 2]. Each cylinder set is checked on the logging sheet for the cylinder number. If the cylinder is not on the logging sheet, that cylinder is reported to the office as missing information. The lab manager checks on the missing information and adds that cylinder on the logging sheet with the cylinder number. Each cylinder has to go through the checking process. Without the cylinder number, the cylinder cannot be stripped. Each cylinder is checked with the rest of the cylinder numbers on the Logging Sheet.

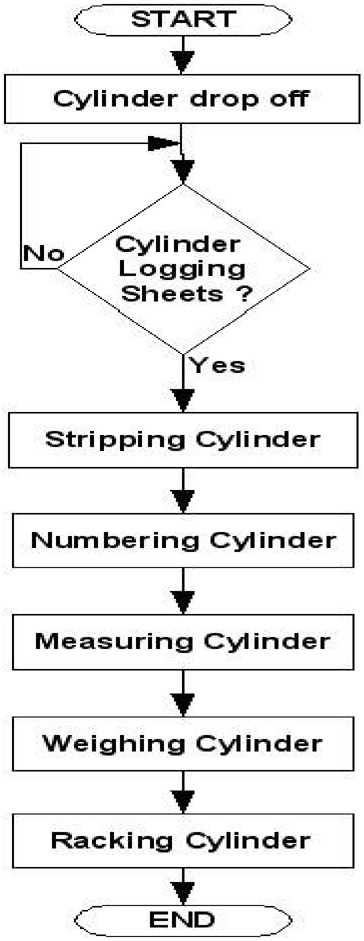


Figure 2.2 A flowchart of the current process model

The checking process becomes lengthy and complex with an increased number of cylinders. Cylinder Logging Sheets contain information on all the cylinders which are cast in the field. Some of these cylinders might still be in the field but they are on the cylinder logging sheets. This makes the checking process more complex and time consuming.

Once the cylinder is checked, the plastic mold is stripped off the cylinder. Stripping is done using the stripping hammer. The cylinder number is written with a permanent marker on a smooth face of the cylinder. The breaking date is also written beside the number, which is available from the Cylinder Logging Sheets. This is the first time the cylinders are marked with cylinder numbers. Cylinders are measured for their diameter using vernier calipers. The average value of two measurements, taken at right angles to each other and at the mid-height of the cylinder, is used for the calculation. According to ASTM standards, any cylinder with more than 2% difference within the same set is rejected for further testing [Ref 2]. Cylinders are measured with 0.25 mm accuracy [Ref 2]. After measurements, cylinders are weighed on a digital scale with an accuracy of 0.01 kg.

Cylinder Logging sheets are finished with measurements and sent back to the office for further use. Cylinders are placed in a curing room in their respective racks. The curing room is divided into 30 racks according to the break date. Each day of the month has a rack.

2.4 ANALYSIS

During the author's internship at Advance Testing Company, the current process was closely observed along with routine failures in the process which sometimes occurred. In most cases, the cylinder testing process becomes unstable on busy days at the laboratory either due to missing reports from field technicians or skipped cylinder pick-ups from construction sites.

In the current process, cylinder information is transferred to office in the form of CFI reports. All other reports during the process are generated from the CFI report, including cylinder numbers. If a technician fails to submit a CFI report to the office on time, cylinders are not generated in the database. Due to automated scheduling of pick-ups, these cylinders then arrive at the laboratory on the following day. This can be corrected by gathering cylinder information from the cylinder tags and notifying a field technician for the CFI report. But paper tags are sometimes lost due to rough handling and transportation. In such cases, cylinders are dropped off at the laboratory without any information along with minimal information in the database. Such cases of missing information are then handled by the lab manager, requiring additional time.

Another problem with the current process is a lack of feedback for the completion of a cylinder pick-up activity. If the assigned field technician fails to pick up cylinders from the field without reporting to the scheduling department, cylinders are assumed to be in the laboratory. If the CFI report is entered in the system, all other reports are generated. Missing cylinders then appear on the system on the seventh day for testing. Due to the dynamic nature of construction sites, it becomes extremely difficult to find these cylinders on site after a delay of seven days.

In extreme cases, if a CFI report is not submitted and a technician fails to pick up cylinders, the cylinders become “invisible” to the system. To avoid such problems, cylinders need to be tracked at each and every step of the process. Such a tracking system can be developed using the latest technology, and it can be automated to reduce human errors as much as possible. Chapter 3 describes a proposed process model to reduce tracking problems using RFID.

CHAPTER 3:PROPOSED PROCESS MODEL

As discussed above, the current cylinder process model has two major limitations, cylinder tracking and cylinder handling. Cylinder tracking can be improved by implanting RFID tags, and handling time can be reduced by implementing an automated device to perform repetitive activities like measuring and weighing.

The improved process model integrates both RFID tags and an automated device into the current process to minimize time waste and to improve the overall efficiency of the system. Details of the RFID technology and the automated device are explained in subsequent chapters. Figure 3.1 shows a process flow diagram for the suggested Improved Process Model.

Pre-numbered RFID tags can be used to improve the tracking ability of the cylinders. A field technician will be carrying RFID tags instead of paper tags which are numbered in sequence. These tags can be embedded below the top surface of the cylinders in a way that they can be partially visible. These tags contain basic cylinder data. RFID tags are also pre-numbered, so cylinders are numbered in the field.

An RFID reader gate is created at the laboratory entrance. When a technician drops the cylinders at the lab, this sensor will detect all cylinders entered into the laboratory. The gate sensor will update the status of the cylinder in the database by removing the flag. At the end of the day, the pending cylinder pick-up list can be automatically generated. This list will reduce the lag time of cylinders coming back to the laboratory. It also reduces the probability of missing cylinders. Cylinders which are not scanned are assumed to be on site, and reported as missing. This report is sent to the scheduling department for next-day pick-up.

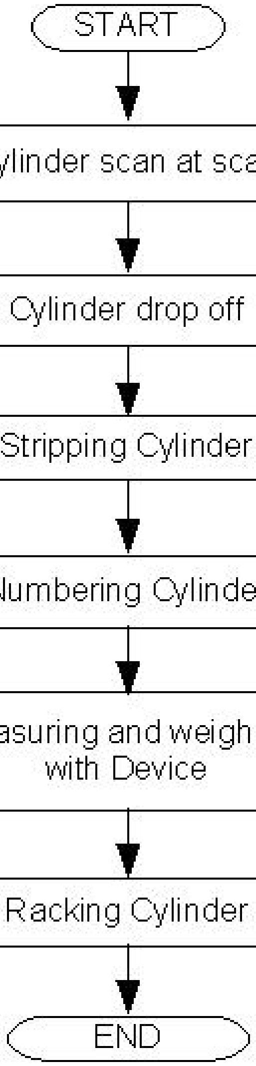


Figure 3.1 A flowchart of the Proposed Process Model

Cylinders are stripped after the physical checking and quality assurance process. After stripping, cylinders are scanned. This scan gives all the details of the particular cylinder, including cylinder number and the breaking date. The cylinder number and breaking date are marked with a permanent marker on the smooth face. These numbered cylinders are placed on an automated device for measurements. The device can measure the diameter of a cylinder using an ultrasonic sensor and a microcontroller. Details of the device are described in Chapter 6. Placing the automated device directly on a digital weighing scale eliminates the handling time for weighing. A built-in RFID reader reads the cylinder number and stores directly into the database the diameter of the cylinder from the device and its weight from a digital weighing scale. At the end, cylinders are placed in the curing room in their respective racks based on breaking date, for curing.

Major improvements:

- Cylinders are numbered in the field just after casting. This is unlike the current process in which cylinder numbers are generated in the office and cylinders are numbered in the laboratory.
- Information about individual cylinders floats with the cylinder, stored in a tag. In the current process, cylinder information is noted on CFI reports and stored in a central database.
- Cylinder location is updated at the laboratory entrance and a log is created. This activity is not present in the current process model.
- Measuring of cylinders is an automated process, eliminating human error.
- Weighing of cylinders is eliminated as a separate activity, since it is done simultaneously while measuring the cylinder using the automated device. This eliminates one more activity from the overall process, further reducing the handling time.

CHAPTER 4:SIMULATION

Creating a model is just one step toward understanding and gaining insight about a system. Simulations are created to conduct experiments with a model in order to understand the behavior and performance of that model. In this case, it is the process of repeating current activities over a period of time to predict the future response of the current activities.

A simulation is generally considered a fixed system with variable inputs taking different values to study the behavior of the output variable(s) [Ref 7]. In other words, simulations may be viewed as input/output devices in which a variable set of inputs is processed to comprehend the output.

In our case, a process model of the current cylinder testing is created and discussed in Chapter 2. To understand the process time for each individual activity and the overall total time for the current process model, a Java-based simulation program is created using BlueJ [Ref 4]. The objective of this simulation is to study the effect of increasing demand of cylinder testing on the current cylinder testing model with respect to time. Simulation results are then evaluated to understand the current process model. Critical and repetitive activities are identified from the data and an alternative process model is proposed to minimize the total duration of cylinder testing. The proposed process model is discussed in Chapter 3. Simulation for the proposed process model is generated to compare both the current and proposed process models. Differences of time for each individual activity and the overall process are analyzed and the efficacy is discussed.

4.1 ASSUMPTIONS

Cylinder testing for strength is generally performed on a set of four or six cylinders for a particular batch of concrete. To simplify the simulation process, each cylinder set is assumed to be a set of six 4” x 8” cylinders.

As described in Chapter 2, the current cylinder testing process model consists of five activities: Checking Cylinders, Stripping Cylinders, Numbering Cylinders, Measuring Cylinders, and Weighing cylinders. Except for checking cylinders, the remaining activities may be viewed as “administrative activities.” Thus, these activities are assumed to be normally distributed with respect to time. Stripping cylinders is close to a normal distribution, but due to the complexity of the activity, it is skewed on the higher side. This simulation is focused on an analysis of the number of cylinders and a comparison of total time between current and proposed process model. Therefore, stripping cylinders is assumed to be a normal distribution instead of a skewed distribution, an assumption which should have minimal effect on the simulation. Cylinder checking is very similar to a sorting activity. The total time to check all cylinders is directly proportional to the total number of cylinders that need to be checked. For simulation purposes, it is assumed that each cylinder is checked with all the remaining cylinders on the cylinder logging sheet. This eliminates the probability of human tendency to remember the locations of cylinders on logging sheets. Also, it is assumed that the cylinder logging sheet contains the details of all cylinders currently present in the laboratory, and does not contain any more.

Standard deviation and mean values of each activity are assumed. These assumptions are based on personal experience at Advance Testing Company and surveys that were conducted among company representatives. Survey Forms [Table 4.1] were sent to company officials who were asked to give minimum, maximum, and average times required for these activities, based on their experience. After examining the received data, the values in Table 4.2 were used for simulation of the activities.

Table 4.1 Survey Form

	Time in Minutes		
Activity	**Minimum**	**Average**	**Maximum**
Checking			
Stripping			
Numbering			
Measuring			
Weighing			
Total Time			

Table 4.2 Standard deviation and mean values of activities

	Time in Minutes		
Activity	Mean	Standard Deviation	Average
Checking			0.5
Stripping	8	2	
Numbering	2	0.5	
Measuring	12	2	
Weighing	6	1	

4.2 SIMULATION MODEL

Figure 4.1 shows a simulation model for the current process. For normally distributed activities, a pseudo random number is generated for the standard normal distribution. Multiplying this random number with the standard deviation and adding it with the mean value gives the time for each individual activity. The value of time is passed to the Simulation class where time is added to total time counter as well as individual activity counter. The same process is repeated for each normally distributed activity of the process for one cylinder.

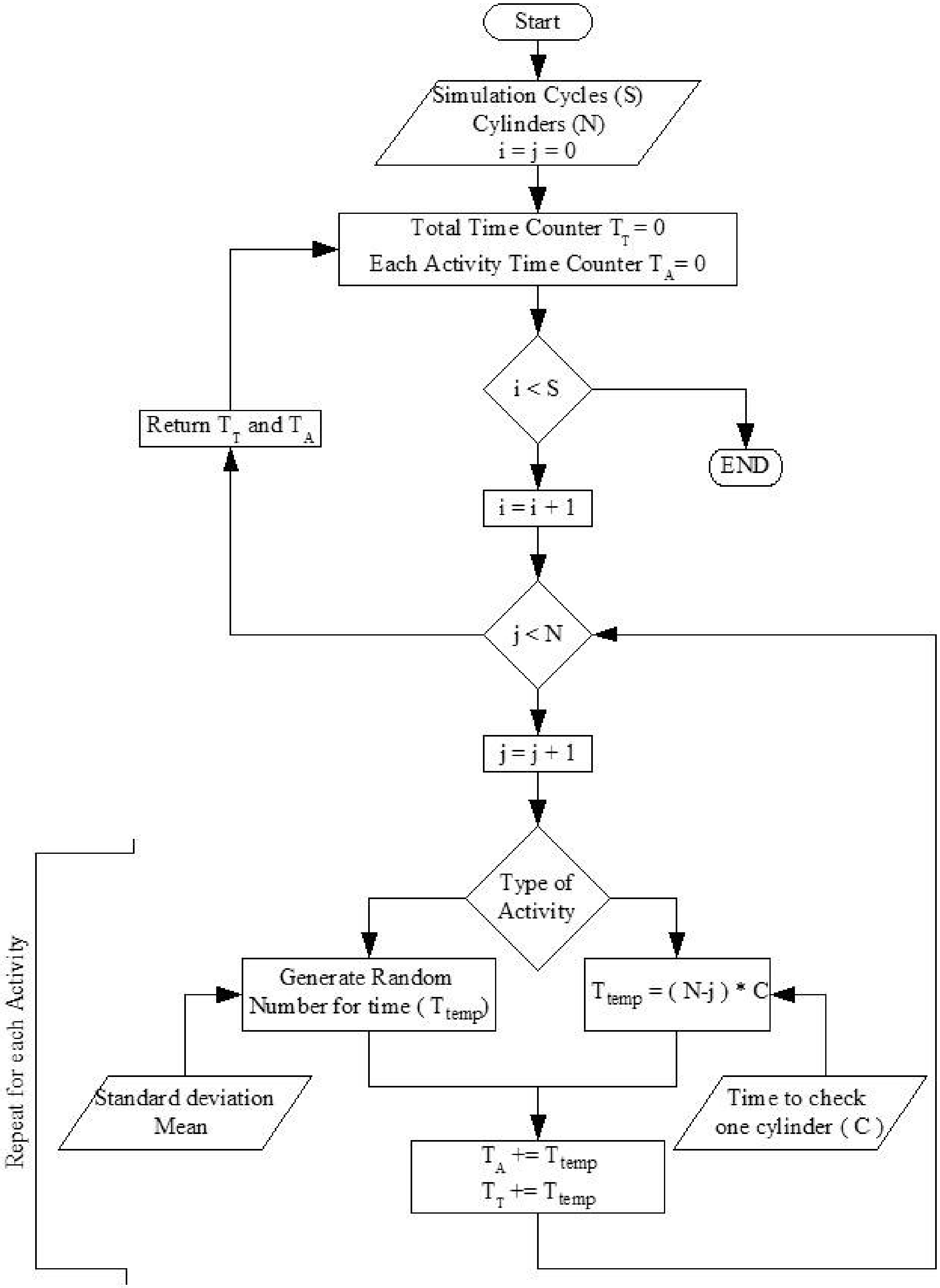


Figure 4.1 Simulation Model for the Current Process

For cylinder checking, the remaining number of cylinder count is passed to the checking activity object. The time to check one cylinder set is multiplied with this count which gives the total time to check that particular cylinder. Checking time is also added to the total time counter and checking time counter. The process is repeated for the total number of cylinders for each day for one cycle of the simulation.

To determine the optimal number of cycles of the simulation, the test runs were performed for between 50 and 1000 cycles. The total time of the process becomes constant after 500 cycles as shown in Figure 4.2. Thus, 500 cycles is considered to be the optimal number of cycles and used in the rest of the simulation.

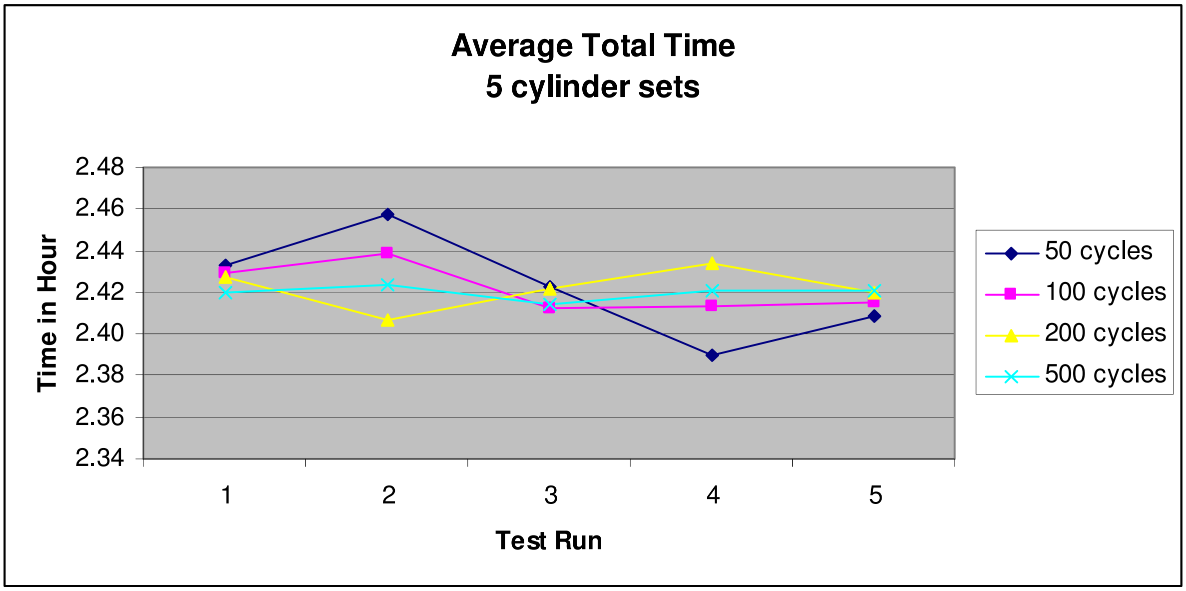


Figure 4.2 Effect of number of simulation cycle on total time

Similarly, a simulation for the proposed process model is developed. This proposed process model consist of three activities –

- Stripping Cylinders
- Numbering Cylinders
- Measuring cylinder using Device

The first two activities are not changed in the proposed process model from the current model. Thus, simulation for both these activities is similar in both the current and proposed process models. Stripping and numbering is simulated with the same values of standard deviation and mean, as used in the current process model simulation. Measuring cylinders using a certain device is a constant time activity. Thus, the time to measure one cylinder is multiplied with the total number of cylinders for each cycle.

4.3 RESULTS AND ANALYSIS

4.3.1 COMPARISON OF TOTAL TIME FOR EACH ACTIVITY

Figure 4.3 compares maximum, minimum and average time required to complete each activity for the current process model. A similar comparison is plotted in Figure 4.4 which reflects the percentage completion time of each activity with respect to total time for the overall process. Measuring and stripping of cylinders takes 40 and 30 percent of total time respectively. Thus, automating such activities can greatly reduce total process time and labor hours.

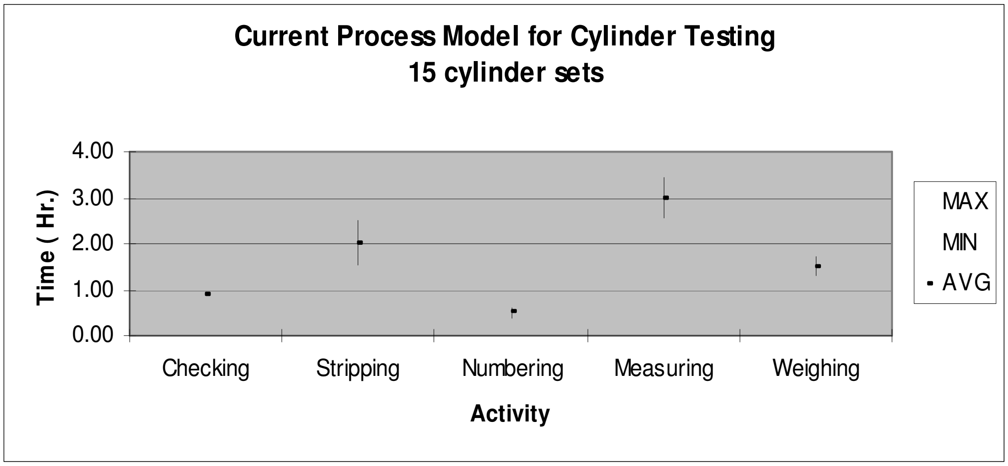


Figure 4.3 Comparison of MAX/MIN/AVG time for each activity

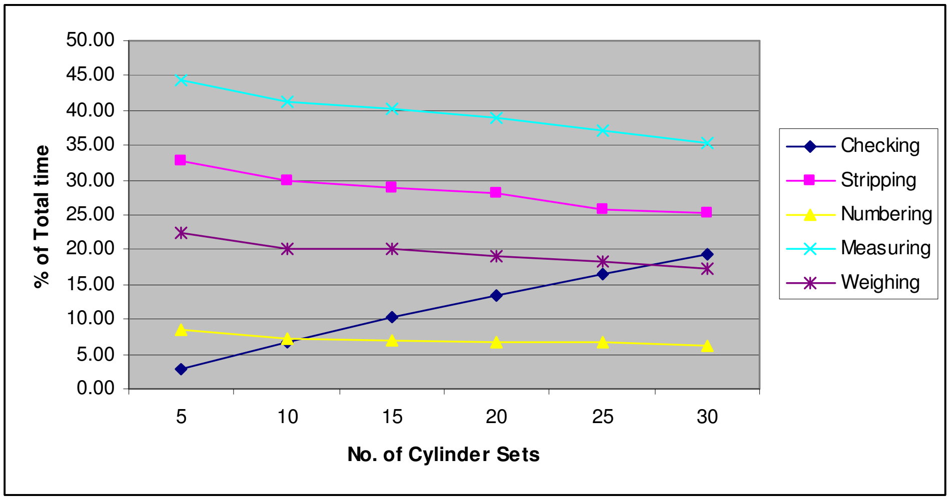


Figure 4.4 Comparison of time of each activity over total time

4.3.2 EFFECT OF NUMBER OF CYLINDER SETS ON TIME FOR EACH ACTIVITY IN CURRENT PROCESS MODEL

From Figure 4.5, in an eight hour working day, almost 10 cylinders can be processed for testing. This can be defined as the break even point for the current process model. If the number of cylinders increases above the break even point, this process model fails and more lab technicians are required to finish the work.

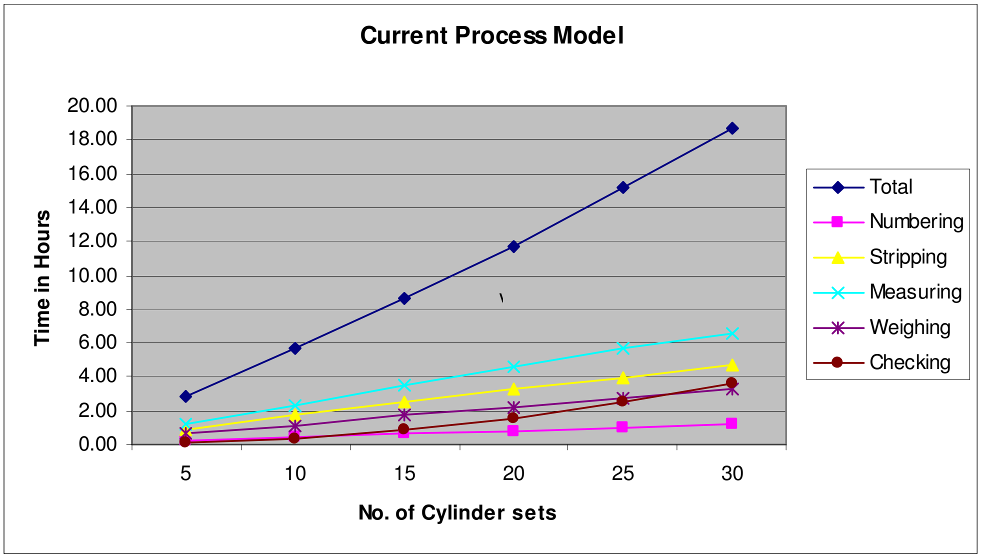


Figure 4.5 Effect of number of cylinder sets over time

4.3.3 CHECKING CYLINDER – CRITICAL ACTIVITY

Figure 4.6 shows that the time required for completing the checking activity, increases quadratically. Currently, the laboratory handles 10 sets of cylinders on an average working day. On busy days, this number increases to 15 to 20 cylinder sets, which involves switching the technician from field to laboratory. If the company plans to expand, the total number of incoming cylinders can grow to at least 30 cylinder sets per day without increasing the man hours. From Figure 4.6, it is clear that 30 cylinder sets takes almost four times longer to check than 15 cylinder sets. Thus, this activity becomes the most critical activity in the process as the number of testing cylinders increases.

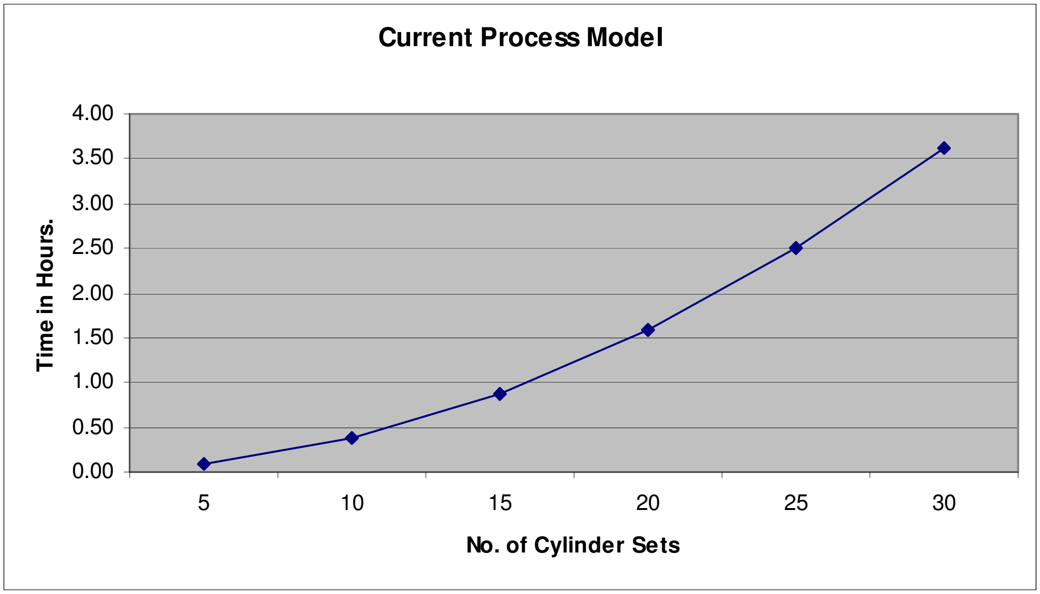


Figure 4.6 Effect of number of cylinder sets over time for cylinder checking activity

4.3.4 COMPARISON OF TOTAL TIME FOR CURRENT AND PROPOSED PROCESS MODELS

Figure 4.7 clearly shows the reduction in total time with the improved process model. Total time reduces to half from five hours at the break even point of the current process. For

30 cylinder sets, total time is reduced from 18 to 6 hours. This increases the capacity of the laboratory from 10 to 30 cylinder sets.

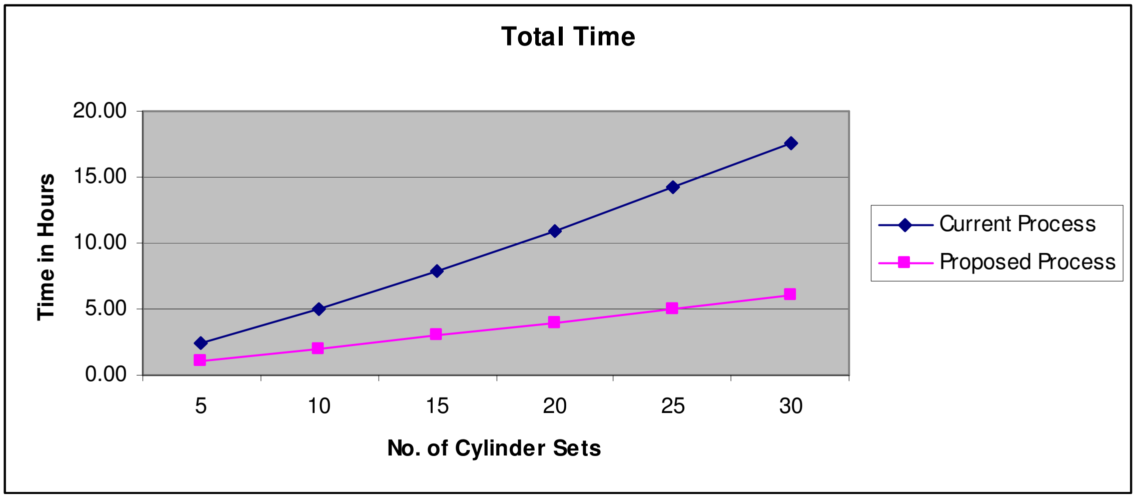


Figure 4.7 Comparison of total time for current and proposed process models

4.3.5 COMPARISON OF TIME FOR MEASURING AND WEIGHING TIMES FOR CURRENT AND PROPOSED PROCESS MODELS

A major reduction of time is noticed in the cylinder measuring activity. The proposed use of automation reduces the measuring time to almost one-tenth, from 9 hours to 1 hour, as shown in Figure 4.8.

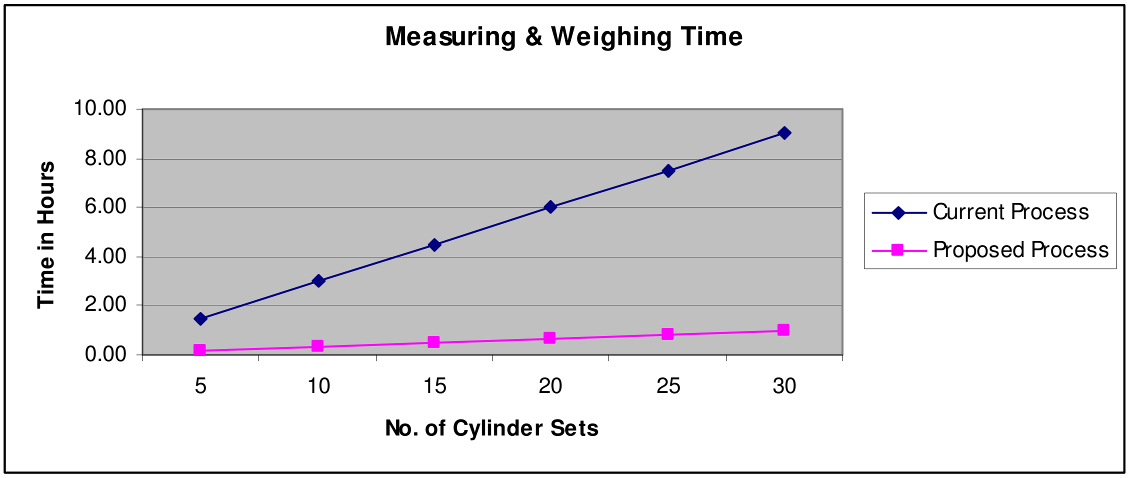


Figure 4.8 Comparison of measuring and weighing time for current and proposed process models

CHAPTER 5:RFID TAGS

5.1 INTRODUCTION

The present industry process for concrete cylinder testing uses a paper tag to identify each cylinder. A field technician writes field data such as the project name, placement location, date, and set number on each cylinder tag. Paper tags are the only identity of the cylinders until the cylinder numbers are written on the face of the cylinder in the laboratory. These tags become crucial to preserve cylinder field data and cylinder identification in the laboratory. These tags can tear or fall off from cylinders or become wet due to the water in fresh concrete. The handwriting becomes illegible in some cases due to wear and tear. To eliminate the loss of such critical data, paper tags can be replaced with Radio Frequency Identification (RFID) tags.

RFID is an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or transponders as shown in Figure 5.1. These tags are made up of a microchip and an antenna. The microchip contains the data, in most cases a serial number, which is transferred to a device, called an RFID reader/writer, via the antenna

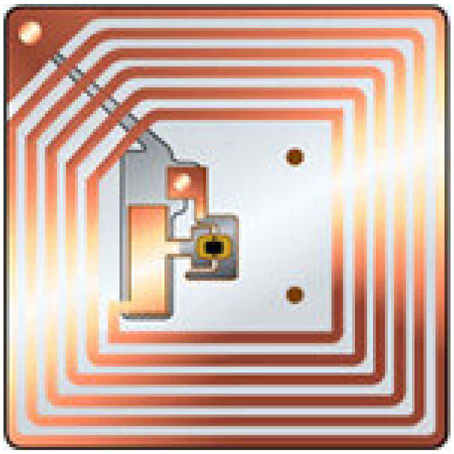


Figure 5.1 RFID tag

in the form of radio waves and vice versa. The RFID reader converts radio waves into digital data, which are transferred to computers for further utilization. There are three types of RFID tags: Active, Passive and Semi-passive. Active tags contain an internal power supply which is used by internal circuits to generate outgoing signals. The tags used in this research are passive tags. Passive tags use a backscattering method, which means they are designed to collect the signal from the reader and transfer the signal back to the source. Semi-passive RFID uses an internal power source to monitor environmental conditions, but requires radio frequency energy transferred from the reader/interrogator similar to passive tags to power a tag response.

5.2 RFID SYSTEM

A typical RFID system consists of three major components: tags, scanner and interface. Depending on the complexity of a problem, other components are added such as antennas. For testing purposes, in this research an RFID starter kit developed by RightTag, Inc. is used. RightTag is a leading manufacturer of standards-compliant RFID equipment and related software application. These help companies select and implement cost effective Automatic Identification and Data Capture (AIDC) solutions. The starter kit includes required software interface and hardware peripherals to initiate RFID integration and test the same.

The starter kit includes an RFID Hand Held Reader/Writer, as shown in Figure 5.2. It is a high performance RFID scanner for use in commercial and industrial applications. It can read in continuous read mode or trigger mode to identify multiple RFID tags. It comes with a built-in RS-232 or USB interface for easy connection to a host, and a set of developer tools, device drivers and software libraries are available for quick, easy integration with existing systems. Table 5.1 contains some specifications of the reader.

Figure 5.2 RFID Reader/Writer (RightTag Inc.)

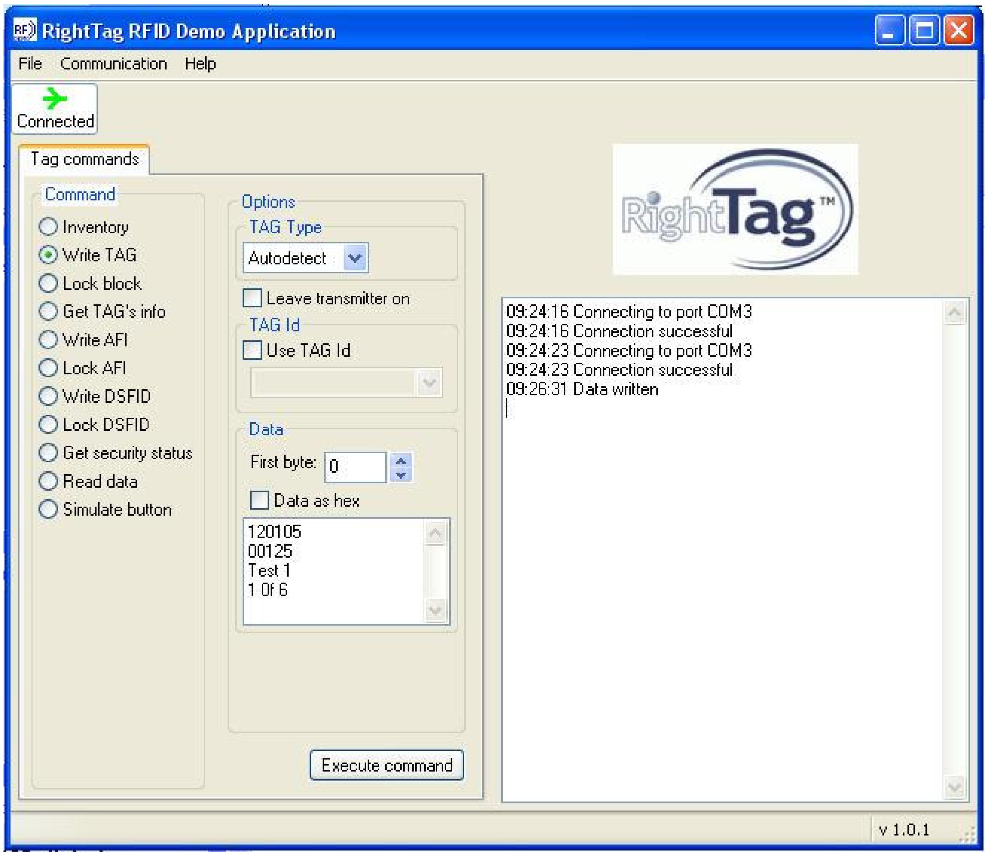
Table 5.1 Specifications of RFID Reader

Operating Frequency	13.56 MHz
Read Range	14 cm with credit card size tag
Tag Compatibility	ISO15693, Tag-it
Communication Interface	RS232 or USB
Operating Temperature	-20°C to +55°C (including self-generated heat)
Storage Temperature	-40°C to +80°C

Two types of tags, RFID paper labels and RFID plastic cards, were tested on cylinders. RFID plastic cards are standard credit card size plastic tags. These tags are passive RFID tags due to the lack of an internal power supply. Both types of tags are of the same size, 2.125" x 3.375", and they work at an operating frequency of 13.5 MHz.

5.3 IMPLEMENTATION AND TESTING

RFID tags were implemented on site during the concrete testing procedure. Along with the standard set of 6 cylinders for each test case, an extra 2 or 3 cylinders were cast with same concrete, and RFID tags were placed on these cylinders. Before attaching RFID tags to cylinders, details of the individual test case were stored in respective tags. The RFID handheld writer converts the data specified by a user into radio waves and stores the same data on a RFID tags. Figure 5.3 shows a snapshot of the RightTag Reader Demo Application, Version 1.0.1, which was used to write RFID tags.



TAG Type: Autodetect

First byte: 0

```
120105
00125
Test 1
1 0f 6
```

```
09:24:16 Connecting to port COM3
09:24:16 Connection successful
09:24:23 Connecting to port COM3
09:24:23 Connection successful
09:26:31 Data written
```

Figure 5.3 Snapshot of RFID interface software

With available types of RFID tags, there are three different methods of incorporating these tags into a concrete cylinder:

- Applying paper RFID tags on the outer surface of a cylinder
- Applying paper RFID tags on the inner surface of a cylinder
- Applying plastic RFID tags inside a cylinder

5.3.1 APPLYING PAPER RFID TAGS ON THE OUTER SURFACE OF A CYLINDER

Paper RFID tags are similar to a sticker. After unwrapping, they stick to almost any object. These tags were attached to the outer surface of the cylinders molds. Examination showed scratched on these tags, mainly caused due to rough handling and transportation. In some extreme cases, tags were damaged significantly and the RFID reader was not able to read the cylinder data. Thus, attaching a paper RFID tag on an outer surface invites the same set of problems as that of attaching paper cylinder tags. Due to the lack of significant improvements for using RFID tags, the idea of attaching RFID tags on an outer surface of a cylinder was rejected.

5.3.2 APPLYING PAPER RFID TAGS ON THE INNER SURFACE OF A CYLINDER

After rejecting the idea of attaching RFID tags on outer surface of cylinders, tags were attached to the inner surface of empty cylinder molds as shown in Figure 5.4. They were tested to check readability just after filling with concrete. The reader was able to read all the tags without any problems. This indicates that tags were not damaged by standard consolidation procedure of concrete filling.

These cylinders were transferred to the laboratory on the next day for cylinder logging procedure. Once again, tags were checked for data readability using the sensor when they were dropped off at the laboratory. Data was obtained from all the cylinder tags. The first problem with this method was during the stripping procedure as it was difficult to locate tags on the inner side before stripping. This raised the probability of damaging the tags during the stripping process.

Figure 5.4 RFID tag on inner surface of a cylinder

After removing the mold from the cylinder, tags placed on the inner surface showed scratches, as shown in Figure 5.5, and indentation of the tag was observed on all cylinders, as shown in Figure 5.6. This type of indentation was considered to be problematic strength testing as it could affect the measured strength. Indentation reduces the average diameter of the cylinder, thus slightly decreasing the strength of a cylinder over the actual strength. Although, the significance of this affect is not calculated, it raised the probability of future study before implementing RFID tags on the inner surface. For this study, RFID tags were not used further on the inner surface of cylinder molds.

Figure 5.5 Scratches on RFID tags

Figure 5.6 Indentation on outer surface of a cylinder due to RFID tags

5.3.3 APPLYING PLASTIC RFID TAGS

Plastic RFID tags are credit card size RFID tags with embedded circuits beneath plastic. They are more durable with respect to the normal wear and tear of handling process.

Initially, these tags were placed in three different ways as shown in Figure 5.7: tags placed on the top of a finished layer of the concrete surface, tags place just before finishing the top surface and tag placed inside the concrete. Placing tags inside concrete showed extremely low strength as the tag tends to create a shear plane inside the cylinder. Placing tags over the finished surface caused an indentation during capping process. Such indentation is not advisable. Tags placed just before finishing the top layer of the concrete showed average results similar to a normal concrete cylinder.

Figure 5.7 Placing plastic RFID tags

From all the test situations discussed above, placing a plastic RFID tags just before finishing the top layer of the concrete was found to be the most suitable method to incorporate RFID tags in concrete cylinder testing procedure. Due to the partial visibility of the tag, stripping of cylinder becomes easy. The reader was able to read stored data in a tag during all the activities of cylinder testing. After 28 days of curing, the reader was able to the read data. Even after breaking the cylinder and with partial damage to the tags, in most cases, data was retrieved. Tests were performed on cylinders with and without the capping. Capping had no effect on the plastic tags. Tests were performed for high and low field temperatures with no effect on readability of tags.

CHAPTER 6: MEASURING DEVICE

Measuring a cylinder is a fairly simple but time consuming process. As shown in Figure 4.4, measuring a cylinder takes more than 40% of that the total time in the current process model for cylinder testing. By automating the same, time can be reduced to a minimum in order to increase overall efficiency of the system.

To initiate the efforts for automating this process, an ultrasonic sensor is used. Ultrasonic sensors are widely used for distance measurement. The sensor produces a sound wave in the direction of an object. The object reflects the sound wave back to the sensor. The travel time (t) between generating and receiving the wave is recorded. Knowing the velocity (υ) of a sound wave, the distance (d) between the object and the sensor can be calculated from the following equation:

$$d = v \times t$$

To measure the distance between two objects, in our case the diameter of a cylinder, an ultrasonic sensor is placed on top of a servo motor as shown in Figure 6.1. As the servo motor rotates, the sensor scans the object from one edge to the other. Figure 6.2 (a) is a diagram of the automated device system. Time (t) is recorded from the first appearance of the object until the last edge. Knowing the rotational velocity (ω) of the motor, the angle (θ) between two edges can be calculated from the following equation:

$$\theta = \frac{\omega}{t}$$

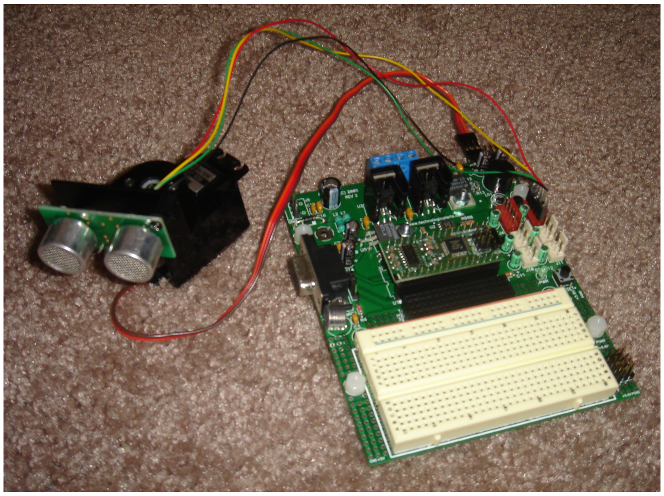
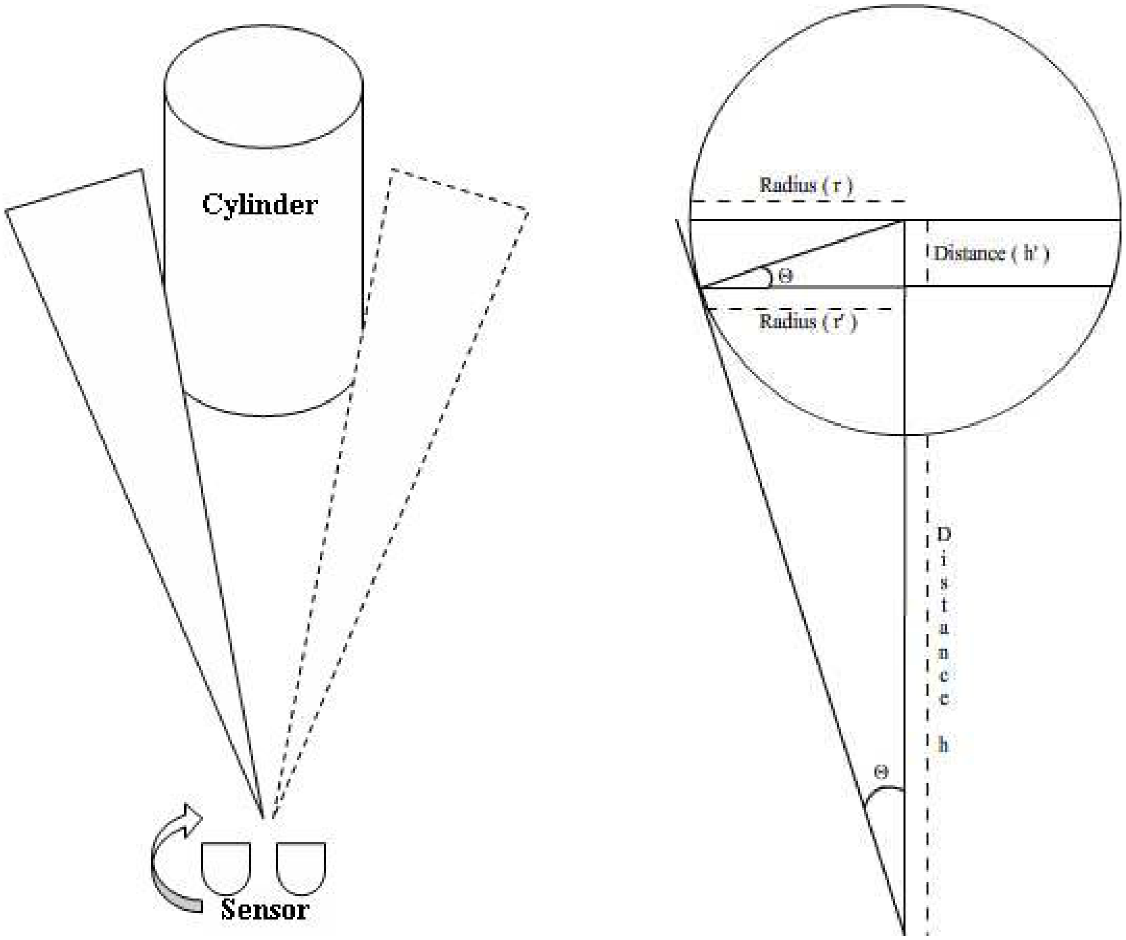


Figure 6.1 Snapshot of ultrasonic sensor attached with 68HC12 Microcontroller

The Devantech SRF04 ultrasonic range finder, developed by Acroname, Inc., is used to illustrate the possibility of an automated device for measuring diameters. This sensor has a range of 3” to 10’. An ultrasonic sensor is placed on a standard servo motor. To interface an ultrasonic sensor and a servomotor, a 68HC12 microcontroller is used [Ref 5], which is a product of Technological Arts, Inc. The device is able to find an object by line of sight. It also records the time duration for object in sight. Since the initial measurement (d) is tangent to a chord rather than tangent to a diameter (D), as shown in Figure 6.2 (b), the following correction is applied:

$$D = \frac{d}{\cos\theta}$$

Further calibration of the device is required in order to find a diameter of the cylinder. This device requires future work in order to achieve the stated objective.



(a) (b)

Figure 6.2 Diagram of Automated Device

CHAPTER 7: CONCLUSION AND FUTURE WORK

7.1 CONCLUSION

It is found that the current process model for cylinder testing has certain limitations. The current process model lacks a tracking ability for cylinders, which increases the probability of missing cylinders in the field. Paper cylinder tags lose cylinder data due to rough handling and transportation. Water in concrete sometimes wipes off the handwritten information of paper tags. In the current process model, the possibility of losing critical information is very high. Also, due to the checking process in the current process model, the capacity of the laboratory to test cylinders is restricted to 15 cylinder sets per day. To accommodate the increased demand of cylinder testing, the laboratory needs to reallocate labor hours from the field to the lab. Growth of the testing facility is restricted as the process becomes complex and less efficient with increased demand.

Implementing plastic RFID tags in the concrete cylinder process improves tracking of cylinders and test results. RFID tags reduce the manual manipulation needed for test data and also human errors. It reduces operating cost by automating the processes involved, from concrete sampling to cylinder testing. It increases the capacity of the testing facility to test concrete cylinders without hiring new employees. It eliminates loss of cylinders due to rough handling and transportation, as data are stored inside the tag in a microchip. Integrating the RFID system with the current process model also helps in generating reports more quickly as it reduces manual data entry. Use of the automation device to measure cylinder diameters reduces time drastically. With the proposed process model and the use of RFID tags and automation devices, the total time to test a cylinder is reduced, which helps with growing the testing facilities to incorporate more concrete cylinders with the same resources.

Overall, an increase in efficiency and a reduced probability of missing information should be obtained by incorporating the latest technologies over the more traditional way of testing.

7.2 FUTURE WORK

Calibration of the automation device to measure cylinder diameters needs to be performed in order to test the accuracy of results. Integration of the RFID system with the Internet can lead to live tracking of cylinders. Clients of the testing facility can then receive reports instantly after cylinder breaks are performed. Stripping cylinders is a tedious and time-consuming activity: automating this activity can lead to further savings in time.

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