DESIGN OF STANDARD OPERATING PROCEDURES FOR CONCRETE DELIVERY AND POUR DATA COLLECTION AND ANALYSIS

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by

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EXECUTIVE SUMMARY

Webcor Concrete Group (WCG) is a self-perform subsidiary of Webcor Builders, a large general contractor in the state of California. Inefficiencies plague the construction industry, resulting in Webcor reaching out to the Cal Poly Industrial and Manufacturing Department and its students for help. The opportunity addressed in this report centers on a lack of concrete pour data collection. This gap results in a struggle to defend against, or pursue, backcharges with their concrete suppliers regarding additional labor costs or wasted material. The project objective is to provide WCG with a baseline data collection system and procedure, leading to increased back-charge accounting, future project justification, and root cause analyses of inefficiencies.

The authors first researched automated GPS and RFID truck tracking systems, but ultimately used an iterative design process to create a manual data collection software solution. With the assistance of current Webcor Project Engineers, the authors were able to view several concrete pours, determining specific and measurable metrics to be collected for the data collection application. After researching software alternatives on the market, the authors pursued a solution that utilized Microsoft Excel and its formulas, charts, and coding language. The Excel workbook underwent several revisions, each building upon the last with project sponsor feedback and recommendations.

Once the final design was completed, the Excel workbook was distributed throughout WCG for Project Engineer use and Project Manager review. This feedback was used to conclude that the design met all project objectives; however, recommendations for additional functionality show that this design can be extended further. It can also be concluded that Industrial Engineering tools and methodology are applicable and beneficial to the construction industry, i.e.
‘Lean Construction.’ Long term implementation of the workbook will ultimately verify the success of the solution.

As a result of the workbook being developed free of cost by the authors, it is recommended that Webcor implement the tool and standard procedures, as there are no economic barriers, but only potential gains. The biggest impacts associated with the design implementation are organizational. In the short term, Project Engineers will dedicate additional time to data collection and input, but could potentially save time if redundant procedures are eliminated. The design also increases accountability of all parties in the concrete construction supply chain, provides a means of tracking long term Project Engineer performance and project progress, and can be used to justify future process improvement projects. Moving forward, it is recommended that an automated GPS or RFID truck tracking system be pursued and that efforts be made to turn the desktop application into a cloud-based one for increased collaboration and data visibility.
## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF TABLES</td>
<td>4</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>5</td>
</tr>
<tr>
<td>I. Introduction</td>
<td>6</td>
</tr>
<tr>
<td>II. Background</td>
<td>8</td>
</tr>
<tr>
<td>Current State &amp; Targeted Research</td>
<td>8</td>
</tr>
<tr>
<td>Lean Construction</td>
<td>9</td>
</tr>
<tr>
<td>Labor Productivity</td>
<td>10</td>
</tr>
<tr>
<td>RFID &amp; GPS Truck Tracking</td>
<td>14</td>
</tr>
<tr>
<td>Current Webcor Concrete Group Computing Tools</td>
<td>16</td>
</tr>
<tr>
<td>III. Design</td>
<td>17</td>
</tr>
<tr>
<td>Customer Requirements &amp; Constraints</td>
<td>17</td>
</tr>
<tr>
<td>Determination of Required Metrics</td>
<td>18</td>
</tr>
<tr>
<td>Proposal for Automated Truck Tracking System</td>
<td>19</td>
</tr>
<tr>
<td>Design Approach for Data Collection System</td>
<td>20</td>
</tr>
<tr>
<td>Design Iterations of Data Collection System</td>
<td>22</td>
</tr>
<tr>
<td>IV. Testing &amp; Methodology</td>
<td>33</td>
</tr>
<tr>
<td>V. Results &amp; Discussion</td>
<td>33</td>
</tr>
<tr>
<td>VI. Summary &amp; Conclusions</td>
<td>35</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>38</td>
</tr>
<tr>
<td>APPENDIX A</td>
<td>41</td>
</tr>
<tr>
<td>APPENDIX B</td>
<td>43</td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table 1: Suggested Recorded Metrics for All Pours</th>
<th>19</th>
</tr>
</thead>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Revision 1 ‘Template’ Sheet</td>
<td>23</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Revision 1 VBA Module for Quantity Tracking Table Population</td>
<td>24</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Revision 1 Example of Populated Quantity Tracking Table</td>
<td>25</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Revision 2 VBA Module for Quantity Tracking Chart Creation</td>
<td>26</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Revision 2 Example of Quantity Tracking Graph</td>
<td>27</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Revision 3 Example of Pour Quantity Tracking Table and Graph</td>
<td>28</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Revision 3 Example of Delay Tracking Table and Helper Cells</td>
<td>29</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Revision 3 VBA Module for Delay Tracking Charts</td>
<td>30</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Revision 3 VBA Module for Pour Scorecard</td>
<td>31</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Revision 3 Example of Completed Subcomponents</td>
<td>32</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Revision 4 Example of Final Design</td>
<td>32</td>
</tr>
</tbody>
</table>
I. Introduction

This report will discuss the design of standard operating procedures for concrete pour and delivery data collection and analysis for Webcor Concrete Group (WCG). Initially, it will provide an analysis of current state procedures and operations within WCG to help identify key metrics for the concrete pouring process, and provide a means for Project Engineers on each of the various Webcor sites to collect data to aid in evaluating the success of a pour.

The project idea was submitted to the California State Polytechnic University, San Luis Obispo, Industrial and Manufacturing Engineering department by Mike Clement, a Project Manager with Webcor Builders. Webcor realizes that inefficiency plagues the construction industry, and has started to recruit Industrial Engineers from Cal Poly in an effort to identify efficiency opportunities and take subsequent process improvement steps. The specific problem targeted is the lack of data available to review following a pour. Without this data, root cause analyses cannot be performed, hindering process improvement efforts and leading to finger pointing between WCG and their concrete suppliers. When concrete pour operations do not go smoothly, money is lost due to unproductive labor time and material waste. Determining responsibility for inefficiencies is necessitated by the financial implications of a pour’s success.

To solve the problem WCG currently faces several objectives have been established for this project:

❖ Identify key metrics to be collected during each pour.
❖ Develop and distribute the process and documentation for baseline data collection.
❖ Provide graphs of actual versus planned quantity of concrete poured over time.
❖ Compile a report analyzing discrepancies and highlighting root cause inefficiencies.
❖ Provide recommendations for concrete supplier truck arrival and departure tracking.

❖ Design a pour evaluation scorecard utilizing aforementioned key metrics.

In order to achieve these objectives, certain steps toward project completion were outlined. One of the authors of this report has had previous experience with WCG through a summer internship, but the second researcher has only had a limited, general construction background. As a result, the first priority was to get onto a Webcor project site to view a concrete pour. After viewing several pours at the Cal Poly Student Housing project site, the researchers were able to gain a better understanding of the pour process, discuss the project further with the Assistant Superintendent and Project Engineer (PE), and determine which metrics the PE would be able to feasibly obtain before, during, and after the pour. With this information, documentation and standard procedures for pour data collection will be provided to PE’s throughout California for future analysis. After viewing the initial pour, it was determined that the only key metric unobtainable by the PE’s were all concrete supplier truck arrival and departure times. As a result, a separate system will be recommended for truck tracking to solve the problem of inefficiency responsibility.

The remainder of this report will further discuss the background of the problem of inefficiency in the concrete construction industry, as well as attempts by other researchers to find process improvement solutions. A portion of the literature review will relate to currently implemented methodologies for truck tracking including both GPS and RFID technologies. Beyond this, other construction process improvement tools will be researched and evaluated as possible solutions to Webcor’s problem. The report will also detail the design process, analysis
of design alternatives, and the testing methodology, ultimately resulting in final recommendations for moving forward.

II. Background

This section serves to provide the reader with all relevant and necessary information to understand the problems affecting the concrete construction industry, previous solutions tested by researchers, and specifications of relevant software applications.

It is somewhat untraditional to use Industrial Engineering (IE) methodologies in the construction industry, but recently Webcor has seen the benefit of IE on the job site. Before discussing the application of IE tools, it is necessary to review what exactly Webcor Builders and WCG do. Webcor Builders is a general contractor that performs work within the state of California. One of their self-perform subsidiaries, Webcor Concrete Group, works as a concrete subcontractor both for Webcor Builders as well as other general contractors in the state. Their work ranges from commercial, residential, and industrial projects both in the private and public sector. The concrete division has been experiencing inefficiencies in the form of labor, material, and processes which provides many opportunities for improvement.

Current State & Targeted Research

Currently, WCG utilizes a process that the PE performs before each concrete pour. This pre-pour checklist is a standard document within the division. WCG also has a standard document for post-pour data collection, called a ‘concrete log.’ These documents are used to record data on individual pour parameters, but this leaves a large gap of information regarding what actually happens during the pour. The concrete log does have a space for comments; however, these tend to be very general, and do not give good insight or solid data regarding root
causes of efficiencies. One of the goals is to bridge this gap with a standard document, combining pre- and post-pour data with data collected during a pour, highlighting any discrepancies from the pour plan regarding volume of concrete placed, ultimately leading to causal identification.

Webcor Builders currently has improvement opportunities in their concrete pour evaluation procedure. The lack of relevant data prohibits consistently successful root cause analyses. This results in an inability to identify key areas for improvement, but also prevents the assignment of financial responsibility to either Webcor Builders or their concrete suppliers. Within the industry, it is common knowledge that construction is highly inefficient, so the first aspect of the literature review seeks to understand the full extent and causes of the inefficiencies present in concrete construction. The application of lean principles in the construction industry will assist in the identification and solution of the previously mentioned issues. The literature review will then examine previous studies and the data points experimenters have chosen to collect when evaluating construction, again ideally concrete construction, processes. Per the suggestion of a technical advisor, research on RFID and GPS technologies currently employed in construction and other transportation industries is presented, as this could be a potential means of tracking arrival and departure times of concrete trucks delivering to the sites. While it may be possible to accurately collect this data through RFID/GPS implementations at Webcor project sites, the remaining metrics will be self-reported by Project Engineers.

*Lean Construction*

The concept of lean construction is still relatively new when compared to lean methodology in general. As previously mentioned, Webcor has started to see the benefits of lean
thinking and IE methodology in their operations. Core elements of lean construction include, but are not limited to, waste reduction, continuous improvements, cooperative relationships, and a systems perspective (Eriksson, 2010). To begin with, Eriksson asserts that “efficient transportation and stockholding of material” can be assessed for waste reduction. Eriksson focuses on the supply chain connectivity and the importance of the relationships within it. A key takeaway from Eriksson’s research, in regards to this project, is the systems thinking mentality. The solution to Webcor’s problem will not arise from looking at each component individually, but rather as an entire system. Supplier participation and Webcor’s performance are equal factors when utilizing this mindset. This research applies to the theory and methodology behind this project as a whole and less with specific deliverables.

_Labor Productivity_

Due to the labor-intensiveness of the construction industry, labor productivity is critical to a project’s success and profitability. After interviewing consultants and industry professionals, El-Gohary and Aziz concluded that the three factors having the greatest impact on labor productivity were labor experience and skills, incentive programs, and availability of material and ease of handling (El-Gohary and Aziz, 2013). WCG prides itself on the quality of their labor crews, but faces issues regarding availability of material. When concrete trucks are delayed, WCG’s crews are idle, resulting in downtime and lost wages.

Pribadi et al. presented an article titled “Factors Relating to Labor Productivity Affecting the Project Schedule Performance in Indonesia” and provided a tremendous amount of information relating to the problem WCG faces. The group highlighted past researchers and the 113 factors in 15 categories that have previously been identified to affect labor productivity.
Pribadi et al. evaluate these factors to ascertain which were most relevant in 2011 (previous research presented dates back to 1989). The scope of this research was much broader than that of El-Gohary and Aziz but the sheer number of factors alone proves how complicated evaluating construction performance can be. It will be the author’s job to accurately focus in on the factors that specifically affect Webcor’s concrete operation.

While analyzing the entire concrete pour system, it is important to not overlook internal systems. Labor productivity is a key area to study in regards to the success of a pour. Dr. Jarkas discusses many factors that influence the productivity of labor in his paper, “Buildability Factors Influencing Concreting Labor Productivity.” He states buildability is the most important factor when it comes to concrete construction, and defines it as “the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building”. This is a key factor when designing concrete pours for a structure, and can vary significantly depending on the component being poured. Many important performance metrics are discussed throughout this paper. Jarkas prioritizes factors affecting the productivity of a pour as follows: concrete workability, congestion of reinforcement, volume of the pour, and height at which the pour is taking place. Each of these factors can vary greatly from pour to pour and thus will affect how productive the labor is. Both the way the concrete is placed and the use of a concrete pump or a bucket will create more variability in the outcome of the pour.

Webcor’s problem is echoed in another paper by Dr. Jarkas, stating that it is difficult to measure the “tangible benefits to the construction industry” (Jarkas, 2015). This is a core problem for this project as it sets out to measure specific buildability factors that will provide a quantifiable benefit to the client. In further research, Ming Lu uses a productivity study to begin
measuring concrete placement productivity. The “recording” stage of the study is for quantity and timing data collection (Lu, 2004), and is what the majority of this project focuses on. Lu adds that the resources needed, or crew size for this project, are also essential for analyzing the quality of a concrete pour. All three of these metrics will be present in the project as seen later in this report.

H. Randolph Thomas also authored a paper titled “Benchmarking Construction Labor Productivity” in which he attempts to do just that. Thomas discusses the challenges that arise through this process, and outlines 5 steps for how to do this:

1. identify the activity or process needing improvement; 2. determine the KPI or criterion to be used to establish who is best; 3. develop a data-collection protocol that assures valid comparisons can be made; 4. analyze the data to determine who shows the best performance; and 5. analyze the activity or process to determine why performance is superior.

While benchmarking is outside the scope of this project, there is some notable overlap, specifically with steps 2 and 3. As metrics and data collection method are determined, it will also be important to analyze past pours, and see what has traditionally led to both positive and negative outcomes. Thomas’ work provides great information on the challenges associated with benchmarking, but it also explains how to be successful in each of the five steps.

H. Randolph Thomas and Carmen L. Napolitan’s paper, “Quantitative Effects of Construction Changes on Labor Productivity,” presented the statistical analysis of data collected over 522 workdays in order to determine how construction changes impact labor productivity. Statistical methodology included studying means, analysis of variance, and multiple regression. While they did find it was possible to make changes with zero impact on labor productivity, they
noted “there is a serious lack of understanding about the impact of changes,” and found that on average, changes resulted in a 30% decrease in productivity. They also noted that there was a “threefold increase in material availability problems” as a result of changes. With regards to this project, this research not only shows the impact of changes regarding material (concrete) availability, but also proves that changes to the scheduled work for the day must be documented as a potential root cause for any arising issues.

The extent of data collection when tracking ready-mix trucks reaches all the way to the ready-mix concrete (RMC) batching plant. Once a truck is batched, or filled, at the plant it begins its route to the jobsite. The truck then proceeds to the job site where it either empties the load or joins a queue of trucks waiting to unload. The analysis of WCG inefficiencies can start here with the supplier. Graham, Smith, and Dunlop aim to model this process from the supplier in their paper, “Lognormal Distribution Provides an Optimum Representation of the Concrete Delivery and Placement Process.” Some of the parameters the authors explored can be used as metrics for this project. These can include the load per truck, the number of trucks, and the volume of the pour. This paper also discusses the variability in the concrete placement process, an area of concern for this project.

Visualization of data and processes is essential in understanding the full scope and impact it has on an organization. Webcor is seeking a tool and process to help visualize concrete placement over time during a pour day. In Jose Lluch’s paper, “Visualization of Repetitive Construction Processes in Excel,” he attempts to visualize the progress of a certain residential development using VBA code and Excel. He extended this into a forecast simulation tool to predict where the project will be based on current work progress. This is similar to one of the
long term applications of this project. It is known that “visual aids are very useful in construction planning, scheduling, design and forensic analysis of construction projects” (Kang, Anderson, and Clayton 2007). This is precisely what Webcor is looking for. The Excel workbook to be designed will be a visual tool to allow Webcor to monitor and analyze the success of their concrete pours in a quantitative way. Lluch’s Excel spreadsheet tracks the progress of a residential construction project by tagging specific stages of completion to areas in a grid. This grid is a specific number of cells in the spreadsheet that correspond to a certain building. Lluch used VBA to automatically update the project progress once a specific task is complete. A similar approach can be used in this project to update the concrete pour tracking graphs as well as delay tracking.

RFID & GPS Truck Tracking

It is important to look into how concrete supply works into the Just-In-Time production style of a concrete pour. The material must be on time and in the correct quantity to facilitate an efficient pour. “On-site positioning and tracking technologies facilitate arranging for the arrival of material…” (Akintoye, 1993). This is exactly what Webcor is seeking to accomplish with the need for truck arrival and exit times. In another paper, Arcot Naresh et al. discuss the use of Continuous Communication and Tracking Systems (CCTS) to track vehicles. At the time, GPS was a government technology that was accurate within 65ft. Current GPS technology has surpassed that benchmark and can prove to be of use for accurately tracking RMC trucks throughout the construction site.

Though GPS technology could be used to track locations of supplier trucks, Radio Frequency Identification (RFID) technology is a newer technology with a growing range of
applications, including transportation, and was investigated as well. RFID has been utilized in the construction industry for over 20 years, with applications of the technology occurring in a variety of processes throughout the construction lifecycle; however, the authors are focused on RFID implementations in, and benefits to, the construction supply chain (Valero et al, 2015).

A complete RFID system requires a tag, attached to each item, that contains unique identification information, an antenna to detect the tags, a reader to receive the ID information, communication infrastructure, and a user interface to display the information pulled from the tag (Janssens, 2016). RFID technologies are currently used to collect automobile tolls using radio-enabled toll booths and transponders (tags) mounted to the car windshield. This method proved to be much more efficient than manual collection of tolls, while maintaining the required accuracy (polygait.calpoly.edu). This application of RFID technology can, and has been, extended to the concrete construction industry to accurately track supplier trucks.

Ming Lu et al. reviewed the pros and cons of RFID implementation in concrete truck tracking, as well as the limitations of GPS in urban areas. While GPS signals could be cut off, the group of researchers found more success when implementing GPS with “dead reckoning” (DR) technology. DR technology is similar to RFID tags in functionality, but utilizes Bluetooth instead. The researchers tested this system over a twelve month period and also found that real time location data could be dispersed via SMS over mobile phone networks.

With regards to utilizing RFID for data collection, an article by Sungwoo Moon and Byongsoo Yang was found titled: “Effective Monitoring of the Concrete Pouring Operation in an RFID-Based Environment.” This article presented the researchers’ approach to designing, testing, and implementing RFID in concrete construction. Through this process they determined
allowable read distances, truck speeds, and how to overcome the interference of the metal concrete trucks (placing a paper panel between the truck and tag). The researchers not only tracked truck arrival and departure times, but also used RFID to track the volume of concrete poured.

Current Webcor Concrete Group Computing Tools

Various computing tools are used in the construction industry, one being Microsoft Excel. Webcor Project Engineers currently use Excel workbooks for the pre- and post-pour procedures mentioned previously. These workbooks are typically filled out from a desktop computer, though some PEs use mobile tablet computers with Excel Online, a cloud-based version of the Microsoft application. Though Excel Online allows for a workbook to be viewed remotely, the application does not allow for VBA (Visual Basic for Applications) code to run, which is a factor that will be considered when considering design alternatives.

A newer tool that various Project Engineers, Project Managers, and Project Directors have begun using is an application called Smartsheet. Smartsheet is a collaborative, cloud-based project management tool which allows for real-time editing of the spreadsheets from anywhere with an internet connection. WCG currently uses Smartsheet for some project management needs and recommended the authors explore a potential implementation for this project. As a cloud-based application, Smartsheet is excellent for collaborating given the ability to share Gantt charts and calendar views, send alerts and reminders, and upload files. The name ‘Smartsheet’ comes from the fact that the user interface resembles a spreadsheet one would find in an Excel workbook, however the aforementioned functionality makes the platform more comparable to Microsoft Project rather than Excel. The user can filter information and run formulas in the

16
various cells, but Smartsheet does not have graphing or charting capability, which was a key deliverable for WCG.

III. Design

The background research provided the authors with a better understanding of the problems WCG currently faces in their operations. Their problems are not unique, and opportunities are found throughout the construction industry. This section will detail the design requirements and constraints, as well as the process design methodology.

Customer Requirements & Constraints

When considering potential designs for creating standard procedures within Webcor, the authors had to balance feasibility with customer requirements. There were several deliverables requested from the customer. The first and foremost item to be delivered is the standard procedure for PEs to follow during a pour. Additionally, WCG requests a concrete pour data collection sheet with a scorecard section to assess a grade for the concrete pour. This “scorecard” will allow WCG to identify problems or successes of each individual concrete pour, and help assign responsibility for any inefficiencies during the pouring process whether that be to WCG or one of their suppliers. This will become a standard document for use throughout the division. Graphs of actual versus planned concrete placement over time constituted an important deliverable as well.

The concrete pour data collection sheet must include comprehensive metrics, including base metrics provided by WCG and others identified by the researchers. This deliverable is constrained by a few factors. Most importantly, it cannot require a large amount of the Project Engineer’s time to complete. Webcor PEs currently have a large workload on pour days, so data
collection must be minimally intrusive. This data sheet is intended to help the PE, not hinder them.

Determination of Required Metrics

Earlier in this report the pre- and post-pour data procedures were described. The objective of this project and the subsequent system design is to fill the gap with mid-pour data collection. However, if the new system absorbs the existing procedures, Project Engineers will be more likely to adopt the design as they would only need to fill out this report. While the design aims to provide justification for, or protect against, back-charges, it can also be used for long-term inefficiency analyses. For example, WCG can identify pours with the greatest crew downtime or material waste and can check for statistical relationships between the outcome and factors such as structural element, size of the pour, mix design, or weather, as well as deviations from the pour plan.

Table 1 lists the metrics to be collected for each pour. Pre- and post-pour metrics were pulled from the pre-pour checklist and the concrete log, and the mid-pour metrics were determined based on sponsor recommendations and author experience with metric development from IME 417: Supply Chain & Logistics Management, a required course in the Industrial Engineering curriculum. In this course, students learn that metrics should be developed in order to drive business goals. With the mid-pour data listed in Table 1, WCG will be able to track deviations from planned concrete placement times along with causes of the delays, while tracking crew downtime as well. Eventually, WCG can use this data to identify improvement opportunities and properly justify projects to remedy these.
Much of the data collected during a pour deals with deviations from the pour plan. It does not take much time for the PE to record this information, but the process needs to be put in place for this to happen. It is of paramount importance that these deviations be recorded in detail. Without a detailed account of what occurred during the pour, responsibility cannot be assessed to mistakes. After watching concrete pours at the Cal Poly Student Housing project in San Luis Obispo, and speaking with the onsite PE, it was determined that all metrics could be feasibly recorded by the PE aside from concrete supplier truck arrivals and departures.

**Proposal for Automated Truck Tracking System**

In order to accurately track concrete supplier truck arrivals and departures, the authors sought to design an automated RFID or GPS system, in addition to the data collection system and procedure, following the work of previous researchers. This system would provide the best support for or against back-charges between WCG and their concrete suppliers for lost wages and material. Though the system would be able to record all truck arrival and departure times without requiring any additional attention from PEs during a pour, additional engineers would be
required for each project to manage the system and an initial monetary investment by WCG would be required as well.

After presenting preliminary research and design concepts to WCG, the sponsor preferred a solution that could be managed by the PEs and decided that the automated truck tracking system was not desired at this point in time. The goal of the project is to give WCG a way to collect and analyze a variety of data during a concrete pour, and the sponsor was satisfied with manual recording of trucks by the PE. In order to minimize the impact on a PE’s mid-pour tasks, it was determined that the cumulative quantity of concrete should be recorded at least once per hour for the duration of the pour. If issues arise during a pour, the PE will be busy actively problem solving, but after conferring with several PEs and PMs a consensus was reached that recording on an hourly basis is still feasible and absolutely necessary for back-charge accounting. Conversely, if a pour is running smoothly, the PE will be able to record the quantity arrived more frequently allowing a substantial statistical analysis in the future.

*Design Approach for Data Collection System*

With the metrics defined and a procedure in place for tracking trucks, the authors could then move forward with the system design. The Systems Engineering Method (SEM), from IME 510: Systems Engineering I, was utilized for the development of the data collection tool. The four steps of the SEM are as follows: (1) Requirements Analysis; (2) Functional Definition; (3) Physical Definition; (4) Design Validation (Kossiakoff et al., 2011). The Requirements Analysis step was addressed above in the *Customer Requirements and Constraints* section. Based on these design requirements, the Functional Definition stage of SEM requires the authors to take into account the platform needed to create the system. In this case, several different software
alternatives were considered in the design. The use of Smartsheet, a cloud-based project management software, was suggested by the project sponsors as it is currently used throughout WCG. Another alternative, Microsoft Excel, was considered for implementation. A more comprehensive review of these two software packages is found in the presented literature, but to summarize: while Smartsheet allows for real time collaboration between multiple parties, it does not contain the data compilation, graphing, and analysis capabilities, which can be found in Excel, that were required for this project.

After eliminating Smartsheet as a software alternative, the authors then considered Microsoft Excel Online, a cloud-based version of the spreadsheet application to see if the same collaborative and data visibility features of Smartsheet could be gained in this way while still preserving the desired functionality. Though Excel Online is a robust platform, and does offer these desired features, it cannot run VBA code nor the subsequent macros. In order to utilize VBA macros, which can be used to create a more user-friendly interface, the desktop version of Excel is required. For these reasons, the researchers and project sponsors concluded that a desktop Microsoft Excel workbook would be the most user-friendly, comprehensive solution that meets the desired functionality.

For a project such as this, the Physical Definition step of SEM relates to individual portions of the Excel workbook. While these sections are not necessarily “physical”, the subcomponents of the solution must be defined in this step. Four major Subcomponents were deemed necessary to achieve the project objectives: (1) Pour Specification Input Table & Pour Quantity Tracking Table; (2) Pour Quantity Tracking Graph; (3) Delay Tracking Table & Graphs; (4) Scorecard. Though not traditional, the prototype portion of the Physical Definition
and subsequent Design Validation steps of SEM were combined to create an iterative design process. The Pour Specification Input & Pour Quantity Tracking tables took original priority for the first revision of the project. This portion includes the metrics previously mentioned and needed to be validated prior to moving forward. Revision 1 was reviewed via conference call with the project sponsors during which the metrics were approved and the design of the next Subcomponent was discussed. Design revisions continued in this manner, with Revision 2 containing Subcomponent 2, and Revision 3 containing Subcomponents 3 and 4. The final revision (Revision 4) included minor formatting adjustments and protection of the workbook to prevent accidental changes outside of the desired input ranges.

Design Iterations of Data Collection System

While the SEM principles learned in IME 510 helped guide the design, the authors gained experience with VBA (Visual Basic for Applications) code in CSC 232: Computer Programming and the ability to write effective code and troubleshoot errors in IME 312: Data Management System Design that was utilized heavily throughout the development of each subcomponent and the overall system design. This section will explore each revision of the design and the subcomponents in more detail.

Revision 1:

The first revision of the design primarily revolved around determining how the Excel workbook would be organized. The currently existing concrete log (for post-pour data collection) is laid out in a way that all concrete pours are recorded on the same sheet in the workbook, however as pour quantity and delay graphs were required for each pour, the authors determined that each pour would require its own sheet. For ease of use, a template sheet was created along
with a macro command that enables the user to copy the template page with the combination
‘Control+Shift+N.’ The user would then rename the sheet to the date of the concrete pour and
could begin filling in data.

As previously mentioned, Revision 1 contained the design prototype for Subcomponent 1
which included the Pour Specification Input Table (left) and Pour Quantity Tracking Table
(right) seen in Figure 1.

![Figure 1: Revision 1 ‘Template’ Sheet](image)

The Pour Specification Input Table includes the pre-, mid-, and post-pour metrics previously
determined, using as many drop down lists as possible to create uniform inputs across all
concrete pours. The ‘Source’ sheet contains the data for the drop down lists and can be appended
by the users to add additional items to the drop down selections. After filling out the Pour
Specification Input Table, the Project Engineer can automatically create the Quantity Tracking
Table by clicking the ‘Populate Table’ button in the top right of Figure 1. This button runs a VBA module to create the table using the code shown in Figure 2.

**Figure 2:** Revision 1 VBA Module for Quantity Tracking Table Population

The code uses the entered start time, quantity ordered, and spacing (time between concrete supplier truck arrivals) to populate the table seen in Figure 3. This module runs on the assumption that each supplier truck contains 9 cubic yards (cy) of concrete, but the total quantity ordered and the spacing are both decided and agreed upon during the pour planning process, and are not assumptions. The code then works by dividing the total quantity ordered by 9 cy/truck to determine the number of trucks required, and rounds up to ensure the required amount is delivered. The table then populates cells according to the number of trucks required, adding the...
spacing time (in Figure 3, this is 8 minutes) to the start time and 9 to the quantity ordered for each time slot for the duration of the pour.

![Figure 3: Revision 1 Example of Populated Quantity Tracking Table](image)

The third column in the Pour Quantity Tracking Table is where the PE will input the actual data recorded during the pour and serves to judge WCG’s concrete placement success.

Upon completing Revision 1, the authors held a conference call with the project sponsors to validate the metrics and ensure the workbook was headed in the desired direction. Project sponsorship approved of both the metrics and Subcomponent 1, allowing for Revision 2 development to begin.

**Revision 2:**

Revision 2 of the workbook included development of Subcomponent 2, a graph of the quantity ordered versus quantity placed over time, which was one of the customer requirements.
Again, VBA code (Figure 4) was utilized to ensure ease-of-use for the user through the creation of another button that would populate a plot of the quantity tracking data.

![VBA Code](image)

**Figure 4:** Revision 2 VBA Module for Quantity Tracking Chart Creation

The ‘Template’ sheet remained the same aside from the addition of a notes section and the ‘Graph’ button that can be seen in the top right of the example shown in Figure 5.
When analyzing the Pour Quantity Tracking Graph, the straight, blue line represents the pour plan; ideally supplier trucks will arrive based on the given spacing and Webcor will place the concrete as it arrives. The orange line represents the actual quantity placed over time and can be used to evaluate WCG’s performance. After sharing Revision 2 with project sponsorship, it was pointed out that an additional column for the cumulative quantity arrived would provide clarity regarding supplier and WCG performance. Deviations between quantity ordered and quantity arrived would reflect on the supplier, while deviations between the quantity arrived and the quantity placed would reflect on WCG; this will be explained further in the next section.

Revision 3:

Before moving on to the development of Subcomponents 3 and 4, the authors added the additional column requested for the Pour Quantity Tracking Graph which required adjustments to Subcomponents 1 and 2. The code in Figure 2 (VBA module for Pour Tracking Table)
Population) was modified to include an additional column range and can be found in Appendix A. Next, the code in Figure 4 (VBA Module for Quantity Tracking Chart Creation) was modified to add an additional chart series to incorporate the new column and can be found in Appendix B. The resulting table and chart can be seen in Figure 6. The requested column is titled “Quantity

Figure 6: Revision 3 Example of Pour Quantity Tracking Table and Graph

Arrived,” is represented by the orange line on the chart, and visualizes the concrete supplier’s performance. The rightward shift from the straight, blue planned line represents an initial delay, but due to the line being straight, it shows that the target spacing time was generally hit for the remainder of the pour. WCG’s performance is now represented by the green line on the chart, and in this example, they tracked the orange supplier line well. The user should not be concerned with comparing the blue and green lines because if the concrete is not on site, then Webcor has nothing to place; in this case, when concrete was on site, it was being poured appropriately. Due to combining the Physical Definition and Design Validation steps of SEM, the required changes
were not as extensive as if all of the Subcomponents had been developed at the same time which will become evident shortly.

The next development step was Subcomponent 3, the Delay Tracking Table and Graphs. Unlike the Quantity Tracking Table which was adjusted based on the size of the concrete pour, the Delay Tracking Table is static and a standard size for each pour. The complexity arose with the graphs which required ‘helper cells’ that ran count and sum formulas off of the data in the table, and the graphs were created from the data in these ‘helper cells’ (see Figure 7). The helper cell text color was set to match the background color in the workbook, but was changed for demonstration purposes.

![Figure 7: Revision 3 Example of Delay Tracking Table and Helper Cells](image)

The VBA code (see Figure 8) is similar to that of the Pour Quantity Tracking chart with some tweaks and the ability to toggle the graphs between visible or not.
The final subcomponent for development was Subcomponent 4, the scorecard. This scorecard summarizes a few key metrics for the overall pour: percent material waste, number of delays, total downtime, and number of trucks returned to the supplier. This subcomponent runs with the click of a VBA macro button, same as the first 3, but should be run after all other data has been entered in the worksheet; the VBA code can be found in Figure 9.
The VBA code ensures the necessary cells have data input before proceeding and will prompt the user if they are not. If these cells are filled in, the scorecard will populate by running a couple functions, but primarily formatting the cells.

At this point in the design process, each subcomponent had been developed allowing for a final functional review of the workbook by the project sponsors. The full Revision 3 workbook can be seen in Figure 10. Following approval from the project sponsors, and no design changes were requested, Revision 4 (final formatting) began.
Revision 4:

Revision 4 consisted entirely of final aesthetic formatting of the workbook. This included the addition of color to background cells, the writing of VBA code to format cell borders correctly, hiding unused rows and columns, and protecting the workbook. See Figure 11 for the final data collection workbook.
IV. Testing and Methodology

Due to the nature of software design, the process followed that of the agile project management cycle with many design iterations. Testing of the design occurred throughout the design process, with feedback coming from the project sponsors regarding the ease of use, formatting, and ability to meet their objectives. Upon completion of the Excel workbook, the file was distributed to Webcor PE’s and PM’s for them to review and provide additional feedback and recommendations. While the majority of the testing comes in the form of user feedback, some performance testing was required as well.

The performance testing of the workbook was necessary to ensure that it would be a robust, long term solution for WCG. Webcor asked for the workbook to be able to contain information for at least 50 concrete pours with a maximum requirement of 100 pours. This equates to the workbook being able to function with 50 to 100 sheets. To test this, the spreadsheet was replicated over 100 times by filling the template page with sample data and replicating it using the coded Control+Shift+N function. For each new sheet, the functionality of the workbook was then tested. The VBA macros, buttons, and formulas performed as expected on each of the spreadsheets. This exceeded Webcor’s performance requirement and proved to be able to handle the largest projects with the most concrete pours.

V. Results and Discussion

After distributing the workbook to Project Engineers, it was apparent that the project had met its objectives. It was expected that minor adjustments to the workbook would be requested after putting it in the hands of actual users. The design as a whole was successful. Project Engineers at various Webcor projects provided their feedback and suggestions to the authors
after testing the workbook on site. These improvements can be classified into two different levels of application. First, some feedback can be used to adjust the workbook immediately. These minor tweaks do not affect the overall goal or theory of the project, but make the workbook more tailored to the user.

Other PE feedback requested would pose more of an issue in revising the workbook. On occasion, a concrete pour will utilize multiple mix designs. This presents a unique problem in regards to the existing workbook structure which only allows for one mix design to be recorded per pour. Instead of adding a way to track the individual mix designs on one sheet, it is recommended that a new sheet is created specific to the mix design. These two sheets will be for the same pour date, but will allow the PE to see if there is a correlation between mix design and outcome of the pour. This approach can be applied to situations such as pouring multiple structural elements on one day or pours with nonstandard load sizes. While these adjustments might limit the impact on PE time, a constraint on the project, they might require more development time than the benefit seen.

Limitations of adapting PE feedback into the workbook are mainly related to personal preferences. The workbook still allows for proper tracking of the requested metrics as well as delays in the pour process. The recommendations that should be addressed immediately are those that have the greatest impact on the overall project goal of collecting baseline data and providing a means of back-charge accounting. One such recommendation is to translate the delay times into dollar amounts based on crew size and labor cost per hour.

The project requires a thorough economic analysis for design implementation, but in this case there is not much to analyze. The workbook comes at zero cost to Webcor since it was
developed by the authors so there is no reason to not implement the workbook and data collection procedure. While a cost could be attributed to the PE time spent entering data into the workbook, it is possible that PE’s will spend less time with data entry as the new design absorbs the pre- and post-pour procedures. Webcor only stands to benefit by implementing the workbook. Short-term, WCG will save money both by defending against back-charges and recovering lost wages by pursuing back-charges of their own. Long-term, WCG will be able to identify areas of improvement and justify projects that can in turn save them money in other ways. It is the recommendation of the authors that WCG implement the data collection procedures and tool designed in this project.

VI. Summary and Conclusions

This project was selected with the goal of addressing the lack of data available to Webcor Concrete Group’s operation. Money was being lost in the form of back-charges and inefficiencies. By creating standard data collection procedures and a tool for engineers in the form of an Excel workbook, WCG should be able to defend themselves from extra charges, pursue charges against their suppliers if necessary, and identify key areas for improvement with the relevant data for project justifications. The most significant conclusions are listed below, followed by a brief explanation of each conclusion.

- Each objective listed in the introduction was accomplished
- IE curriculum and methodology was successfully applied in the concrete construction industry
- Feedback confirms, and long term implementation will verify, the project as a valuable tool for WCG
• Design theory can be extended to include automated and cloud based systems

The authors were able to meet all original objectives, but would have discussed the initial design ideas with WCG management sooner in the project. This would have led to an earlier design pivot, ultimately allowing more time for workbook development and testing. Moving forward, the authors recommend that Webcor investigate an automated truck tracking system as this will provide solid evidence for back-charges. Researchers have had success with both RFID and GPS implementations and a future project should be performed to determine the feasibility for Webcor and the best alternative. The authors also recommend a cloud-based application to allow tracking of the project in real time from a remote location. PE’s could input data from the field during the pour, instead of transferring the information afterwards. Webcor now has the tool they requested and is ready to begin collecting data. Ultimately the success of the initiative rests on the Project Managers and Project Engineers. The data can be analyzed in the future to determine where there are opportunities for improvement, but only if the data is collected to begin with. An automated truck tracking system and cloud-based application will require a greater initial investment, but would not require as much manpower on a day to day basis, helping the success of WCG’s process improvement initiative.

The implementation of this project throughout Webcor Concrete Group will have significant organizational impacts as well as minor environmental consequences. An immediate organizational impact is that of Project Engineer time spent working with this workbook. This is a new tool for Webcor to use, but was designed to be intuitive and user-friendly and, as mentioned previously, has the potential to absorb the pre- and post-pour procedures which could decrease PE time spent on data entry. Long-term organizational impacts include PE performance
tracking and the development of future process improvement projects. As pour data is collected over the course of a project, material waste and delay figures can be attributed to a Project Engineer and evaluate their performance success. With regards to future projects, as baseline data is gathered, opportunities for improvement will be identified and the data collected will serve as justification for pursuing process improvement projects. The minor environmental impacts include decreased material waste and decreased pollution. These are long-term impacts because results will not be seen until processes are improved. As Webcor uses the collected data to become more efficient, less trucks will idle on site and fewer trucks will be sent back to the supplier because the concrete sat too long. The combination of all the information presented in this report will benefit Webcor for years to come.
REFERENCES


APPENDIX A: Revision 4 VBA Module for Quantity Tracking Table Population

Option Explicit

Sub DataPop()

' Formatting
ActiveSheet.Columns("A:").AutoFit
ActiveSheet.Columns("B:").HorizontalAlignment = xlCenter
ActiveSheet.Range("G7:J1000").Borders.LineStyle = Excel.XLLineStyle.xllineStyleNone
ActiveSheet.Range("S5:J6").BorderAround = _
Weight:=xlMedium

' Truck calculation based on CY and Spacing
Dim OrderQty As Integer
OrderQty = ActiveSheet.Range("D14").Value

Dim Trucks As Double
Trucks = OrderQty / 9

Dim TrucksRem As Double
TrucksRem = OrderQty Mod 9

If TrucksRem > 0 Then
    Trucks = Int(Trucks) + 1
End If

Dim MyValue As Long
MyValue = Trucks + 7

Dim MyValue1 As Long
MyValue1 = MyValue + 1

Dim MyValue2 As Long
MyValue2 = MyValue1 + 1
Appendix B: Revision 4 VBA Module for Quantity Tracking Chart

```vba
Option Explicit

Sub ShowCht()
    If ActiveSheet.ChartObjects("Chart 1").Visible = True Then
        ActiveSheet.ChartObjects("Chart 1").Visible = False
    ElseIf ActiveSheet.ChartObjects("Chart 1").Visible = False Then
        ActiveSheet.ChartObjects("Chart 1").Visible = True
    End If
    Dim RwCnt As Long
    RwCnt = Range("G7", Range("G7").End(xlDown)).Count + 6
    Dim ChartRangex As Range
    Dim ChartRange1 As Range
    Dim ChartRange2 As Range
    Dim ChartRange3 As Range
    Set ChartRangex = ActiveSheet.Range("G7", Range("G7").End(xlDown))
    Set ChartRange1 = ActiveSheet.Range("H7", Range("H7").End(xlDown))
    Set ChartRange2 = ActiveSheet.Range("I7", Range("I7", "J7" & RwCnt))
    Set ChartRange3 = ActiveSheet.Range("J7", Range("J7", "J7" & RwCnt))
    ActiveSheet.ChartObjects("Chart 1").Activate
    ActiveChart.ChartArea.Select
    ActiveChart.SetSourceData Source:=ChartRange1, PlotBy:=xlColumns
    ActiveChart.SeriesCollection(1).Name = ActiveSheet.Range("H6")
    ActiveChart.SeriesCollection(1).XValues = ChartRangex
    With ActiveChart.SeriesCollection.NewSeries
        .XValues = ChartRangex
        .Values = ChartRange2
        .Name = ActiveSheet.Range("I6")
    End With
    With ActiveChart.SeriesCollection.NewSeries
        .XValues = ChartRangex
        .Values = ChartRange3
        .Name = ActiveSheet.Range("J6")
        .MarkerForegroundColor = RGB(51, 153, 51)
        .MarkerBackgroundColor = RGB(51, 153, 51)
    End With
End Sub
```