ABSTRACT

VAUGHAN, JOSHUA LEE. Effects of One Innovative Technology on CM Time. (Under the direction of Dr. Min Liu and Dr. Michael L. Leming).

In construction projects, construction managers (CMs) spend a significant portion of their time gathering project data, assessing production rates, communicating with project participants and tracking project quality. Executing those tasks takes time. More effective automation can improve efficiency resulting in more effective project management operations. The CM considering ways to improve efficiency and reduce overall management costs must consider the costs and benefits of any proposed management aid, however. Vela Systems® (Vela) is a construction field management software package intended to provide key project information to its users in a mobile platform and improve both management efficiency and communication on the project. The purposes of this thesis are to 1) propose a framework to assess tangible and semi- or intangible costs and benefits of innovative construction technology applications, 2) determine costs and benefits of the use of Vela by conducting a case study, 3) summarize lessons learned through the application of Vela from firsthand users so that CMs can avoid pitfalls on other projects, and 4) based on both analysis and field experience, identify the most important features and benefits of this type of management tool. This study provides new data collected during real-time immersion in the project as part of the project team over a 6 month period. The study found that the use of Vela, coupled with mobile technologies such as tablets and iPads, increased productivity by 11.9% and decreased the duration of reaction activities of operations-level construction personnel by an average of 3.8 hours per week, and thereby increased value to the project

through improved allocation of managerial time. The results are important to owners, construction firms, trades and design consultants.

Effects of One Innovative Technology on CM Time

by
Joshua Lee Vaughan

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

2011

APPROVED BY:

Dr. Min Liu Committee Co-Chair	Dr. Michael L. Leming Committee Co-Chair

Dr. Edward J. Jaselskis

DEDICATION

This thesis is dedicated to all those with whom I have received support during my educational endeavors. Without their guidance I would have be unable to complete such an undertaking. I wish to thank my professors, my committee, and the Civil, Construction, and Environmental Engineering department for providing me with such a fine education in the field of engineering. Finally and most importantly, I wish to thank my family for their continuing love, support, and understanding throughout my educational career as well as my future endeavors in life.

BIOGRAPHY

Joshua Vaughan was born in Raleigh, North Carolina in 1984. He grew up in Fuquay-Varina, a small town outside of Raleigh, and graduated from Fuquay-Varina High School in 2003. After attending a technical school, he decided to return to college and attended Wake Technical Community College to complete the required humanities and social science courses. While working part time to pay for school, he gained a value for the education he received and became a member of the Golden Key International Honor Society and was on the Dean's list as well as the president's list for multiple semesters.

In Fall 2007, he was accepted into the School of Engineering at North Carolina State University. He completed the necessary course requirements and graduated Summa Cum Laude in both Civil Engineering and Construction Engineering & Management bachelor's degrees. While earning undergraduate credits, he was inducted into the Chi Epsilon Civil Engineering Honor Society as well as the Tau Beta Pi Engineering Honor Society and National Scholars Honor Society. He became a member of the AGC and ASCE student chapters and was awarded the NSF Transfer Scholarship and the General Contractors Association of Raleigh Scholarship. In April 2009, he successfully passed the FE Exam.

Concurrent with his undergraduate studies, Joshua worked with various construction firms over the summers as well as working for the university. Set to further his education, he received the Dean's Fellowship and stipend to attend graduate school at North Carolina State University. While earning a Master's degree in Construction Engineering & Management, Joshua was asked to conduct research on behalf of Skanska Building, USA on construction management innovations, headed by Dr. Michael Leming and Dr. Min Liu.

ACKNOWLEDGEMENTS

I would like to thank Skanska for allowing me to immerse myself into their construction project via an internship and for everyone's assistance along the way. Without the participation of the interviewees and data collection subjects, this research project would not have the needed merit when approached by a reader working in the industry. I want to also acknowledge and thank my research committee who allowed me the opportunity to investigate the latest technological trends in construction from first-hand experience and observation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Background

Mobile technology allows users to send and receive information as well as conduct business without being in the office. This technology is used in construction management in various forms. Construction management is typically document intensive, with many actions and decisions needing to be recorded, filed and transmitted as well as many contract documents needing to be printed, revised, copied, and distributed to numerous project participants. Electronic or digital versions of contract documents allow project participants to review, edit and submit drawings faster than traditional methods of marking up multiple sets of drawings and having them mailed to each participant. Digital records work well for project documents such as submittals, Requests for Information (RFIs), Architect Supplemental Instructions (ASIs). The use of digital technology and electronic information exchange has slowly migrated to the field. ENR described electronic data exchange from the field office to the workface as the 'last mile' in information sharing (Sawyer 2010). In recent years, construction management firms have begun using software programs aimed at helping the construction manager (CM) in conducting day-to-day operations more productively. The Construction Manager at Risk firm (CMAR) on a library project decided to use Vela Systems® (Vela) software coupled with tablets, iPads, and Mobile Electronic Resource Stations (MERS) to manage the digital records requirements on the job.

Vela Systems is a field management suite designed for tablet PCs, as well as laptops and other computers, and an application for the Apple iPad. According to Vela, the software is "aimed at increasing efficiency and streamlining field administration and back-office processes for firms in the architecture, engineering, construction, and owner (AECO) industry." Vela was created out of a research project focusing on mobile software for the AECO industry by the MIT Center for Real Estate and the Harvard Graduate School of Design (Kanner and Omansky, 2005). Currently, Vela software has been used by over 70 companies within the construction and design industries according to company literature.

The CMAR began its implementation of these technologies on a university library project in June, 2010. Vela Classic was used initially in late 2010. Vela Classic is a software program which operates on a tablet or PC and relies on the user to manually upload and download project information or changes by connecting to an Ethernet cable and syncing with Vela's server. This is typically done in the morning prior to work and in the evening before leaving for the day. Since this software was used in a limited fashion and for a short period of time, this thesis will not focus on the use of Vela Classic.

This research focuses on Vela Web (VW), which is the next-generation web-based version of Vela Classic. Released in late 2010, VW is designed for pen-based tablet PCs and Windows-based computers with a connection to the internet. VW allows project information and reports to be accessed via a "cloud" eliminating the need to sync information to and from a remote Vela server. This allows for real-time transfer of information from the field to all project Vela users but also requires a wireless network on the jobsite or the use of mobile broadband cards. Shortly after the release of VW, Vela released the Vela Mobile application (VM) for the Apple iPad in May of 2010. There have since been multiple updates to increase user functionality and repair programming bugs. The release of VM allowed Vela software to operate on a less expensive platform while providing off-line functionality (see Appendix A).

Most recently, Autodesk, Bentley, and Tekla have partnered with the Vela Systems software for integration of data and documentation with the 3D Building Information Model (BIM). This allows for data from materials management, commissioning, and quality management which are gathered during the construction process to be viewed in the model, helping to bridge the gap between the field and office.

1.2 Problem Statement

A vital aspect of construction management is to plan, directly observe, coordinate, and verify the actions of the various trades involved in the project. The time spent in clerical activities reduces the time spent in project planning, verification, and assessment. The numerous meetings that CMs are required to attend can be even more time consuming than necessary due to an insufficient transfer and transparency of information from the previous work week. Scanlin (1998) reported that communication consumes about 75% to 90% of a CM's time and information therefore needs to be current and available on demand. Poor communication is a significant part of project failures and any tool which can increase communication between parties is desirable (Biggs 2000). Field verification is an important part of a CM's responsibility but they often must return to the field office to create, edit, and sort data, fill out daily reports, compose as well as respond to e-mails, upload photo attachments, and gather any necessary contract documents for clarification or field verification. While these clerical tasks are necessary for a CM to perform his or her duties, they consume time that could otherwise be spent on site.

IT implementations have been attempted in an effort to improve the performance of operations-level staff of CM firms. The majority of IT investments are typically justified on the basis of either subjective arguments or acts of faith (Andresen et al. 1999). Past research has indicated that technology implementation in the construction field lags behind the majority of other occupational fields. Figure 1.1 (Teicholz 2004) demonstrates the construction industry's slight downward trend in productivity while other sectors continue to improve their productivity. Figure 1.2 (Ekstrom and Bjornsson 2004) provides reason for this downward trend as its lack of IT investments reflects its negative productivity rate. It is clear from these two figures that ways to improve construction productivity are needed and the current technology offers realistic means to increase the productivity.

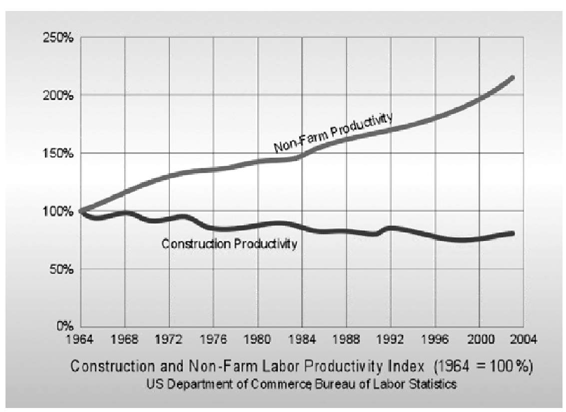


Figure 1.1-Historical Construction Productivity (Teicholz 2004)

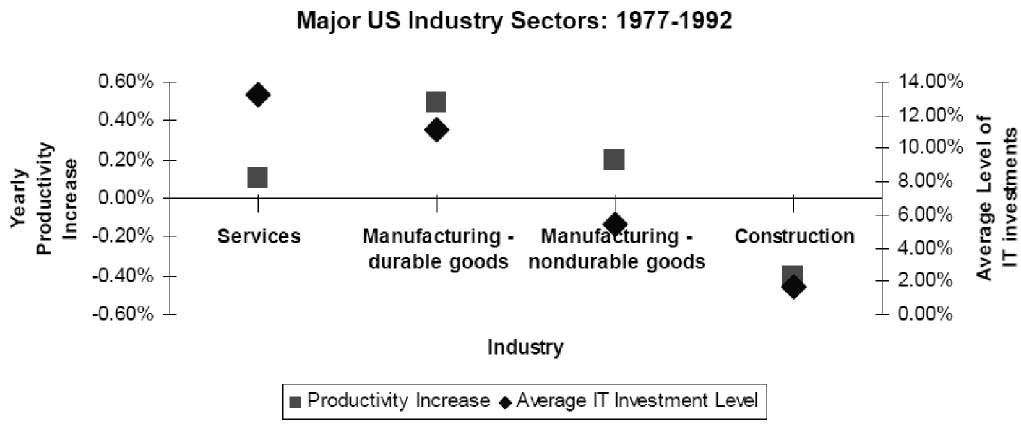


Figure 1.2-Rates of Production Increase and Amount of IT Investment by Sector (Ekstrom and Bjornsson 2004)

Previous research has established guidelines and set forth metrics for determining cost-benefit analyses of various IT implementations and innovative CM technologies. Other research has performed such analyses and provided perceived benefits but under assumptions of its successful use and solely from the viewpoint of the CM firm. Importance has been placed on the necessity of collecting data in real time (Becerik-Gerber and Rice 2010).

1.3 Objective

The primary objective of this investigation is to determine how the end-user of a CM firm is affected by mobile field management technologies when using technologies such as Vela. Primary metrics involve CM's productivity and efficiency with the use of Vela. Weekly hours worked, and Vela's effects on weekly planning activities and reaction activities are also examined. This thesis seeks to quantify the purchasing and implementation costs associated with the use of one typical software application from a benefit-cost approach. Benefit findings are to be examined from both quantitative and qualitative perspectives. The key metrics of efficiency and productivity are examined to help estimate the benefits of implementation and to help optimize common management processes. These results can serve as a benchmark for comparison on future projects of similar size and scope using similar technologies.

2. REVIEW OF LITERATURE

2.1 <u>IT Benefit-Cost Analysis</u>

The terms “innovative construction processes” or “innovative technologies” have been misunderstood as being associated with a costly and risky expenditure, although it is often perceived as an investment rather than as an expenditure from the perspective of a construction firm (Robinson 1997). Despite this fact, the majority of IT investments are typically justified on the basis of either subjective arguments or acts of faith (Andresen et al. 1999). Items to consider when a CM firm is investing in new and innovative construction management technologies include: costs, implementation strategy, project complexity, and perceived benefits. Of these, the likely benefits are typically the most difficult to measure (Construct IT 1998). Liberatore (2001) determined that 76% of respondents in the construction industry indicated that there is value in future research in the area of project management software.

Previous scholarly articles identified how IT cost-benefit data can be collected. The evaluation of the cost and benefits likely to be derived from an IT implementation must be reflected by available data collected at the point of evaluation (Marsh 2000). This supports the case study-based research approach used in this study to evaluate Vela for construction project information management.

Past research has indicated that the use of wireless communication devices such as cellular phones, portable computers, and digital cameras increase the efficiency of many tasks associated with a CM’s daily managerial and observational duties. (Jaselskis et al.

2010). The following report compares the “up-front” costs associated with Vela and the advantages or benefits provided by its use throughout the project.

Lim (et al. 2010) reported that investments in new and innovative technologies often resulted in a loss of competitiveness of that construction firm due to the competitive nature of various firms to get their final bid price as low as practically possible. Their study was limited, however, by the inability to incorporate the advantages provided to other construction stakeholders such as owners, architects, and engineers. They assumed that all innovations implemented were ultimately successful. Their research approach was primarily qualitative in determining the direct value of selected innovations.

Nuntasunti and Bernold (2006) performed a cost-benefit analysis of wireless construction technologies and concluded that its use provides both monetary savings to the construction firm as well as reduced time spent in weekly project meetings. This was for a hypothetical project however, so the benefits cannot be assessed by other firm with any degree of repeatability.

Jang and Skibniewski (2009) studied the effects of an embedded sensor system for construction materials tracking using a cost-benefit analysis. They concluded that there were both quantitative and non-quantitative benefits associated with its use. The report also suggested that the framework for the research could be extended into the field of web-based project management systems. The study was limited by using various task durations gathered from multiple construction and engineering companies and applying these durations to one specific construction project to determine unit labor hour savings.

Cost-benefit research on BIM and other related construction technologies has been attempted through conducted surveys. Becerik-Gerber (2010) conducted a cost-benefit analysis of BIM. Due to the difficulty of obtaining empirical data, she conducted a survey and evaluated the benefits and costs based on the responses. The study was not able to measure the intangible and semi-tangible benefits and costs associated with the technology. Becerik-Gerber suggested a better cost-benefit analysis could be performed if examined through a detailed case study with extensive interviews.

In the past decade, research has examined cost-benefit tradeoff of innovative construction processes or technology. Many studies only considered the qualitative aspects of a cost-benefit analysis based on survey data after project completion. Other research examined quantitative benefits on partially or wholly theoretical examples. Little research has been conducted using a systematic framework to measure both tangible and intangible costs and benefits based on empirical project data. A need exists to discover the real impact innovation has using a real-world case study including collection of survey data during the project rather than afterwards, and develop a repeatable method to determine efficiency gains provided by construction management software. This paper addresses those needs by providing a framework for measuring the costs and benefits associated with construction project information management software with collected data from an active case study, analyzing the costs and benefits, and assessing the positive and negative features associated with that construction management software. A theoretical ROI is presented to further estimate benefits of using construction management software and other technologies.

3. METHODOLOGY

3.1 Introduction

Case study research typically collects data from a natural setting, without external experimental controls. The goal of a case study is to identify primary causes and effects, and relationships. Quantitative data may be limited. The objectives of this study were consistent with those of the case study approach (Meredith 1998).

The data collected in this case study was used to conduct a benefit-cost analysis and to examine the differences on management production before and after technology implementation. Analysis was based on comparing the distribution of time spent in various tasks using pre-implementation baselines for productivity and efficiency ratings to help quantity the benefits associated with this particular construction management technology.

3.2 Cost Benefit Analysis

Interviews were conducted to determine how weekly CM hours are distributed across selected types of activities, both with and without the use of Vela software. Responses were based on the latest 20 weeks of fully functioning Vela use. To avoid the weekly fluctuations that often occur with changes in real world construction activities and reduce the variability of activity durations, average durations were determined over the 20 week period.

The cost-benefit analysis was conducted on data collected throughout the 6 month case study. Costs were classified as purchasing costs or implementation costs. Purchasing costs were the costs associated with buying the necessary hardware and software for its implementation. Implementation costs were the indirect costs, including maintenance and training associated with the use of Vela. These costs were developed in terms of labor-hours and were collected using both direct observation and interviews with the CMAR's Vela users.

The benefits of using Vela were categorized as either quantitative or qualitative benefits. Quantitative benefits were assessed based on the time each CMAR Vela user spent doing various types of work each week, on average. Common managerial tasks were classified as planning, assessment, reaction, or clerical. A pre-Vela baseline efficiency was estimated as the portion of time spent on planning and assessment activities. From this data, productivity effects before and after the use of Vela could be estimated. Qualitative benefits were assessed through discussions and interviews with key project participants who used Vela, as well as the Vela staff, including one of the co-founders.

3.3 Return on Investment

Estimates of the return on investment (ROI) requires determining the additional planning time gained through the use of Vela. Additional time spent planning should improve project management productivity and would probably improve project quality. The direct time savings of having an electronic document library on hand at all times, reducing travel time and providing more time on the job are also included in the overall time gain. The estimated value of avoided rework was obtained. By comparing the resulting time savings to the value of having an additional CM on the project, an ROI can be generated based on how much equivalent CM time is recovered with the use of Vela. These values were used in calculating a potential dollar value in avoided rework provided by the use of Vela on mobile devices. The amount of avoided rework due to additional CM time on the project is not necessarily linearly related. There are diminishing returns for an additional CM at some value. This report uses a linear relationship based on the relatively narrow range of additional CM time available.

4. PROJECT DESCRIPTION

4.1 Case Study Project

The research was conducted on a university library construction project. This is a CM-At-Risk project with a phased Guaranteed Maximum Price (GMP) of approximately $100 million. The scheduled duration of the project is approximately 2 years. The CMAR does not self-perform any construction tasks as the CMAR contract requires a 100% brokered project. The CMAR directly manages over 35 individual trades of which 5 used Vela substantially. The CMAR staff is composed of 7 CMs and 3 superintendents. The library is a 5-story steel framed structure with concrete slabs on metal deck. The library is planned to be certified as a LEED Silver building, utilizing chilled beams and radiant panels for HVAC needs. The unique exterior consists of a 100% unitized glass panel curtain wall system and will more than double the current library seating capacity.

Construction of the library began in October 2009 and Vela Classic was introduced after 9 months. Vela Classic required syncing both at the beginning of the day to collect any new project data and at the end of the day to upload any newly generated project information. After roughly one year of construction, VW was incorporated into the workflow of the field personnel using tablets with an integrated bar-code scanner as well as a built-in camera for documentation and material tracking purposes. An “unlimited seats” license was purchased from Vela for a monthly subscription fee in order to maximize the number of participants using the software. In addition to superintendents having tablets, a Mobile Electronic Resource Station (MERS) was developed to provide access to the most recent contract documents, RFIs, plans, specs, and shop drawings to both superintendents and trades personnel. The MERS pictured in Figure 4.1 also provides the ability to print a hard copy in 8.5” x 11” or 11” x 17” and return to their area of work.

Figure 4.1-Mobile Electronic Resource Station (MERS)

4.2 <u>Vela Software</u>

Figure 4.2 demonstrates how Vela software serves as a central hub for information flow between the key project participants. Four different modules were employed to help organize gathered project data and provide a means of classifying information depending on which end-user is accessing the information. The darker arrows surrounding the central “Vela Systems” icon signify the transfer of information both into and out of the “cloud”-based VW. Special characters are placed at the end of the individual inputs and outputs to denote which module is responsible for storing and distributing certain information. The grey arrows represent the flow of coordination within the project with the owner coordinating with the CMAR and A/E and the CMAR coordinating with the A/E, Owner, and trades as well.

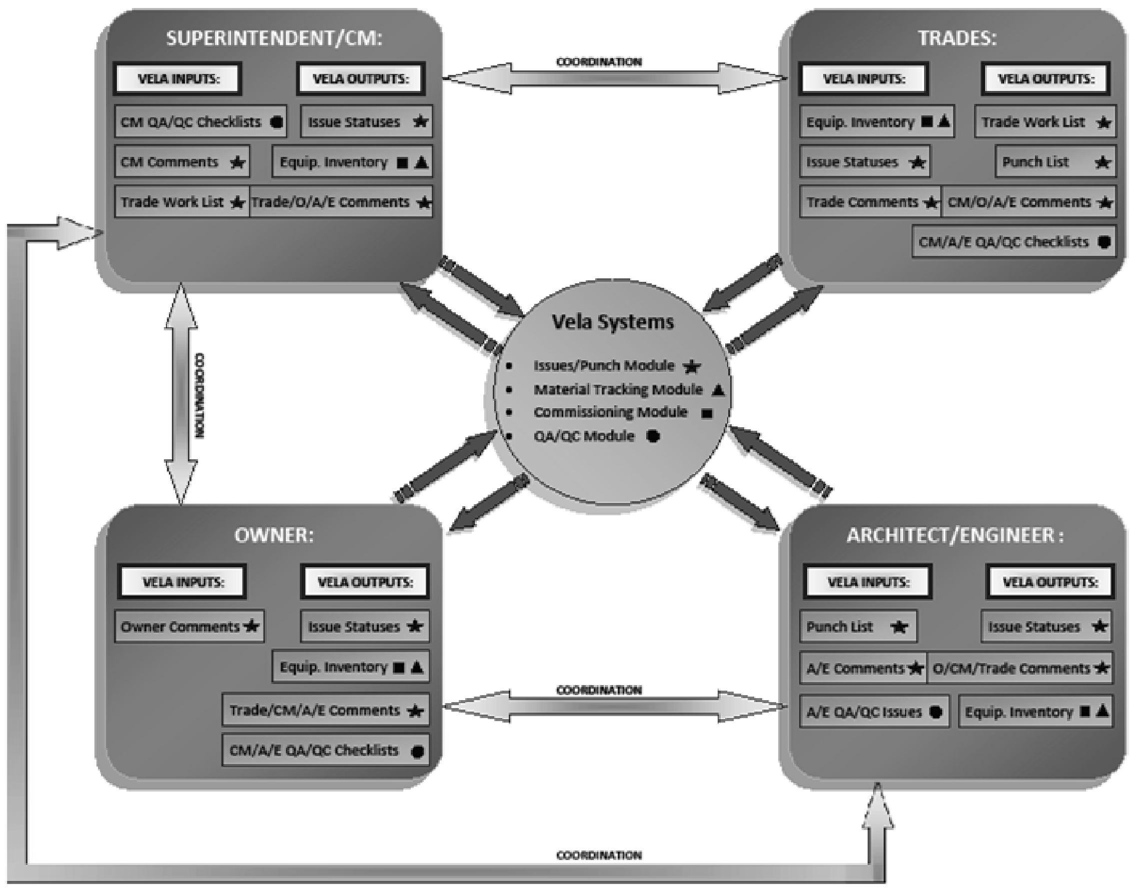


Figure 4.2-Flowchart of Vela's Inputs and Outputs in Relation to Project Team Members

The owner plays more of an observational role within VW as they receive pertinent project information but need not input data, aside from owner comments. The CM and Architect/Engineer (A/E) are the participants responsible for generating the majority of project data, including work lists, punch lists, QA/QC test reports, and inspection reports.

The trades receive outputs from VW in the form of QA/QC reports and acceptance, work lists, punch lists, and comments posted by the other participants. The trades' inputs consist mainly of internally generated QA/QC checklists, and generated issues which have been completed or have changed status. This "cloud"-based medium allows for rapid information flow to all end-users.

4.3 Importance of Vela to Project Participants

While the features of Vela are certainly important to the CMAR, it also can have significant importance for the end-users who are not part of the CMAR staff. By understanding how other project participants view the features provided by Vela, a broader understanding of the critical attributes can be developed.

Interviews were conducted with 16 project participants who were or would be using Vela software on the project. CM personnel, Design Professionals of Record/Engineers of Record (DPOR/EOR), owners, and trades' Project Managers were interviewed to determine which features were of most importance in the construction phase of the project. A five point scale was used to determine the importance of each of Vela' features. The scale ranged from 1 to 5: 1) Extremely Important 2) Very important 3) Somewhat Important 4) Not Very Important 5) Not At All Important/Not Applicable. Twelve features listed were identified in collaboration with Vela and by preliminary interviews with end-users of the software.

Table 4.1 shows the average importance of each feature and the overall ranking of findings. The respondents were asked to rate the importance of each feature both to themselves and to the group they represented.

Table 4.1- Self Evaluation: Importance of Vela Features (Statistical Mean)

		Importance of Feature to:				Overall	Rank
Item	**Description**	**Skanska**	**NCSU**	**Trade(s)**	**DPOR/EOR**	**Avg.**	
1	Access to construction documents (plans/RFIs/Specs/Shop Drawings/Cut Sheets) in the field through use of tablet PC, iPads, and Mobile Electronic Plan Tables, eliminating the need to go back and forth to carry plans/RFIs/Specs. to and from job site.	***1.38***	***2.67***	***1.33***	***1.50***	***6.88***	2
2	Access to "Real Time" information (plans/RFIs/Specs/shop drawings/cut sheets) updated daily via "syncing" with the Vela server.	**<u>1.25</u>**	***2.67***	***1.33***	**<u>1.00</u>**	**<u>6.25</u>**	1
3	Attach annotated pictures to QA/QC checklists as well as Issues/Punchlist generated in the field via camera in tablet PC (as opposed to manually downloading pictures from a camera, printing and stapling to a hard copy checklist).	2.00	3.00	2.33	2.00	9.33	5
4	Generate action items for Subcontractors via Punchlist/QA/QC checklists which go directly into an electronic database (as opposed to manually having to write down on paper and add in excel later for distribution to subs).	1.75	3.33	2.00	2.00	9.08	4
5	Filtering of punchlist items/issue by issue type, work area, or responsible party for easy and clear distribution to subcontractors (as opposed to manual sorting in excel).	1.75	3.33	3.00	***1.50***	9.58	8
6	Having an electronic record and database of all QA/QC checklists rather than having a file of hand-written paper forms which requires manual sorting and organization. This creates an electronic "paper trail" to serve as an audit trail, reducing risk to Owner and GC. (Can demonstrate legal "Duty of Care" in the courtroom)	2.25	***2.67***	1.67	***1.50***	8.08	3
7	Save time via use of electronic "pushpins" to precisely locate an issue, punchlist item, RFI, etc. to more accurately communicate it to the subcontractors rather than having to verbally and physically explain and/or show a specific location.	1.75	3.67	**<u>1.00</u>**	3.00	9.42	7
8	Ability to track quality issues & defects for specific materials (at the piece or unit level of detail) through bar-coding of the specific pieces.	2.25	3.67	2.33	2.00	10.25	10
9	Access to a visual representation of supply chain information (manufacturing, shipping, & installation status) through bar-coding materials and linking them to the BIM so that at any point in time, one can see in the model the status of any given piece or material.	2.13	3.33	3.00	2.00	10.46	12
10	Market differentiator for clients/owners (differentiates Skanska's services from others in the industry through use of innovative techniques which improve project delivery)	1.63	***2.67***	3.00	3.00	10.29	11
11	Ability to create new RFIs on electronic plan sheets as question/concern arises in the field for quicker processing time eliminating the need to return to the office to generate an RFI.	2.38	3.00	2.00	2.00	9.38	6
12	Provide the Owner electronic deliverables (manuals, warranties, commissioning info, etc) all linked into the BIM model through Vela creating a single electronic information hub for future building operations & facility staff.	2.25	**<u>2.00</u>**	3.00	2.50	9.75	9

Note: Feature importance is shown as bold and underlined for most important features and bold and italicized for second most important features.

The ability to provide access in real time to updated information, including plans, specifications, shop drawings, RFIs, and ASIs to all users (Item 2) was the single most important feature for to the CMAR and the DPOR/EOR, a finding consistent with expectations for the two project participants responsible for tracking, releasing, modifying, and distributing all construction documentation. This was also the second most important feature for both the owner and trades.

The feature of primary importance for the trades and their project managers is that of using electronic "pushpins" on PDF plan sheets in Vela to communicate work lists or punch list issues to other trades and managers (Item 7). For the owner, the greatest importance is having electronic deliverables linked to the BIM for continued use by the facilities and operations staff (Item 12). While not the most important feature with any project participant, Item 1 was found to be the second most important feature of Vela for all parties surveyed.

The second most important feature, according to the parties interviewed, is Item 6, having a database and record in electronic format which can be easily sorted, filtered, and organized, as well as providing an electronic audit for tracking QA/QC issues. What separates Vela software from that of a spreadsheet is that all information is available to all parties as it is updated, and even more importantly, Vela tracks and records the history of all changes, edits, and any additions/deletions in Vela which have occurred. This feature can improve accountability for trades.

5. COSTS

5.1 Introduction

Construction-related software costs include the purchasing cost as well as the implementation and maintenance cost. Purchasing costs are monetary while the implementation and maintenance costs are mainly labor costs. Purchasing costs include the price for acquiring the software license, Vela's implementation and training services for key users, and the hardware necessary for its effective use. Implementation costs equates to the CM's staff time required to establish, configure, modify, and maintain such a system, as well as on-site training for other users (i.e. owner, subs, A/E, other CM staff). Implementation costs are typically more difficult to estimate accurately yet they must be accounted for when trying to obtain the total cost involved.

5.2 Purchasing Costs

The purchasing costs for establishing VW are summarized in Table 5.1. The total cost was about $90,500. The Apple iPad VM app is free but will only function with an active subscription to Vela's services. Much of this cost was transferred to the trades, primarily mechanical, electrical, plumbing, drywall, and curtain wall trades in their respective contractual scopes of work. These costs are then ultimately transferred to the owner. Because the majority of the costs ultimately fall to the owner, all trade-purchased hardware becomes the sole property of the owner and the tablets and iPads serve as electronic deliverables containing all project data, QA/QC issues, work lists, punch lists, safety reports, plan sheets, specifications, as well as all BIM models containing gathered equipment/commissioning information. The intent is for the facilities department to use the information in future maintenance and facility operations.

Table 5.1-Vela Purchasing Costs

CATEGORY	PAID BY	AMOUNT	ITEM	SINGLE OR RECURRING PURCHASE (S/R)	AVOIDABLE COST (TRIAL AND ERROR)
Vela Software	CMAR	$ 10,000.00	Unlimited Users, 24 months @ $1200/month	R	
	Vela (Donation)	$ 9,000.00	Project Start-up	R	
	Trade Cost	$ 9,500.00	Implementation and training on-site (2 days)	R	
Tablets	Tablet (Donation)	$ 4,509.36	Standard tablet x 1	S	
	Tablet (Donation)	$ 5,400.00	Barcoding tablet x 1	S	
	CMAR	$ 4,509.36	Standard tablet x 1	S	
	CMAR	$ 10,800.00	Barcoding tablet x 2	S	
	Trade Cost	$ 5,400.00	Barcoding tablet x 1	S	
	Trade Cost	$ 10,800.00	Barcoding tablet x 2	S	
Wireless Accessories	Trade Cost	$ 4,500.00	WLAN router x 3	S	
	Trade Cost	$ 400.00	Short-range antenna x 2	S	
	Trade Cost	$ 300.00	Long-range antenna x 2	S	
	Trade Cost	$ 400.00	Wireless access point x 2	S	
Wireless Broadband USB Devices	Trade Cost	$ 560.00	USB modem x 7	S	✓
	Trade Cost	$ 350.00	1 Month subscription for each device at $50/month	R	✓
	Trade Cost	$ 450.00	Mobile broadband card x 3	S	
	Trade Cost	$ 2,100.00	1 Year subscription for each device at $50/month	R	
Apple iPads	Trade Cost	$ 1,360.00	iPad 64GB x 2	S	✓
	Trade Cost	$ 2,487.00	iPad 2 64 GB x 3	S	
	Trade Cost	$ 89.95	Protective case (iPad 2)	S	
	Trade Cost	$ 179.90	Protective case (iPad) x 2	S	
Barcoding	Trade Cost	$ 945.00	Bluetooth scanners x 3	S	
	Trade Cost	$ 825.98	Barcode printer x 2	S	
	Trade Cost	$ 120.00	Barcode labels (1.25" x 2.75") x 2	R	
Mobile Electronic Plan Station(s)	Trade Cost	$ 2,260.00	Metal field office station	S	
	Trade Cost	$ 199.98	UPS battery backup x 2	S	
	Trade Cost	$ 119.99	Articulating wall mount x 2	S	
	Trade Cost	$ 237.08	Laser Printer x 2	S	
	Trade Cost	$ 39.78	Foldable USB Keyboard x 2	S	
	Trade Cost	$ 1,788.20	46" 1080p LCD HDTV x 2	S	
	Trade Cost	$ 799.98	Desktop Computer x 2	S	
	Trade Cost	$ 45.98	6' VGA/SVGA Cable x 2	S	
TOTAL:		$ 90,477.54			$ 2,270.00

*Note: Trade's purchases were included into their scope of work and subsequently, into their bid price. For this reason, all hardware devices become the sole property of the university following completion of the library project.

The CMAR incurred over $25,000 or 28% of the total costs while the various trades incurred over $46,000 or 51% of total costs. The remainder of the costs were carried by the tablet manufacturer and Vela with 11% (or just under $10,000) and 10% (or $9,000), respectively. Figure 5.1 shows the distribution of costs between project participants.

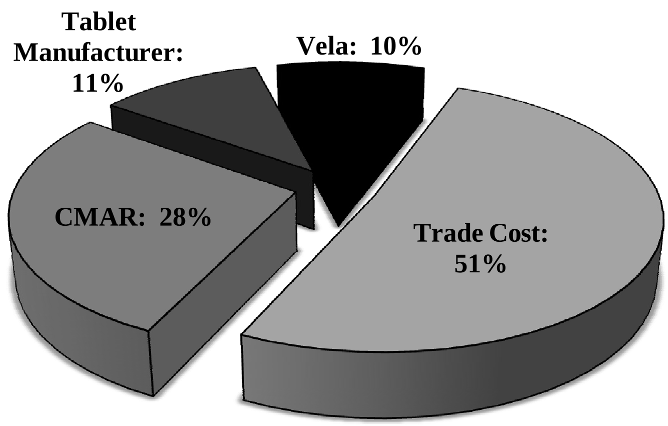


Figure 5.1-Percentage of Purchasing Costs for Implementation of Vela

It is important to distinguish between the costs that directly relate to the web-based project management functionality and the costs associated with implementation and development costs as well as learning curve costs associated with the adoption of new technology. In Table 5.1, an "AVOIDABLE COST" column is used to identify which purchases could be eliminated from future implementations. These costs were the result of examining optimal configurations to provide wireless internet access across the project site. For example, wireless network hardware was originally established to cover the project site with Wi-Fi signal but it was discovered that this necessitated the use of multiple signal repeaters that hindered the bandwidth speed and data transfer rate as the transfer rate is inversely proportional to the number of repeaters installed. Realizing the limits of the Wi-Fi hardware, the electrical contractor provided USB mobile broadband devices which plugged directly into the tablets. These USB devices did not mate fully with the tablets however, which resulted in lost internet connectivity and a potential for lost or damaged USB devices due to the unsecure connection.

These hardware shortcomings eventually led to the use of mobile broadband cards which enable the user to connect to the internet while having the card in a pocket or similar personal location. While this proved to be an adequate solution to the internet connectivity issues which plagued the other internet devices, the short battery life of 4 hours did not provide the optimal solution. Apple iPads were then acquired. These iPads ran Vela's VM app and provided off-line functionality as well as the ability to use the built in 3G cellular service when a wireless signal could not be obtained. Shortly thereafter, iPad 2s came to the market and were purchased, which additionally allowed the user to capture pictures and video directly. As a result, many of the earlier purchases were classified as avoidable costs for future applications.

5.3 <u>Implementation Costs</u>

There must be an allowance for users to become familiar with any new technology. The majority of the implementation costs were associated with the initialization of the Vela software. This included mass uploading of contract documents, establishing the location hierarchy which is specific to each individual project, creating and uploading QA/QC checklists, and importing all mechanical equipment and curtain wall panels to be tracked. A CM staff member was designated as a “document manager” and was responsible for uploading and replacing plan sheets within Vela. The “document manager” was selected based upon their current duties on the project (i.e. hard copy RFI/ASI mark-ups) as well as their competency with computer usage and PDF editing software.

Two day on-site training and online training were provided by Vela as part of the paid service with VM. Two CMAR staff members were selected to provide the additional training necessary for the rest of the CMAR team. The trainers were delegated with this task due in part to their previous experience with BIM-related software in the pre-construction department as well as their public speaking and teaching skills. Throughout the 6 month research period, training was held every week. The training was gradually reduced as the number of new Vela users and the introduction of major trades began to level off. After the initial, Vela hosted training, the weekly costs incurred during the case study involved: (1) training sessions provided by the CMAR, (2) the generation of handouts and deliverables, (3) continuous document control, including electronic RFI mark-ups, hyper-linking RFIs on electronic plan sheets, and (4) replacing out dated plan sheets with the most current revision. The document manager was responsible for uploading and replacing plan sheets within Vela. A total of 16 hours were necessary for the document manager to perform these project initialization tasks. This activity was a cost, performed concurrently with hard copy document control. A summary of the recurring weekly costs are provided in Table 5.2.

Table 5.2-Summary of Weekly Implementation Costs

Activity	Total Min. Hrs/wk	Total Max. Hrs/wk	#/Type Persons Involved
Training for new Vela users (Total)	2	4	2 CM Trainers
Performing electronic mark-ups	6	14	1 Document Manager
Uploading contract document and plans	2.25	2.5	1 Document Manager

6. BENEFITS

6.1 Introduction

The benefits usually associated with successful technological innovations in construction are that of increased effectiveness for its users, lower staff demands, time savings in common construction management activities, and monetary savings due to improved CM practices (Anderson 2000). For this case study, the quantitative and qualitative benefits of using Vela VW, Vela VM app, and their associated hardware are presented where applicable. Various productivity measures are also presented in this report.

6.2 Quantitative Benefits

A list of typical activities encountered by a CM on a weekly basis was used to assess benefits compiled. The activities were classified: (1) assessment, (2) reaction, (3) planning, and (4) clerical. CMAR staff were selected for interviews based on their extensive use of Vela on this project and for their construction experience and past use of various other construction management software. Five interviewees were surveyed: 2 Assistant Project Managers, 1 Project Engineer, 1 Senior Superintendent, and 1 Assistant Superintendent. Their combined experience in the construction sector was 69 years and experience with construction management software, including BIM, was 21 years. On average, each participant had 13.8 years of construction experience and 4.2 years experience with the innovative construction technologies.

Reaction time refers to the time spent addressing issues which have arisen in the field due to inaccurate or incomplete planning or assessment. Reaction takes place when potential conflicts or issues are inadvertently overlooked during the planning and managing phases of construction and must be later corrected. Reaction items consume the resources usually reserved for planning and assessment and can involve time delays as well as unnecessarily incurred costs to address and correct them. Resolving these issues detract from planning time. Assessment comprises gathering, organizing, and evaluating the appropriate project data in order to make informed decisions about the construction process. Planning refers to reviewing and confirming plans, specifications, schedules, and trade and supplier coordination and communication prior to the actual start of an activity. Finally, clerical duties are ones which do not necessarily directly contribute value to the project, yet are necessary for communication and the transfer of information and ideas. Clerical often include, but are not limited to, emailing, marking up plans, annotating drawings and/or pictures, and logging information via spreadsheets or word documents. The conceptual assignment of management time as assessment, reaction or planning is not new. The addition of a time specifically assigned for clerical work was included in this study since it was originally thought that clerical activities might be significantly affected by this technology.

It was originally anticipated that Vela use would significantly affect the time or proportion of management time spent in several of these categories. Specifically, it was anticipated that the use of Vela would increase planning time by reducing both clerical time and assessment time. By increasing planning time, reaction time will be reduced because the CM is leveraging the planning time to the project's advantage.

6.3 <u>Qualitative Benefits</u>

In addition to the quantitative benefits associated with improved productivity and efficiency, supplementary qualitative benefits result from the use of Vela coupled with a mobile communication platform. These qualitative benefits can be categorized into four sectors: communication, operation, clerical, and quality. A summary of the various sectors along with specific qualitative benefits of each sector is presented in Table 6.1. This list was developed in part from discussions with one of Vela's co-founders and through discussions and interviews with key project participants using Vela. Qualitative benefits may be subjective but for the CMAR's employees these benefits were considered to be an important list of attributes associated with Vela use by construction firms.

Table 6.1-Qualitative Benefits of Using Vela

Category:	Qualitative Benefits:
Communication	Improved transparency of information
	Trades notified daily of worklist items/quality deficiencies via E-mail
	All necessary parties can observe and communicate on issues
	Instant status updates on issues in Vela
	Centralized hub for project information/plans/issues/quality
	Replaces having to send emails with large number of CCs and attachments
Operation	Reduction in clerical time
	Mobile Platform
	Vela is both tablet and iPad compatible
	Ability to quickly sort and filter issues
	Less effort for organization of QA/QC checklists, worklists, punch lists
	Vela generate reports for distribution with photos and comments attached
	Audit trail for risk mitigation
Clerical	Plans/Specs/RFIs available to project members in a mobile electronic format
	No longer need to transfer hand written notes to electronic format
	Vela “cloud” archives and stores all project data, saving physical space and paper usage
Quality	QA/QC deficiencies automatically create action items for responsible trades
	Owner can verify that issues are being addressed and closed out in a timely manner
	Promotes a robust quality management program
	Streamlined integration of photo and plan sheet attachments to issues for documentation
	Ability to document construction issues in the field eliminates unnecessary future rework

Many of the qualitative aspects listed in Table 6.1 help increase efficiency. This is due in part to the qualitative benefit related to the increased speed at which information is transferred from one party to another and information being readily available and easy to manage. The increase was assessed quantatively.

It is believed that Vela can promote consistency within certain business practices. Multiple users on different projects have the ability to perform certain construction processes in a similar manner through the use of the software and creating uniformity throughout the management firm. One aspect that encompasses all categories of benefits listed in Table 6.1 is the ability to consistently replicate certain tasks independent of the various users or projects.

It is important to distinguish between efficiency and productivity as it relates to VW and other construction management software benefits. Efficiency is defined as doing things right or the amount of error-free work performed over a period of time (Helms 2006). Productivity, unlike efficiency, pertains to the quality of work being performed

Using a standardized program for managing construction projects often requires reengineering current business practices, focusing on IT implementations. This standardization of business practices and workflows leads to increased efficiencies of the users, meaning that end-users are not simply performing their duties but performing their duties in a more structured and organized manner, with more effort-free time spent that can be replicated throughout the construction firm. With firm-wide usage of Vela or other project information management software, a CM can transition from project to project or project team to project team with less time necessary to adapt to slight variances in operations. Due to this standardization, Vela helps promote a robust quality management program for the project management personnel.

An organized workflow helps establish ease of project information sharing across multiple project teams. Using the same CM software, project teams act less independently of one another with fewer differences between regional offices to the next. These features of mobile “cloud”-based CM software promote more effective project participants and hence, a more effective project team.

It may be difficult to precisely quantify monetary savings or time delays if out-dated project information was never initially circulated and many potential benefits cannot be readily quantified because of the nature of construction. For example up to date, real-time information can prevent or reduce potential rework and minimize delays. The indirect benefit of Vela related time savings can be significant in providing the CM an opportunity to remain focused on proactive planning and project progress rather than spending too much time solving problems, that is, in the reaction phase. The CM can assess construction activities in progress and confirm ones scheduled to start in the near future more readily. This capability has important potential implications in Lean Construction as well. The CM can allocate a larger portion of the available management time to potential additional planning and assessment rather than reaction and clerical activities.

One potentially important impact of Vela is that of reduced overtime. If Vela can reduce the total weekly overtime hours worked, CM stress is reduced and job satisfaction may be improved. The reduction in productivity with long-term overtime is well established.

Reaction and rework are wasteful activities that should be minimized. The Construction Owners Association of Alberta (COAA) identified five causes of rework in their Fishbone Rework Cause Classification diagram shown in Figure 6.1 (2004). All of the 5 causes of rework are addressed by VM for the iPad and VW for computers and tablets.

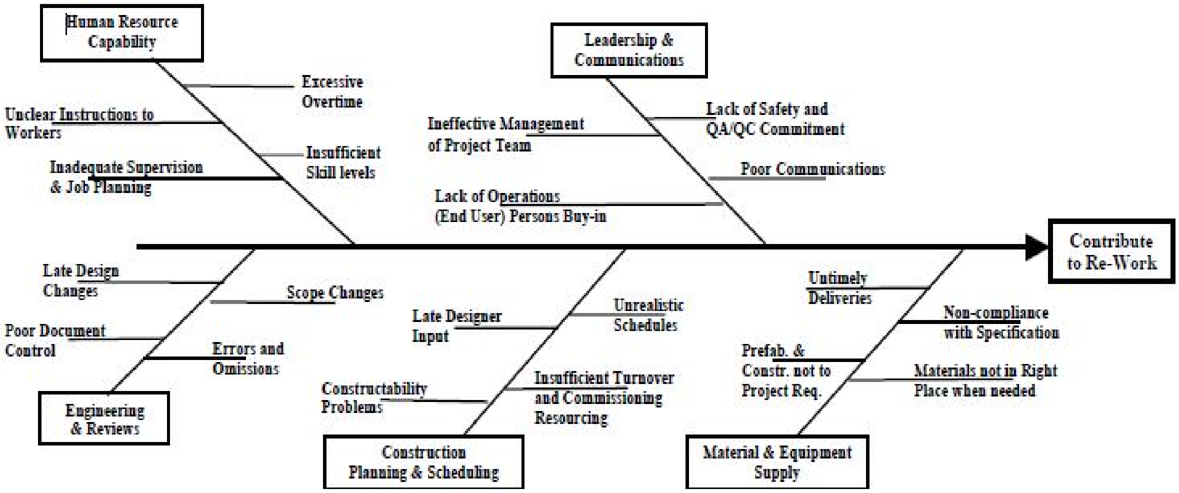


Figure 6.1-COAA's Fishbone Rework Cause Classification (Fayek et al. 2004)

Specifically, Vela addresses the aspects of "Unclear Instructions to Workers", "Inadequate Supervision & Job Planning," and "Excessive Overtime" under "Human Resource Capability." "Unclear Instructions to Workers" is addressed by providing trades with automatically generated e-mail notifications with the ability to view and change the status of issues using iPads provided from the CMAR on a project by project basis, or through the MERS located on site.

"Inadequate Supervision & Job Planning" and "Excessive Overtime" are also addressed by Vela. The additional planning time and reduced total weekly hours worked by the CM clearly affect those two factors contributing to rework and delays. "Poor Document Control" and "Errors and Omissions" listed under "Engineering and Reviews," are two issues addressed by the ability of Vela to leverage the instantaneous information transfer provided by the internet. In doing so, all participants have the most current set of plans, specifications, RFIs, and ASIs available as they are released for distribution. Hyperlinked RFIs on PDF plan sheets aid in the effort to provide improved information flow in the field. Vela also helps in the category of “Leadership & Communications” in all subcategories except “Lack of Operations (End-user) Persons Buy-in”.

Communication is a major driving factor of VM and VW. The analytical reporting feature found in Vela software can also potentially improve management and project performance measures. Vela’s material tracking and commissioning features coupled with the integrated barcode scanners of the tablets or Bluetooth barcode scanners for use with the iPad addresses the aspect of “Materials not in the Right Place when Needed” in the “Material & Equipment Supply” category. A case study of the Syncrude Aurora 2 Project in Alberta, Canada, found that “Human Resource Capability”, “Engineering and Reviews”, and “Material & Equipment Supply” issues accounted for over 97% of rework on construction projects. The distribution of rework costs was allocated equally with “Human Resource Capability”, “Engineering and Reviews”, and “Material & Equipment Supply” (Fayek et al. 2004). Vela VW and VM can address those rework causes in at least some capacity and can therefore potentially reduce the amount of rework costs encountered on a project through improving the project controls listed.

A qualitative benefit which cannot be directly observed but should be considered throughout future implementations is reduced overall project cost through decreased contingencies placed in trades’ bid price. If Vela can help reduce rework on projects through improved communication and increased CM efficiency and productivity, trades can become more competitive with their bid prices by knowing that Vela or similar construction management software reduces rework and saves money. This savings is then passed on to the owner in reduced contingency.

7. QUANTITATIVE RESULTS

7.1 Pre-Vela and Post-Vela Activity Durations

The data collected for determining productivity and efficiency gains through Vela is presented in Table 7.1. The 25 CM activities and their durations pre-Vela and post-Vela were categorized into the four types of management time categories. The data pertains primarily to the use of VW as VM was not widely used at the time of data collection.

Since particular construction management activities would have differed drastically over a 6 month span, when considering a 2 year project, pre-Vela activity durations were obtained by examining the 5 CMs based on their experience and breath of construction knowledge to obtain best estimates on the activity durations. Post-Vela calculations were gathered by having each CM track their activity durations on a weekly basis, then complied to provide a 20 week average.

The immediate benefit can be seen in the difference in the total weekly hours worked. The average number of hours worked for the interviewed salary employees was 62.1 hours without the use of Vela software. This value was reduced to 54.5 hours with the use of Vela software, representing a decrease of 12.2% from 62.1 hours without the use of Vela. A further analysis using ANOVA indicated a strong correlation to Vela use and a reduction in total weekly hours worked.

Table 7.1-Durations of Weekly CM Activities

		Activity	Avg. Duration Pre-Vela (Hrs.)	Avg. Duration Post-Vela (Hrs.)
DIRECT VALUE ADDING ACTIVITIES	PLANNING	CM Team Meeting	1.6	1.6
		OAC Meeting	1.6	1.6
		Review Plans/Specs/Shop Drawings/Submittals	5.6	5.6
		Coordinate with PMs of Trades for the week's activities	3.2	3.5
		Email/Phone suppliers to verify delivery dates and quantities	1.4	1.1
		Determine what productivity for following week must be to stay	1.6	1.6
		Email/Phone other trades about coordination issues/construction	1.6	1.6
		Plan for next week's construction/installation	2.8	4.0
		PLANNING SUBTOTAL	19.4	20.6
	ASSESSMENT	Follow up statuses of past week's issues	2.6	1.0
		Monitor productivity of installation/construction	3.2	2.8
		Verify last week's issues have been corrected/addressed	2.0	2.2
		Conduct Meetings with Sub and A/E on rolling punch list issues	2.6	1.8
		Go to field to verify progress and quality	4.2	4.4
		Assess productivity of past week/month	2.2	1.4
		Walking with Owner/Commissioning Agent	2.8	2.5
		ASSESSMENT SUBTOTAL	19.6	16.1
CONTRIBUTORY VALUE ADDING ACTIVITIES	REACTION	Coordinate with PMs of Trades for the weeks activities	2.3	2.5
		Follow up statuses of past week's issues	2.3	1.4
		Monitor productivity of installation/construction	2.0	1.6
		Verify last week's issues have been corrected/addressed	1.2	1.2
		Conduct Meetings with Sub and A/E on rolling punch list issues	2.4	1.8
		Document/Photograph unresolved issues and their location	2.0	1.1
		Email/Phone other trades about coordination issues/construction	2.8	2.4
		React to any issues/discrepancies which have arisen in the field	3.8	3.0
		REACTION SUBTOTAL	18.8	15.0
	CLERICAL	Process Pay Applications	1.8	1.8
		Update information in the BIM to serve as electronic deliverable to Owner	2.5	1.0
		CLERICAL SUBTOTAL	4.3	2.8
		TOTAL WEEKLY HOURS	62.1	54.5

Statistical analyses were performed on the CM weekly activity data to examine the hypothesis that Vela saves time for the CM and provides additional benefits of value to the project. Statistical analysis was conducted using JMP® software (SAS, 2011) to determine if there was a statistically significant difference in the total weekly time spent pre-Vela and post-Vela, and a significant difference in the times spent in different types of activities.

It is important to note that the average durations represent a single time span within a construction project. It is expected that as various construction activities begin and others come to a close, and as the speed of construction varies, the allocation of management hours could change substantially. This report did not attempt to estimate the benefits associated with software for other projects or time frames other than the period of time considered for this particular library construction.

The collected data was summarized in bar charts representing activity durations prior to the use of Vela (Figure 7.1) and after implementation of Vela (Figure 7.2). The weekly durations pre-Vela indicate both planning and assessment consume most of the CM time at 31% and 32%, respectively. Reaction time and clerical time account for the remaining 37% with reaction time consuming 30% and clerical duties consuming the remaining 7%.

7.2 <u>Examination of Collected Data</u>

The durations of all 4 management time classifications decreased with the use of Vela except for planning which increased in duration through “value added” planning time. The reduction in total weekly hours worked and reaction activity hours post-Vela showed a statistically significant difference from the pre-Vela data. ANOVA did not show a statistically significant difference between assessment, and clerical activities pre-Vela and post-Vela, but paired-t analysis of data did indicate Vela reduces the durations of these activities.

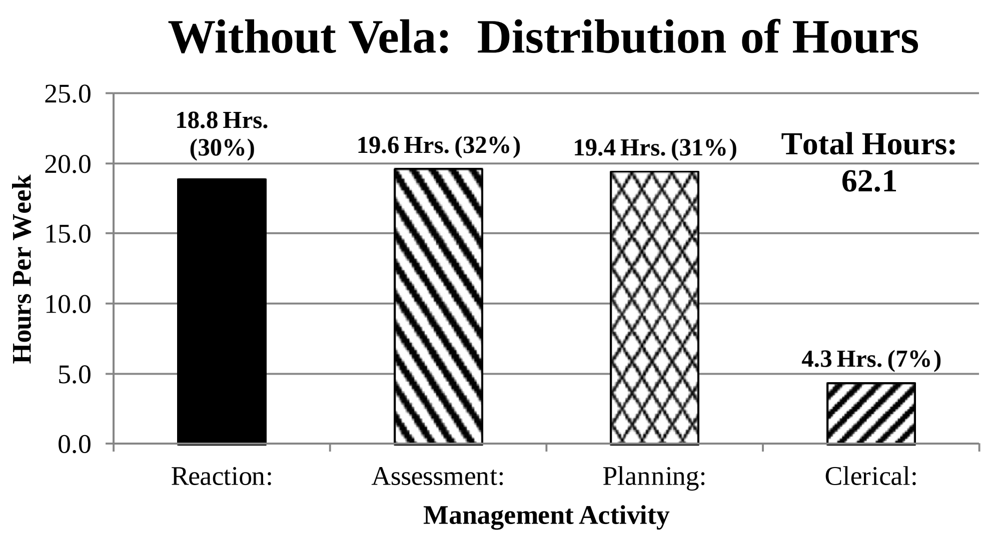


Figure 7.1-Distribution of Activity Durations Without Vela

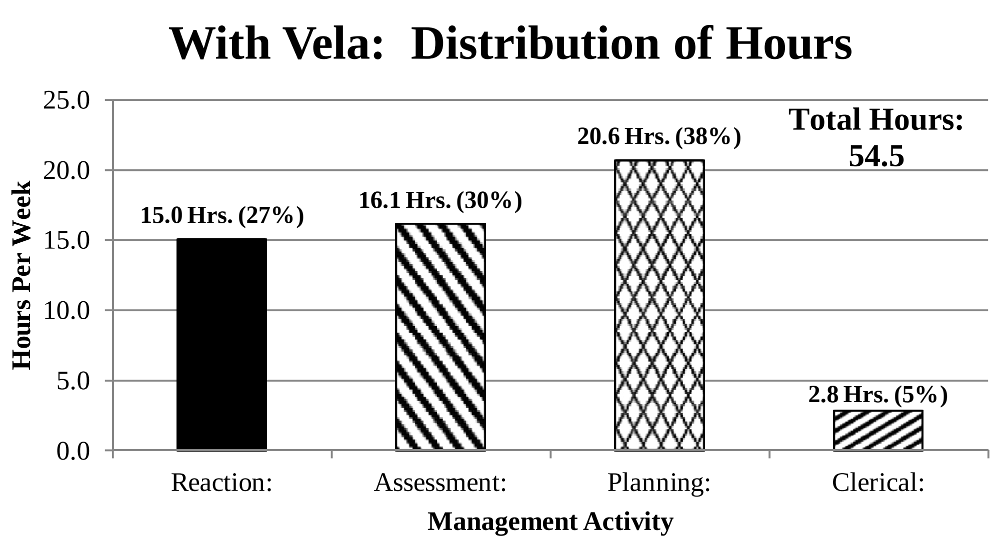
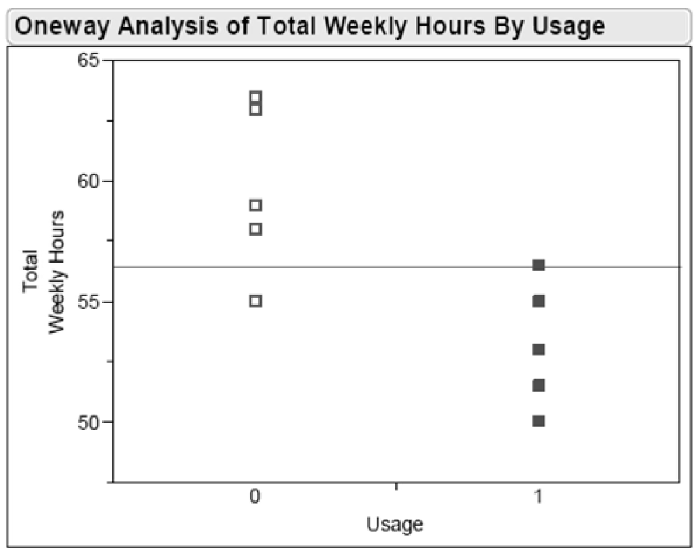


Figure 7.2-Distribution of Activity Durations With Vela

7.3 Oneway ANOVA Analysis

A oneway analysis of variance was performed to examine the effect of Vela on the total weekly hours worked. Although the degrees of freedom (DOF) are limited, the p value was 0.011, for an F ratio of 10.82, indicating a statistically significant difference at a 95% confidence limit between the total duration spent by the CM before and after Vela use was initialized. Figure 7.3 shows the hours spent by each CM for the 2 cases considered, without Vela, 0, and with Vela, 1.

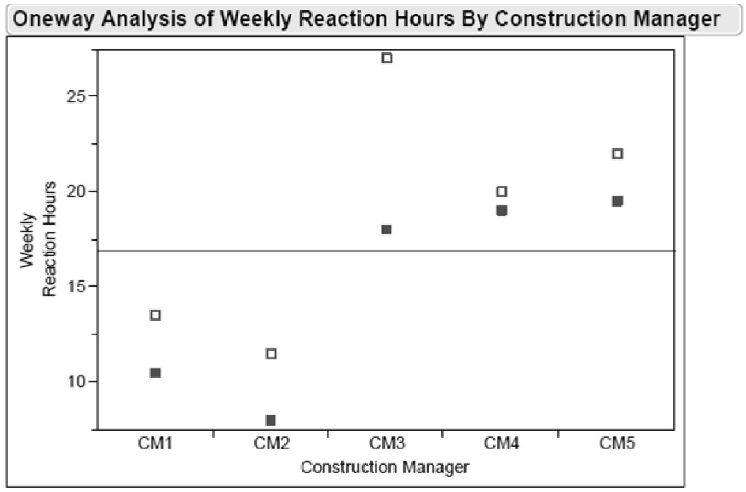


Outlined squares represent pre-Vela, solid squares represent post-Vela

Figure 7.3-Total Weekly Hours by Usage

Further investigation into differences with or without Vela in time spent in one of the categories, that is, reaction, assessment, planning or clerical, was performed to help assess quantitative effects of Vela on classes of management time. Examining reaction activities, the ANOVA provided a p value of 0.335 for an F ratio of 1.05, indicating no statistically significant difference in hours spent on reaction activities before and after implementation of Vela. The result is similar for assessment activities before and after Vela, with a p value of 0.423 and an F ratio of 0.71. No statistically significant difference in planning hours was found due to Vela with a p value of 0.762 for an F ratio of 0.10. Clerical activities were also not affected in a statistically significant manner ($p = 0.540$). It is important to recall that a portion of the weekly hours saved through the use of Vela appeared to have been added to planning time, a "value adding" activity.

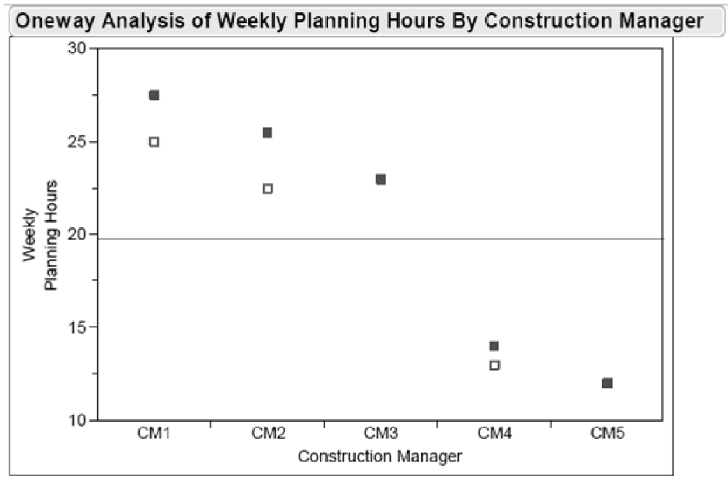
It is believed that the reinvestment of weekly hours saved using Vela was shifted to provide more "value added" planning time, accounting for the lack of a statistically significant difference in the planning time spent pre-Vela and post-Vela. Additional analysis was performed to examine the differences between responses of the 5 CMs surveyed by category of activities, pre-Vela and post-Vela. The examination of the reaction activities indicated that a statistically significant difference existed between at least one of the CMs with an F ratio of 5.85, and a p value of 0.040. Visually, the data in Figure 7.4 suggest that CM1 and CM2 are somehow different from CM3, CM4, and CM5 regarding reaction based activities. This grouping may be a result of the different types of responsibilities and specific assignments or job functions of the CMs. It is recommended that further research in his area be conducted. Additional studies should include more CM personnel in each of several categories.



Outlined squares represent pre-Vela, solid squares represent post-Vela

Figure 7.4-Weekly Reaction Hours by Construction Manager

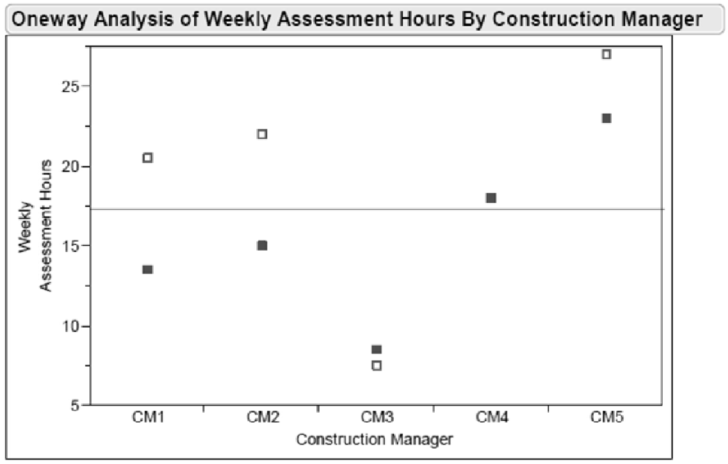
Average planning hours indicated possible clustering as seen in Figure 7.5. CMs 1, 2, and 3 averaged more than 20 hours per week planning while CM4 and CM5 averaged less than 20 hours per week. Again, these findings may be the result of varying duties or functions of the individual CMs. Additionally, ANOVA found that at least one CM had a statistically significant difference in planning hours.



Outlined squares represent pre-Vela, solid squares represent post-Vela

Figure 7.5-Weekly Planning Hours by Construction Manager

Assessment activities showed a statistically significant difference for at least one CM at a 95% confidence level, with an F ratio of 6.43 and a p value of 0.033. Observing Figure 7.6, it appears that CM3 is the most likely candidate for this statistically significant difference. The distribution of clerical activities between CMs did not provide a statistically significant difference at a 95% confidence limit. All values were relatively small, however and three were identical.



Outlined squares represent pre-Vela, solid squares represent post-Vela

Figure 7.6-Oneway Analysis of Weekly Assessment Hours by Construction Manager

7.4 <u>Paired-T Analysis</u>

Additional examination of management time pre-Vela and post-Vela was performed using a paired-t analysis. This analysis examined the difference between pre-Vela and post-Vela activity times for the same individual. Figure 7.7 shows the difference in reaction activity times pre-Vela and post-Vela plotted against mean activity duration. The analysis supports the conclusion that less time was spent on reaction activities after Vela was introduced. This, and the finding that less total time was worked each week with Vela, are critical findings of this study. The paired-t analysis indicated a significantly significant difference for reaction hours pre-Vela and post-Vela with a p value of 0.050. Figure 7.8 shows the paired-t analysis of weekly hours which exhibited a statistically significant difference pre-Vela and Post-Vela with a p value of 0.021 with only 4 DOF.

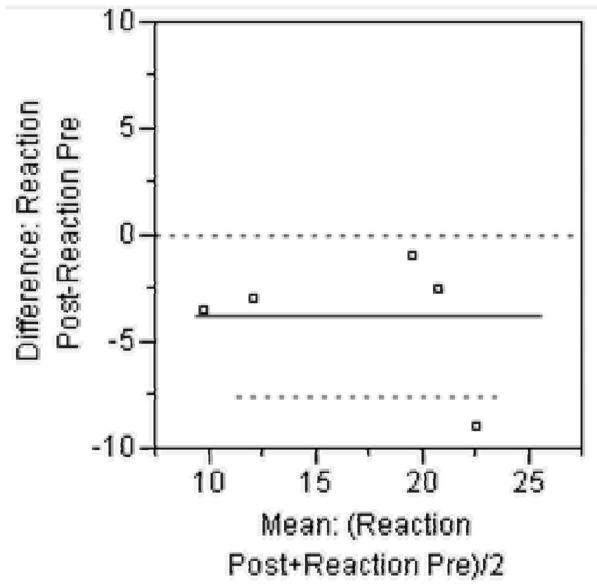


Figure 7.7 -Reaction Activities Pre-Vela and Post-Vela

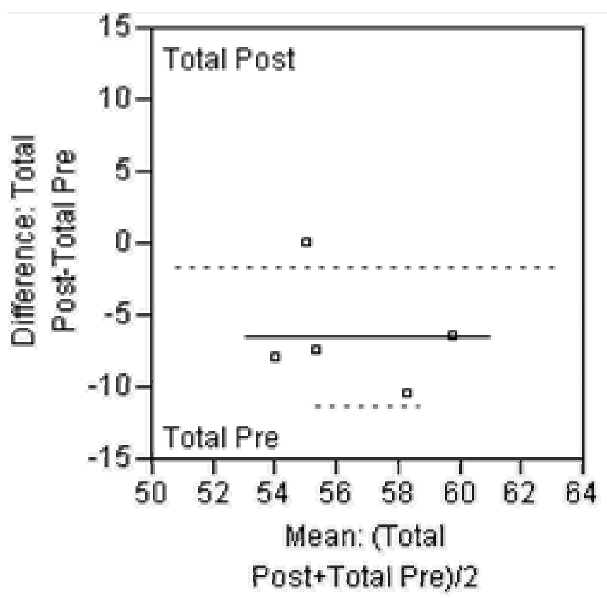


Figure 7.8 -Total Weekly Hours Pre-Vela and Post-Vela

Assessment time appears to have decreased by an average of 3.4 hours per week after the implementation of Vela, but statistical evidence is not strong given the limited DOF. Observation of Figure 7.9 and analysis indicates that Vela does appear to provide some reduction in assessment hours worked.

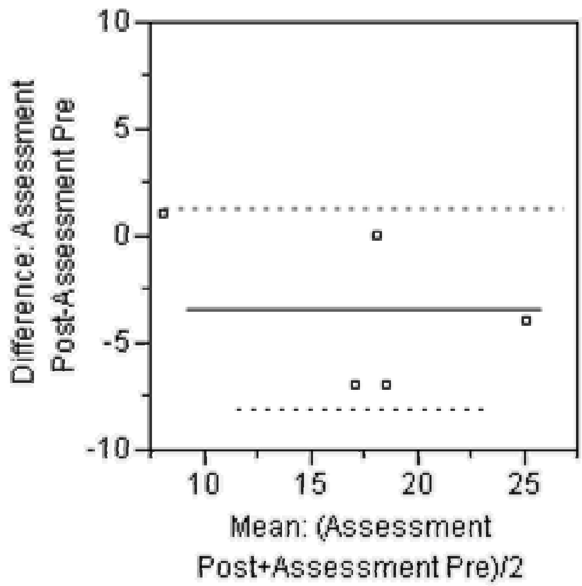


Figure 7.9-Assessment Activities Pre-Vela and Post-Vela

Analysis of clerical time pre-Vela and post-Vela verified there was no statistically significant difference. The same conclusion is reached when analyzing planning activities pre-Vela and post-Vela, although planning was the only activity that increased after Vela implementation. The difference in planning activity hours was just short of providing a statistically significant difference with a p value of 0.11 when considering a 90% confidence limit. Further research should help provide a more significant conclusion. This activity was the only one that increased with the use of Vela. The net difference in planning activity hours was the only positive difference found and was a result of CMs reinvesting a portion of their reclaimed work hours into "value added" planning time.

The degree of management time was essentially equal during both the pre-Vela period and the post-Vela period. The gap of time between pre-Vela and post-Vela observations was such that management activities were relatively similar and are not believed to have affected the activity durations observed in any significant manner.

7.5 Further Benefit Results

Not only was there a reduction in the total amount of time needed to complete the CM weekly activities, but the distribution of time changed significantly and favorably when Vela software was used. Assessment time decreased slightly from consuming 32% of the week's activities to 30% of the week's activities. The reduction in assessment time is consistent with the ability of VW to store real time project data which can then be quickly sorted, filtered, and evaluated without having to use a separate piece of software to enter, store, and analyze data. By having all project data located in a centralized hub, various project data can be accessed quickly and efficiently, rather than having to locate various files, ensure that they are up to date and that everyone has the correct version. Clerical time also decreased slightly from 7% to 5%. It is important to note that while VW provides project data to project participants automatically and in real-time, e-mail correspondence is still necessary for notifying others of the changes in data and directing them to particular items within VW.

Other construction management tasks require various other software. Records of phone conversations, RFIs and sequences of emails to and from various suppliers and other

CMAR employees may be best managed by other software such as Prolog. Processing pay applications was performed outside of the VW program so no benefits were gained in this area with VW. Program interaction with these and other packages such as scheduling may be beneficial, but an analysis of these needs are outside the scope of this study. However, with VW and its BIM integration adaptor, project data related to material tracking and commissioning can be synced to the BIM model to help provide status updates on various equipment and serve as an electronic deliverable to the owner for use with facilities management. Without the use of VW, this task would consume 2.5 hours each week but with VW, this duration was reduced to about 1 hour each week. Without VW, material tracking and commissioning would have to be manually updated for one piece of equipment or particular material at a time and would require the 2.5 hours observed pre-Vela.

The reduction in assessment time and clerical time allows planning time to increase from 31% to 38%. A 7% increase in planning time can provide an opportunity for more thorough scheduling or coordination with various trades, and could result in identifying important issues earlier and “on paper” in plans, specifications, or bid documents, before such issues arise in the field. The additional “value added” planning time appears to have resulted in more efficient management time as average reaction time was reduced from 18.8 hours per week to 15.0 hours per week, although direct evidence of this calculation is not available.

7.6 Calculation of Productivity

Using the data gathered in this study, a productivity metric was developed to help quantify the increased CM productivity provided by Vela. Applying this metric to construction management in other projects requires determining the management activities that typically occur in a specific phase of construction and estimating the time allocated to each of those activities. Since a primary job function of a CM is to manage field operations and construction processes, any activity that detracts from this activity should be examined for relative value. For the purposes of this case study, these value adding activities are considered to be project planning and assessment. The term recovered hours, for the proposes of this thesis, represent the amount of time needed to complete a certain activity, or group of activities, prior to the use of Vela. By summing the total recovered activity hours and dividing by the actual amount of hours spent on those activities, a productivity can be calculated based on a pre-Vela baseline of 1.00.

The average recovered hours of planning and assessment time, post-Vela was 19.4 hours and 19.6 hours, respectively. In addition, 1.5 hours were added to the recovered planning time since the use of Vela was found to save time throughout the work week and by reducing clerical, reaction, and assessment times. For example, Table 7.1 shows the increase in activity duration post-Vela with the planning activities of “Coordinate with PMs of Trades for the week’s activities” and “Plan for next week’s construction/installation” for a total, additional 1.5 hours. Recovered planning time is therefore the post-Vela total planning hours plus the 1.5 hours of additional planning gained.

A simple review shows the difference in total planning hours between pre-Vela and post-Vela to be 0.8 hours on average. However, this is due to the reduction in time for the planning activity "Email/Phone fabrication shop to verify sequence and number of units," that decreased from 1.4 hours to 1.1 hours on average. Therefore, the recovered hours of that activity is still 1.4 hours because the same amount of planning is taking place, just in a more efficient and productive manner. Using the same approach, the recovered hours of assessment time post-Vela is equivalent to the pre-Vela hours spent on assessment.

Summing the total recovered hours of planning and assessment post-Vela yields 40.5 hours per week on average (19.6 hrs + 19.4 hrs + 1.5 hrs. = 40.5 hrs.). Summing the total actual hours spent on planning and assessment results in 36.2 hours per week on average. Dividing the recovered hours by the actual hours results in a value of 1.119. This finding indicates that the use of Vela results in a productivity increase of 11.9% from a baseline established without using Vela. This productivity gain is a result of the beneficial redistribution of management activities and the addition of recovered activities while decreasing total weekly working hours. Table 7.2 summarizes the recovered and actual hours along with an estimate of improved productivity with Vela.

Table 7.2-Observed Gains in Productivity for Total CM Effort

Metric:	Pre-Vela	Post-Vela
Recovered Hours	39.0	40.5
Actual Value Adding Hours	39.0	36.2
Contributory Adding Hours	23.1	15.0
Productivity	Base	1.116

7.7 Travel Efficiency

The logistics and layout of the library are such that the field office is located approximately 1200 feet (ft.) from the project site with no direct line of sight to the project due to existing buildings. Golf carts and other utility vehicles are used to travel between the project and field office. One-way travel is about 4 to 5 minutes. This time was based on the average of 4 timed runs to and from the job site. Superintendents were asked to estimate the number of trips to retrieve construction documents throughout the day. Responses ranged from 2 to 5 times a day in most circumstances. With the use of VW or VM, superintendents have access to all construction documentation on the tablets or iPads. With a mobile platform, superintendents can use Vela's software to access the most recent versions of documents.

Not only does the superintendent not have to return to the field office for documents, but he or she can carry all documents to the site at once, a procedure not convenient on moderate-sized projects or practical for large sized projects with paper files. It is possible to calculate the amount of time which would potentially be lost due to unnecessary travel assuming a completion date of September 2012. Table 7.3 shows a comparison between the maximum and minimum time that could be saved over the remaining duration of the project. The projected time savings of between 36 and 114 total accumulated days demonstrates the reason that every project participant interviewed felt that the second most important feature provided by the tandem use of Vela software and mobile devices was having all up-to-date documents readily available at any point on the project. When considering weekly time savings, travel efficiency provides 2.8 hours per week in avoided travel time. The calculation of time savings is based on the total number of working days from VW implementation in January 2011 to project completion in September 2012. Weekends, all major observed holidays, and vacation time throughout the year were excluded.

Table 7.3 -Estimated Time Savings Through Gained Travel Efficiency

Quantity	Max	Min
# Trips/day	5	2
Time back/forth	10	8
Working days/yr.	260	260
Years left in proj.	1.75	1.75
Total minutes	22750	7280
Total hours	379	121
Total days	38	12
x 3 Superintendents	114	36

Note: Not including vacation times

There are economies of scale with such implementations and on much smaller and less critical projects it becomes more difficult to justify such an investment (even though the scale of the investment would be smaller as well). The broader implications of such an investment are as follows: increased project data for analytic reporting by the CM firm's corporate executives, given industry-wide adoption of such software, it is expected that projects would see a decrease in overall costs through a reduction in rework due to trades not receiving important project information in a timely manner, decreasing the contingency placed in bid packages, with a lower price to the owner, and establishment of systematic processes by using Vela and similar software.

7.8 Calculation of Efficiency

In addition to the productivity gained through the use of Vela, a quantifiable efficiency value can be calculated based on the activity and duration data gathered. By finding the increased proportion of direct value added in hours each week with the use of Vela, and comparing the fraction of total weekly hours spent doing the right things, i.e. recovered hours including planning and assessment, post-Vela and subtracting from the same fraction pre-Vela, a value of .114 is generated. This provides evidence that for this case study, Vela also increased the efficiency of its users by 11.4%. By increasing the efficiency its users, Vela provides an opportunity for CMs to perform more direct value adding activities such as planning and assessment, rather than clerical and reaction, throughout the work week.

8. INVESTMENT VALUE ANALYSIS

The use of Vela software, coupled with mobile technologies resulted in a productivity gain of 11.9% on average for each CM actively using the software. It is difficult to estimate the financial benefits of the project because the efficiency is a pre-Vela baseline metric. A means to quantify the Vela benefit in simple, easy to estimate financial terms was developed. While other methods can be developed, and could be considered in subsequent research, the approach used in this study is both simple and conservative. A value of the investment was compared based on total weekly hours saved by the use of Vela and the cost of having an additional CM working on the project.

For each user, 7.5 hours per week were saved, on average, as noted in Chapter 7. When considering all 5 of the CMs interviewed, the total time saved using Vela accounts for 37.5 hours saved. This is the equivalent of hiring an additional 75% of a CM, if a 50 hour work week is considered to be standard.

The cost of having an additional CM of the jobsite full time, 50 hours per week includes the base salary and any labor burden, including healthcare, disability, pension, social security, 401k, bonuses, and time off and fringe benefits typically provided for the CM. According to the Human Resources division of the CMAR, the average base CM annual salary for the region of the project was approximately $90,000 without labor burden. Approximately 1/3 of the base salary was used to account for the labor burden. This results in a cost of approximately $120,000 for each full time CM on the job. If an additional CM were on the project for the entire estimated duration of two years, the total investment, including burden, would be $240,000.

The case study data indicated that Vela can conservatively provide an equivalent of 75% of an additional CM through time savings. Applying the 75% time recovered to the $240,000 cost of a full time CM results in a savings equivalent to $180,000, about two times the cost of the software and hardware on the project. Clearly the investment resulted in a very positive return on payback. Another way of looking at the analysis is that the investment was paid back, that is, the breakeven occurred, in about 1 year.

The purchase price of the MERS should be excluded from the analysis since it can operate without the use of Vela and this report focuses on the use of Vela and its mobile peripherals. For this analysis, the cost is included since Vela was positively affected by the MERS. The total investment of the MERS, Vela, iPads, and tablets was about $90,500. Of this, approximately $5,500 was associated with the MERS and the other $85,000 was the cost associated with providing Vela on the various platforms.

If the additional CM were on the project for the entire proposed duration, the total investment, including fringe benefits, would amount to $240,000. From the case study data collected, Vela can conservatively provide an equivalent of 75% of an additional CM through decreased weekly hours worked.

Vela also provides additional benefits not considered in this simple analysis. The additional benefits that should be considered include:

1. Reduced employee stress and improved employee retainage. Reducing the time spent by employees from just over 60 hours to about 50 hours per week will increase

weekly production efficiency of the CM staff by over 7% according to RSMeans Construction Cost Data 2010 (2010).

2. Vela allowed users to reinvest 1.5 hours into additional planning time, further preventing potential rework associated with lack of sufficient planning.
3. Travel efficiency improvements were observed with the use of the Vela electronic document library and having all uploaded project documents available on a mobile platform, eliminating the need to return to the field office to gather the required document(s).
4. Decreased contingency in trades' bids due to potential avoided rework. If trades become accustomed to a CMAR using such construction information management software, they could decrease the amount of contingency placed in the bid because the additional planning time could result in potentially lower rework costs to the project and trades.

Further benefits associated with increased punch list productivity and efficiency were not able to be captured during the case study. These potential benefits only occur during the punch list portion of the project which did not occur during the research period. Further research is suggested to identify these benefits in more detail.

9. CONCLUSIONS & RECOMMENDATIONS

9.1 Limitations of Research

While the results of the study indicated Vela was promising, it is important to recognize the limitations of this type of study. With the rapid pace of technology development, hardware used in this case study was modified during the study. The hardware became better and use of the software became easier. The software also improved. It was not possible to clearly differentiate between the versions or to provide qualitative assessment of the value of each modification. The overall findings, however clearly demonstrate the value of this type of software/hardware combination.

Some of the activities listed in Table 7.1 in Chapter 7 refer to project-specific tasks and activities which might not occur on other projects. For this reason, it is possible the productivity and efficiency gains resulting from this case study would not be duplicated on other projects with varying levels of staff, different technologies, and different management practices. One additional observation in this study that does not show up in the surveys but is an important factor is the individual's degree of comfort in adapting to new technology.

This study did not examine other contract types. This was a university project in which pre-qualified subcontractors were selected on the lowest responsive bid. Pricing agreements with Vela and hardware suppliers can differ from those observed in this report. These variations in cost can affect subsequent cost-benefit and ROI analyses.

The benefits and additional efficiencies provided by Vela during punch list activities were not included as part of this report. The advantages were specific to a certain time period in the construction process and therefore were considered as an independent potential benefit and not part of the case study.

Vela has also developed a safety module in addition to VM and VW that is designed to provide safety managers and others with the necessary tools for conducting safety checks and writing reports. The benefits provided by this module were not studied during this research period. The safety management division is separate from the operations division of the firm acting as CMAR for this project.

9.2 Conclusions

This study also concluded that operations-level construction personnel can increase their efficiency and productivity by decreasing clerical, reaction, and assessment time while increasing "value added" planning time to improve the effectiveness of project team operations. Decreases in reaction and assessment activities were observed with the use of Vela, however, the limited DOFs prevented an observation that was statistically significant.

Along with the purchase cost, an initial investment of 16 hours was needed to customize the software for the particular project. Additional weekly implementation costs were observed to be between 10.3 hours and 20.5 hours of labor burden to the CMAR. These implementation costs accounted for training, document control, and managing new RFIs and ASI mark-ups electronically.

This innovative technology trial, including all hardware and software, cost approximately $90,500 dollars to implement. While that is a substantial investment, given the complexity of the project and the number of trades on the project, it was an investment that can pay for itself by preventing unnecessary and expensive rework or delays due to issues with inadequate information transfer and quality management and by reducing non-productive time, such as job site travel.

The primary results of this case study are:

(1) Many construction management activities were found to be positively affected by the use of new construction management technologies, including Vela, tablets, iPads, and wireless access.

(2) On average, the CMs surveyed had a gain of 11.9% in management productivity with the use of Vela. This increase was due to additional hours invested in planning and assessment activities and decreased actual weekly hours worked.

- “Value added” planning time increased by 1.5 hours per week on average.
- Reaction time decreased by 3.8 hours per week and was statistically significant.
- No statistically significant change in assessment and clerical times was observed.
- Decrease of an average of 7.5 hours worked per week

(3) Reducing travel time from the field to gather documents could potentially recover a total of 12 to 38 days for each user in a two year project, considering 2.8 hours per week saved.

(4) Theoretical ROI of 112%

- Based solely on the benefit of reduced weekly hours worked

This investment is financially favorable on a high profile, $100 million project. In this project, the use of a substantial quality control and construction management program such as Vela was less than 0.1% of the total project cost.

9.4 Recommendations

Further investigation is needed to determine which projects are or are not well-suited candidates for such innovative technologies. Determination should be based on, but not limited to:

- Project size
- Complexity level
- Duration
- Criticality
- Contract type
- A/E/Owner/Subs involved
- Project team dynamics and size
- Technology or hardware is already in possession by the CM firm

It is important to realize that as further research on the topic of CM-based technologies is conducted, new software, hardware, and implementation strategies will be developed and implemented rapidly.

For this case study, the DOFs were limited, making statistically significant conclusions difficult. Recommendations are as follows:

1. Additional surveys with more subjects, and more DOF, would provide additional benefits to this research.
2. Grouping was also observed when collecting survey data from the CMs. This grouping may be a result of the different types of responsibilities and specific assignments or job functions of the CMs. It is recommended that further research in his area be conducted.
3. CMs' responses were not classified based on their respective duties and further insight into their job functions would help provide reasons for fluctuations in gathered responses.
4. The potential benefits of avoided rework due to Vela were unable to be analyzed for the case study. Additional data that determines who is financially responsible for the various types of rework encountered on a construction project could help to further calculate an ROI, taking into account the added benefits of potential avoided rework.

10. REFERENCES

1. Andresen, J., Baldwin, A., Betts, M., Carter, C., Hamilton, A., Stokes, E. and Thorpe, T. (2000). “A Framework for Measuring IT Innovation Benefits.” *ITcon*, Vol. 5, 57-72. <http://www.itcon.org/2000/4> (Accessed June 3, 2011).

2. Becerik-Gerber, B., and Rice, S. (2010). “The perceived value of building information modeling in the U.S. building industry.” *ITcon*, Vol. 15, 185-201. <http://www.itcon.org/2010/15> (Accessed June 17, 2011).

3. Biggs, M. (2000). “Why choose a web-based project management solution.” *InfoWorld*, 22(5), 72-73.

4. Burgy, C., and Garrett, Jr., J. (2002). “Wearable Computers: An Interface between Humans and Smart Infrastructure Systems.” *Bauen mit Computern*, Bonn, Germany.

5. Construct IT (1998). “Measuring the Benefits of IT Innovation.” *Construct IT Centre of Excellence.*

6. Ekstrom, M, and Bjornsson, H. (2004) “Information technology and purchasing strategy: two necessary enablers of more efficient construction processes.” CIFE Tech. Report #160.

7. Helms, M. (2006)."Effectiveness and Efficiency." <http://www.enotes.com/management-encyclopedia/effectiveness-efficiency> (Jul 25, 2011).

8. Fayek, A., Dissanayake, M., and Campero, O. (2004). “Developing a standard methodology for measuring and classifying construction field rework.” *Canadian J. of Civil Eng.*, 31(6), 1077-1089.

9. Jang, W., and Skibniewski, M. (2009) “Cost-benefit analysis of embedded sensor system for construction materials tracking.” *ASCE J. Constr. Eng. Manage.*, 135(5), 378–386.

10. Jaselskis, E., Ruwanpura J., Becker T., Silva L., Jewell P., and Floyd E. (2010). “Innovation in construction engineering education using two applications of internet-based information technology to provide real-time project observations.” *ASCE J. Constr. Eng. Manage.*, 110(3), 311–323.

11. Liberatore, M., Pollack-Johnson, B., and Smith, C. (2001). “Project management in construction: software use and research directions.” *ASCE J. Constr. Eng. Manage.*, 127(2), 101–107.

12. Lim, J. N., Schultmann, F., and Ofori, G. (2010). “Tailoring competitive advantages derived from innovation to the needs of construction firms.” *ASCE J. Constr. Eng. Manage.*, 136(5), 568–580.
13. Marsh, L. and Flanagan, R (2000). “Measuring the costs and benefits of information technology in construction.” *Eng., Constr. and Architectural Manage.,* 7(4), 423-435.

14. Meredith, J. (1998). “Building operations management theory through case and field Research.” *J. Operations Manage.,* Vol. 16, 441-454.

15. Nuntasunti, S., and Bernold, L. (2006). “Experimental assessment of wireless construction technologies.” *ASCE J. Constr. Eng. Manage.*, 132(9), 1009–1018.

16. RSMeans (2010). “RSMeans Building Construction Cost Data.” Kingston, MA: Reed Construction Data, 2010.

17. Scanlin, J. (1998). “The Internet as an enabler of the Bell Atlantic project office.” *Project Manage. J.* June 1998, 6-7.

18. Teicholz, P. (2004). “Labor productivity declines in the construction industry: causes and remedies.” *AECbytes Viewpoint*, Issue 4. <http://www.aecbytes.com/viewpoint/2004/issue_4.html> (May 15, 2011).

APPENDIX

Appendix A

COMPARISON OF VARIOUS MOTION TABLETS AND IPADS CURRENTLY IN USE ON THE JAMES B. HUNT LIBRARY PROJECT

Motion Tablets

Currently there are two different tablets in use by the CMAR on the project. These tablets are the Motion J3400 and Motion F5v. The J3400 and F5v are similar tablets when comparing internal specifications such as performance specs but the F5v tablet incorporates a barcode reader as well as a RFID reader. The barcode reader is currently being used on the Hunt Library to track the fabrication, delivery, installation, and commissioning of the unitized curtain wall panels, along with QA/QC checks of the curtain wall panels throughout the supply chain. Just recently, the CM firm has also integrated Vela coupled with bar-coding into the commissioning process and QA/QC checks of the mechanical equipment.

Both the J3400/3500 and the F5v incorporate built-in cameras, making the ability to take pictures in the field directly from the tablet possible. The resolution of the camera is 2 MP for both devices. While most cellular phones can now exceed this resolution, field use and experience has proved that picture quality is quite good and capable of showing construction details via a tablet produced picture.

Figure 1 depicts the two tablets in use. From left to right are the J3400 and the F5v tablets. The Motion Computing J3400 has the largest screen of the two, measuring 12.1” diagonal (approximately 10.25” horizontally). The dimensions of the J3400 make it compatible with other wide displays such as modern televisions and laptops. The F5v has the smaller screen at 10.4” diagonal and this is most likely due to integrating the RFID reader and barcode scanner while trying to minimize size and weight to increase portability.


Figure 1-Motion J3400, and F5v Indoors

The weight of the various tablets seems to be a direct result of the number and type of batteries installed as well as its size. The J3400 and the F5v tablets are MIL-STD-810F and 810G respectively (Department of Defense Test Method Standard for field ruggedness) as well as being IP54 rated for resistance to dust and moisture intrusion. This ruggedness and extended battery life comes at the price of weight though as the J3400 weights 4.2 lbs. (with 2 batteries installed) and the F5v 3.3 lbs (1 battery installed). It should be noted that one is able to “hot-swap” batteries while the tablet computer is still running in case of the need for an emergency battery swap (as might be the case with heavy use of the F5v as battery life is expected to be about 4 hours maximum).

The screen visibility when outside is one aspect where Motion Computing has put a lot of effort into improving their new products. Outside (although direct sunlight was not available the day pictures were obtained), it becomes apparent how much all three tablets are susceptible to smudges and fingerprints. Once smudged, it is quite difficult to remove the smudges with simply a cloth or rag while in the field and a special microfiber cloth is necessary to remove them. As seen in Figure 2, given the angle of the sunlight, the smudges can become quite a hindrance. The screen on the F5v seems to be the brightest and has a slightly higher pixel density than the J3400, creating a higher resolution display. Both the J3400 and F5v includes an optional AFFS+ LED Backlight which makes viewing in direct sunlight (even while wearing tinted UV protection safety glasses) possible (when smudges and fingerprints are not an issue) and should be considered as standard equipment for any future tablet purchases.

Figure 2-J3400 and F5v Outdoors

iPads & Vela

Currently Skanska is using Vela Systems' Vela Web "cloud"-based software for assisting various aspects of managing the project (from QA/QC checklists and issue generation to material tracking, commissioning, safety, and a mobile electronic library). The CMAR has also implemented the use of both the iPad and iPad 2 (shown in Figure 3) for is off-line functionality of Vela through the use of the VM App (screen shot in Figure 4). Currently, Vela does not offer a Windows-based software package of Vela that can function without internet access. The previous version of Vela, Vela Classic, was only offered as a windows-based software program, however. Because of this, it is necessary to either establish a wireless network on site or purchase wireless cards for each tablet being used in the field, or alternatively, use iPads with their off-line functionality of the VM app.

Figure 3-Apple iPad 2

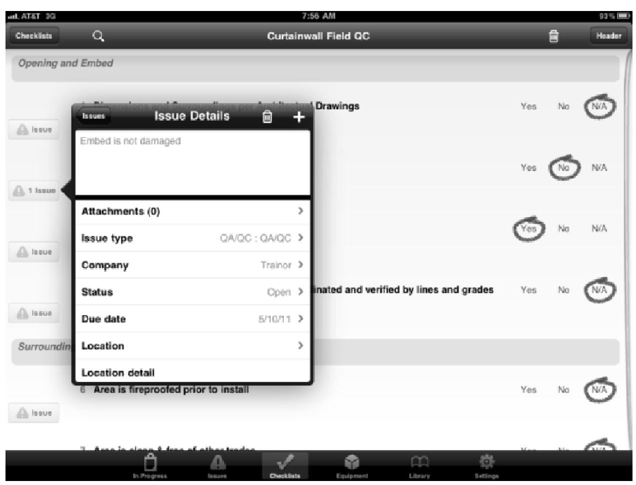


Figure 4-Vela Mobile iPad App

While the new iPad 2s can perform in a manner similar to the tablets in terms of taking pictures and annotating them, the iPads (iPad and iPad 2) cannot run the robust modeling software for viewing various BIMs which the Motion tablets are capable of.

Hardware Comparison

The major difference between the iPads and the tablets are the drastically different price points associated with each, as well as the differences in functionality. See Figure 5 for a table of tablet and iPad prices. The current purchase price of a J3400 for CMAR purposes costs approximately $4500 (according to CMAR IT). This price included the base price of the J3400 tablet itself ($3,064), as well as hardware upgrades such as increased memory, faster processor, and optional View-Anywhere display, and CMAR specific software which needed to be installed prior to use in order to make the tablet functional as a laptop replacement for field personnel. For the F5v with similar accessories and options, the total was approximately $5400 (with a base price of $3,386 for the F5v tablet). For this reason, only the base price of the tablets, with accessories, are compared to the purchase price of the iPads. For the tablets, including all listed costs below, the total equates to approximately $3,700 and $4,100 for the Motion J3400 and F5v, respectively. The iPad with 3G capabilities and 64GB of storage costs $680, plus an Otterbox Defender case for $90 and an Opticon OPN2002 Bluetooth barcode scanner for $315, totaling near $1,100. For the iPad 2 with similar options, the price raises to approximately $1200. Even neglecting the Skanska specific software required on the tablets, it is still possible to purchase 3 iPad 2s with camera and bar-coding capabilities for the price of one Motion F5v or 3 iPads 2s with camera (no bar-coder) for the cost of one Motion J3400. Note that both the iPad and iPad 2 prices include 64GB storage plus 3G and Wi-Fi capabilities. Note that cases will still need to be purchased for both the tablet and iPad to increase protection and provide portability.

	Cost			
Item	**J3400/3500**	**F5v**	**iPad Wi-Fi + 3G**	**iPad 2 Wi-Fi + 3G**
Tablet w/ hardware upgrades	$3,064.00	$3,386.00	$ 679.00	$ 829.99
Case	$ 149.00	$ 149.00	$ 89.95	$ 89.95
Docking station	$ 299.99	$ 349.99	Incl.	Incl.
Keyboard	$ 149.99	$ 16.99	N/A	N/A
Extra Battery	Incl.	$ 169.99	N/A	N/A
Skanska Software	???	???	N/A	N/A
Barcode reader	N/A	Incl.	$ 315.00	$ 315.00
Total:	$3,662.98	$4,071.97	$ 1,083.95	$ 1,234.94

Figure 5-Table of Hardware used for Vela

As shown in Figure 6, the iPads can perform the same bar-coding functions as the Motion F5v with the use of an Opticon OPN2002 Bluetooth barcode scanner. The scanner retails for $315 and provides greater portability than the tablet integrated barcode scanner with its compact size while emitting an audible beep when a barcode has been scanned, unlike the F5v. This allows for barcodes being more easily accessible while the audible beep helps to verify to the user that the barcode has been properly scanned. This technology is in its infant stages and has just been acquired on the case study project. Testing of this hardware and its functionality is currently underway but one slight issue has been discovered. It seems that each barcode scanner can only be paired (and therefore will only work) with one iPad at a time, meaning that each iPad needs to have a dedicated companion barcode scanner with it for total functionality. The CMAR has discovered that by labeling the iPads and barcode scanners with corresponding labels, it prevents any unnecessary confusion when an employee or trade obtains an iPad and scanner to take into the field.

Figure 6-iPad and Opticon OPN2002

The new Windows 7 operating system, when combined with the Motion tablets, results in much more intuitive and user-friendly handwriting recognition with the stylus as compared to the tablets running Windows XP. This is much improved over the previous versions of hand writing recognition, therefore helping new users to adapt to the tablets quicker and creating a much more pleasant user experience. With the iPads, writing is performed using a scaled-down virtual keyboard which works well, though not as efficient as using a physical keyboard due to the lack of tactical feedback for the user. Annotations can still be performed using the iPad as well, but sketching on the iPad with one’s finger results in less than desirable results as the iPad lacks the precision needed to annotate with great detail while in the field.

Conclusion

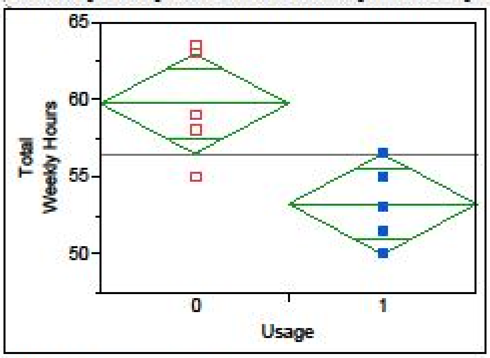
For the CMAR's purposes, the main distinction between the tablets and iPads is that tablets can replace current desktop and laptop computers in use, while iPads can only serve to supplement them. A tablet can essentially perform all the duties that a desktop or laptop computer can. An iPad would need to be used in conjunction with another computer device, however, to have all the capabilities which Skanska personnel deem necessary for basic managerial functionality.

Despite the negative implications associated with their high cost, the tablets still have functions that iPads currently cannot match. It is important to note that other programs necessary for day to day CM responsibilities such as word processers and spreadsheets can still be used on the iPads but this is a less efficient method of writing and data entry than with the use of the tablet. Through further experience with both peripherals, the CMAR plans further investigation into the benefits and shortcomings of each device in an effort to determine which combination of technology is best utilized when it comes to Vela and managing construction processes.

Appendix B

Data Analysis 2 - Fit Y by X of Total Weekly Hours by Usage

Oneway Analysis of Total Weekly Hours By Usage



Missing Rows	2
Excluded Rows	2

Oneway Anova

Summary of Fit

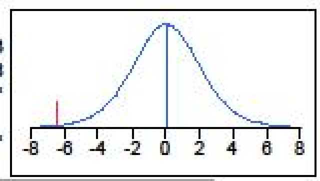
Rsquare	0.574908
Adj Rsquare	0.521772
Root Mean Square Error	3.1245
Mean of Response	56.45
Observations (or Sum Wgts)	10

t Test

1-0

Assuming equal variances

Difference	-6.500	t Ratio	-3.2893
Std Err Dif	1.976	DF	8
Upper CL Dif	-1.943	Prob > |t|	0.0110*
Lower CL Dif	-11.057	Prob > t	0.9945
Confidence	0.95	Prob < t	0.0055*



Analysis of Variance

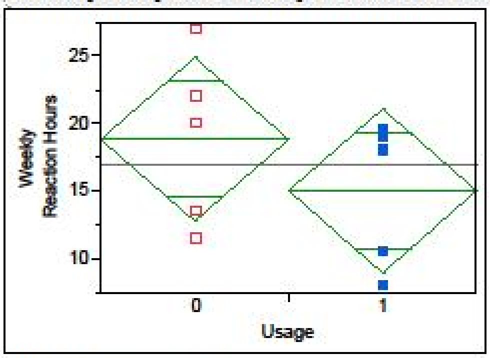
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Usage	1	105.62500	105.625	10.8195	0.0110*
Error	8	78.10000	9.763		
C. Total	9	183.72500			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
0	5	59.7000	1.3973	56.478	62.922
1	5	53.2000	1.3973	49.978	56.422

Std Error uses a pooled estimate of error variance

Oneway Analysis of Weekly Reaction Hours By Usage



Missing Rows	2
Excluded Rows	2

Oneway Anova

Summary of Fit

Rsquare	0.116115
Adj Rsquare	0.005629
Root Mean Square Error	5.860887
Mean of Response	16.9
Observations (or Sum Wgts)	10

Analysis of Variance

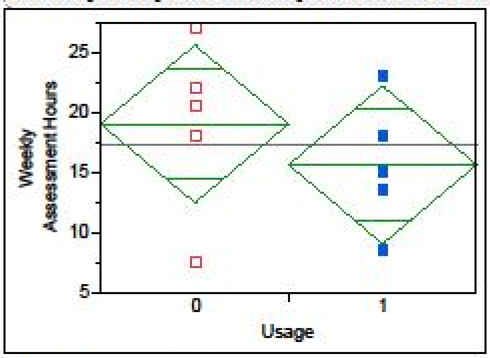
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Usage	1	36.10000	36.1000	1.0509	0.3353
Error	8	274.80000	34.3500		
C. Total	9	310.90000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
0	5	18.8000	2.6211	12.756	24.844
1	5	15.0000	2.6211	8.956	21.044

Std Error uses a pooled estimate of error variance

Oneway Analysis of Weekly Assessment Hours By Usage



Missing Rows	2
Excluded Rows	2

Oneway Anova

Summary of Fit

Rsquare	0.081847
Adj Rsquare	-0.03292
Root Mean Square Error	6.365925
Mean of Response	17.3
Observations (or Sum Wgts)	10

Analysis of Variance

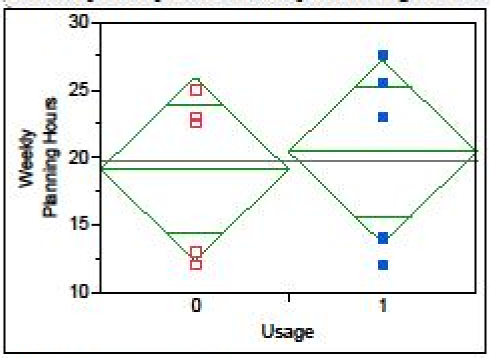
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Usage	1	28.90000	28.9000	0.7131	0.4229
Error	8	324.20000	40.5250		
C. Total	9	353.10000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
0	5	19.0000	2.8469	12.435	25.565
1	5	15.6000	2.8469	9.035	22.165

Std Error uses a pooled estimate of error variance

Oneway Analysis of Weekly Planning Hours By Usage



Missing Rows	2
Excluded Rows	2

Oneway Anova

Summary of Fit

Rsquare	0.012136
Adj Rsquare	-0.11135
Root Mean Square Error	6.556485
Mean of Response	19.75
Observations (or Sum Wgts)	10

Analysis of Variance

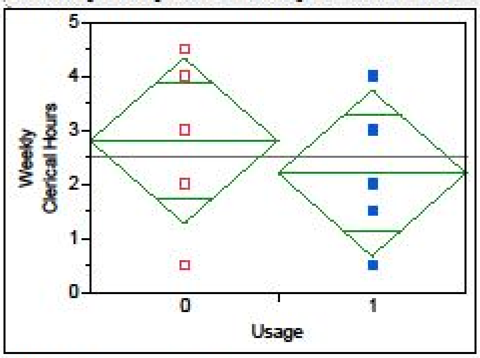
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Usage	1	4.22500	4.2250	0.0983	0.7619
Error	8	343.90000	42.9875		
C. Total	9	348.12500			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
0	5	19.1000	2.9321	12.338	25.862
1	5	20.4000	2.9321	13.638	27.162

Std Error uses a pooled estimate of error variance

Oneway Analysis of Weekly Clerical Hours By Usage



Missing Rows	2
Excluded Rows	2

Oneway Anova

Summary of Fit

Rsquare	0.048649
Adj Rsquare	-0.07027
Root Mean Square Error	1.48324
Mean of Response	2.5
Observations (or Sum Wgts)	10

Analysis of Variance

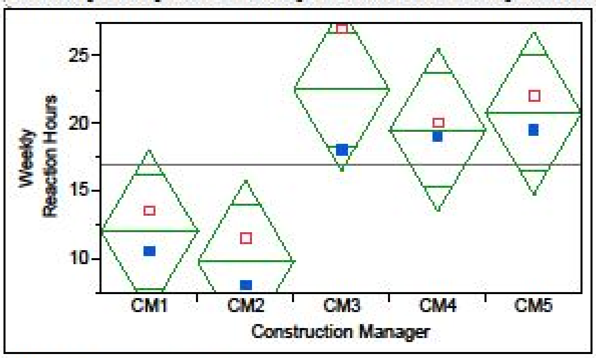
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Usage	1	0.900000	0.90000	0.4091	0.5403
Error	8	17.600000	2.20000		
C. Total	9	18.500000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
0	5	2.80000	0.66332	1.2704	4.3296
1	5	2.20000	0.66332	0.6704	3.7296

Std Error uses a pooled estimate of error variance

Oneway Analysis of Weekly Reaction Hours By Construction Manager



Missing Rows	2
Excluded Rows	2

Oneway Anova

Summary of Fit

Rsquare	0.823898
Adj Rsquare	0.683017
Root Mean Square Error	3.309078
Mean of Response	16.9
Observations (or Sum Wgts)	10

Analysis of Variance

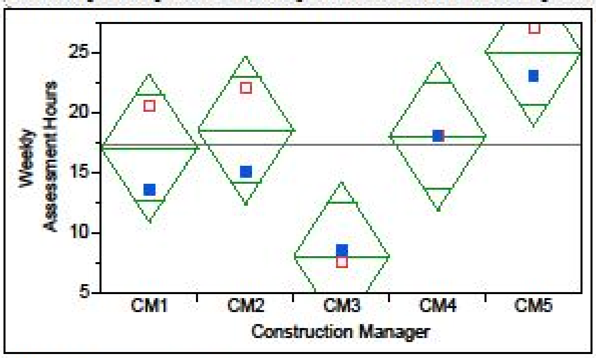
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Construction Manager	4	256.15000	64.0375	5.8482	0.0398*
Error	5	54.75000	10.9500		
C. Total	9	310.90000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CM1	2	12.0000	2.3399	5.985	18.015
CM2	2	9.7500	2.3399	3.735	15.765
CM3	2	22.5000	2.3399	16.485	28.515
CM4	2	19.5000	2.3399	13.485	25.515
CM5	2	20.7500	2.3399	14.735	26.765

Std Error uses a pooled estimate of error variance

Oneway Analysis of Weekly Assessment Hours By Construction Manager



Missing Rows	2
Excluded Rows	2

Oneway Anova

Summary of Fit

Rsquare	0.837157
Adj Rsquare	0.706882
Root Mean Square Error	3.391165
Mean of Response	17.3
Observations (or Sum Wgts)	10

Analysis of Variance

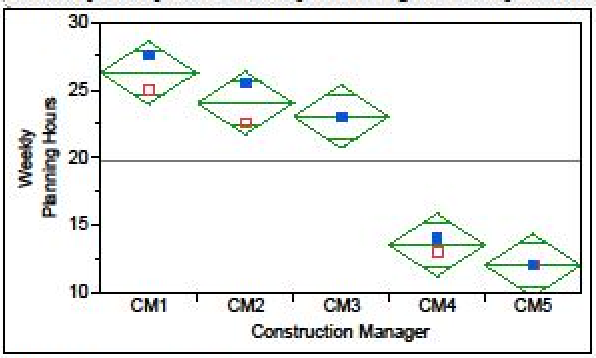
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Construction Manager	4	295.60000	73.9000	6.4261	0.0331*
Error	5	57.50000	11.5000		
C. Total	9	353.10000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CM1	2	17.0000	2.3979	10.836	23.164
CM2	2	18.5000	2.3979	12.336	24.664
CM3	2	8.0000	2.3979	1.836	14.164
CM4	2	18.0000	2.3979	11.836	24.164
CM5	2	25.0000	2.3979	18.836	31.164

Std Error uses a pooled estimate of error variance

Oneway Analysis of Weekly Planning Hours By Construction Manager



Missing Rows	2
Excluded Rows	2

Oneway Anova

Summary of Fit

Rsquare	0.976661
Adj Rsquare	0.957989
Root Mean Square Error	1.274755
Mean of Response	19.75
Observations (or Sum Wgts)	10

Analysis of Variance

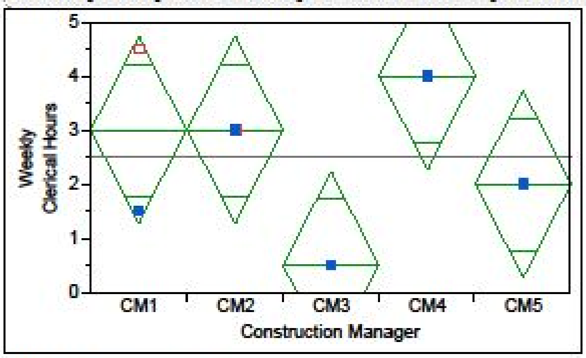
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Construction Manager	4	340.00000	85.0000	52.3077	0.0003*
Error	5	8.12500	1.6250		
C. Total	9	348.12500			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CM1	2	26.2500	0.90139	23.933	28.567
CM2	2	24.0000	0.90139	21.683	26.317
CM3	2	23.0000	0.90139	20.683	25.317
CM4	2	13.5000	0.90139	11.183	15.817
CM5	2	12.0000	0.90139	9.683	14.317

Std Error uses a pooled estimate of error variance

Oneway Analysis of Weekly Clerical Hours By Construction Manager



Missing Rows	2
Excluded Rows	2

Oneway Anova

Summary of Fit

Rsquare	0.756757
Adj Rsquare	0.562162
Root Mean Square Error	0.948683
Mean of Response	2.5
Observations (or Sum Wgts)	10

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Construction Manager	4	14.000000	3.50000	3.8889	0.0844
Error	5	4.500000	0.90000		
C. Total	9	18.500000			

Means for Oneway Anova

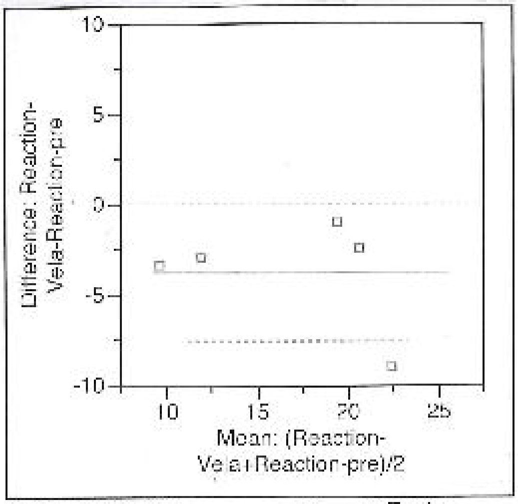
Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CM1	2	3.00000	0.67082	1.276	4.7244
CM2	2	3.00000	0.67082	1.276	4.7244
CM3	2	0.50000	0.67082	-1.224	2.2244
CM4	2	4.00000	0.67082	2.276	5.7244
CM5	2	2.00000	0.67082	0.276	3.7244

Std Error uses a pooled estimate of error variance

 D

Matched Pairs

Difference: Reaction-Vela-Reaction-pre



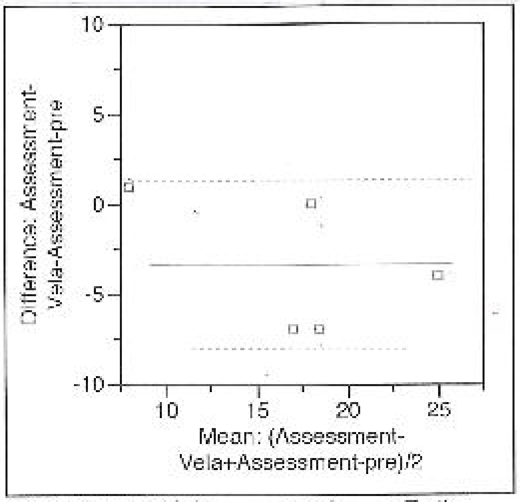
w/ Vela

Reaction-Vela	15	t-Ratio	-2.78256
Reaction-pre	18.8	DF	4
Mean Difference	-3.8	Prob > |t|	0.0497*
Std Error	1.36565	Prob > t	0.9752
Upper 95%	-0.0083	Prob < t	0.0248*
Lower 95%	-7.5917		
	5		
relation	0.87652		

Less than spent on [illegible] w/ Vela

Matched Pairs

Difference: Assessment-Vela-Assessment-pre



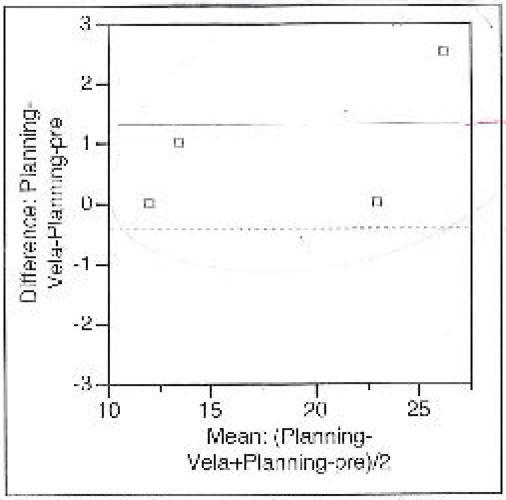
f => more than shaky

[Ass T]

Assessment-Vela	15.6	t-Ratio	-2.01046
Assessment-pre	19	DF	4
Mean Difference	-3.4	Prob > |t|	0.1147
Std Error	1.69115	Prob > t	0.9426
Upper 95%	1.29539	Prob < t	0.0574
Lower 95%	-8.0954		
N	5		
Correlation	0.85953		

Matched Pairs

Difference: Planning-Vela-Planning-pre

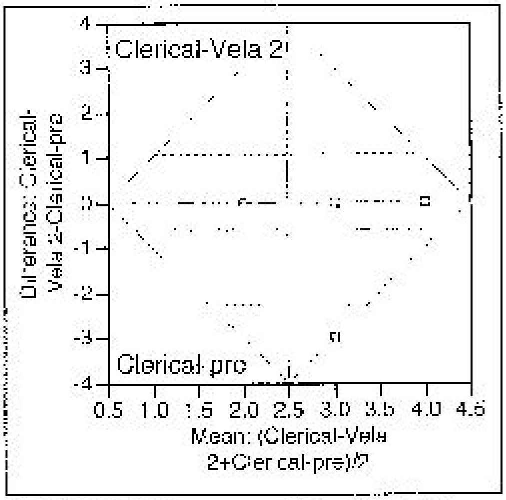


more planning

Planning-Vela	20.4	t-Ratio	2.081666
Planning-pre	19.1	DF	4
Mean Difference	1.3	Prob > ltl	0.1058
Std Error	0.6245	Prob > t	0.0529
Upper 95%	3.03389	Prob < t	0.9471
Lower 95%	-0.4339		
N	5		
Correlation	0.98599		

Matched Pairs

Difference: Clerical-Vela 2-Clerical-pre



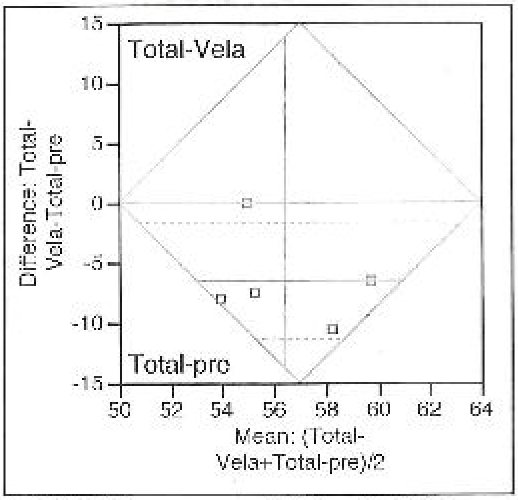
Clerical-Vela 2	2.2	t-Ratio	-1
Clerical-pre	2.8	DF	4
Mean Difference	-0.6	Prob > |t|	0.3739
Std Error	0.6	Prob > t	0.8130
Upper 95%	1.06587	Prob < t	0.1870
Lower 95%	-2.2659		
N	5		
Correlation	0.59969		

Vaughan_Diff: Matched Pairs of Total-pre, Total-Vela

Page 1 of 1

Matched Pairs

Difference: Total-Vela-Total-pre



Total-Vela	53.2	t-Ratio	-3.70673
Total-pre	59.7	DF	4
Mean Difference	-6.5	Prob > |t|	0.0207*
Std Error	1.75357	Prob > t	0.9896
Upper 95%	-1.6313	Prob < t	0.0104*
Lower 95%	-11.369		
N	5		
Correlation	0.22288		