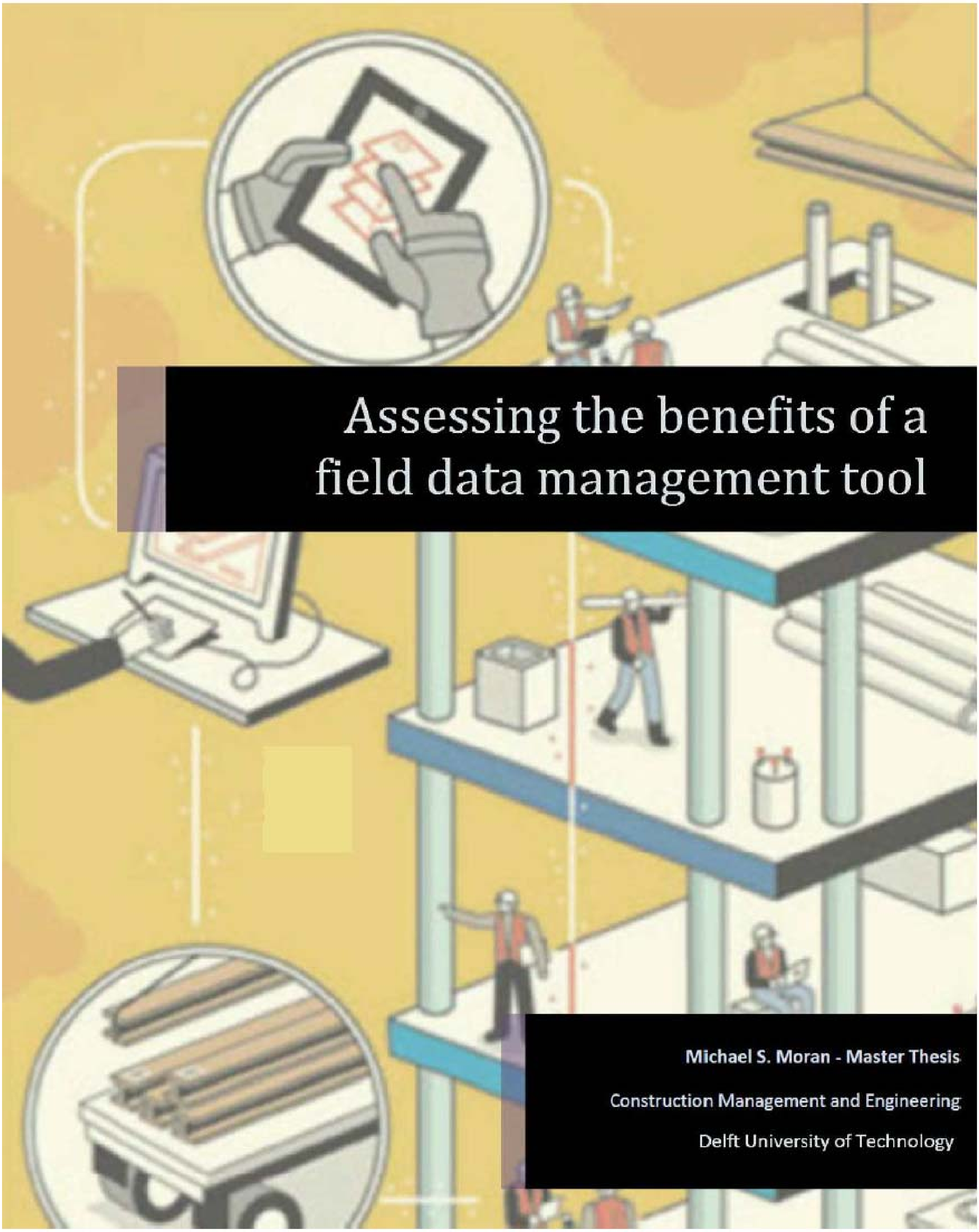

Assessing the benefits of a field data management tool

Michael S. Moran - Master Thesis

Construction Management and Engineering

Delft University of Technology

Delft University of Technology

Assessing the benefits of a field data management tool

Masters Thesis by

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Michael Moran, August 2012

CONTENTS

ABSTRACT

A new generation of mobile construction site management software applications is enabling real-time communication of key on-site data. These field data management tools (FDMT) improve project efficiency by automating and reducing the durations of construction management tasks and also improve quality of the final built product by enabling quick and reliable communication of accurate project data. The purposes of this thesis are threefold:

1) *to survey existing tools and construction approaches which allow construction service providers to achieve fundamental efficiency improvements in terms of time and quality*

2) *to quantitatively measure the efficiency gains achieved by users of a particular FDMT (Vela) across 15 projects within a particular company (Skanska), determine the extent to which certain factors influence varying levels of these efficiency gains, and situate this measurement of efficiency within a comprehensive framework model which construction service providers can use to quantify the costs and benefits of FDMT use.*

3) *to assess the current state of the construction industry's use of FDMTs, with the aim of documenting best practices and highlighting shortcomings in order to create recommendations in a business process reengineering framework*

This research will form the basis for recommendations as to how construction companies can optimize the way that they manage field data, with potential for significant efficiency gains.

EXECUTIVE SUMMARY

This study begins by examining the chronic problems of waste, inefficiency and poor quality in construction projects, and looking into some of the causes. Next, a series of approaches and tools which remedy these problems are explored and elaborated upon. Field data management tools, which combine and enable aspects of these existing solutions, are then explained in detail, and it is demonstrated how they can save time and improve quality, leading to significant savings and a high return on investment when properly implemented.

An experimental method for evaluating and comparing efficiency gains obtained through using a particular field data management tool (Vela) on 15 construction projects is then created, and quantitative research is undertaken, collecting data through means of surveys. The data is then analyzed so that the average efficiency gains on each project can be compared, in order to identify causes for variations in performance and highlight the factors which influence these variations.

The last section presents two distinct series of recommendations. Firstly, suggestions are given as to how projects can achieve incremental efficiency improvements by learning from best practices of data management methods from the projects with the highest efficiency gains. Secondly, the observations of how field data is managed at an enterprise-wide level is critically considered and compared with the full potential of such tools identified in the literature review. This will form the basis for suggestions as to how construction companies’ field data management approaches can be improved and deepened in areas where it is already in use, as well as expanded to new work applications, with the aim of creating fundamental improvements in process efficiency.

GLOSSARY OF KEY TERMS

ADCT - Automated data collection technology - the methods of automatically identifying objects, collecting data about them, and entering that data directly into computer systems (i.e. without human involvement). Technologies typically considered as part of AIDC include bar codes, Quick Response (QR) Codes, radio frequency identification (RFID), magnetic stripes and voice recognition.

BIM- Building information modeling - a process involving the generation and management of digital representations of physical and functional characteristics of a facility. The resulting **building information models** become shared knowledge resources to support decision-making about a facility from earliest conceptual stages, through design and construction through its operational life and eventual demolition.

Business process reengineering - the analysis and redesign of workflow within and between enterprises with the aim of achieving dramatic improvements in critical performance measures, such as cost, quality, service, and speed.

CMAR - Construction manager at risk - project delivery method which entails a commitment by the construction manager to deliver the project within a GMP in most cases. The construction manager acts as consultant to the owner in the development and design phases, but as the equivalent of a general contractor during the construction phase.

CMMS - Computized maintenence management system - a software solution which maintains a computer database of information about an organization's maintenance operations.This information is intended to help maintenance workers do their jobs more effectively (for example, determining which machines require maintenance and which storerooms contain the spare parts they need) and to help management make informed decisions.

DB - Design-build - Project delivery method which relies on a single point of responsibility contract and is used to minimize risks for the project owner and to reduce the delivery schedule by overlapping the design phase and construction phase of a project.

DBB - Design-bid-build - An owner develops contract documents with an architect or engineer consisting of a set of drawings and a detailed specification. Bids are solicited from contractors based on these documents; a contract is then awarded to the lowest responsive and responsible bidder.

DBB with CM - Design-bid-build with construction management - With partially completed contract documents, an owner will hire a construction manager to act as an agent. As substantial portions of the documents are completed, the construction manager will solicit bids from suitable subcontractors. This allows construction to proceed more quickly and allows the owner to share some of the risk inherent in the project with the construction manager.

Efficiency - the extent to which time or effort is well used for the intended task or purpose.

FDMT - Field data management technology - computer software solutions which collect data regarding construction site activities. Information is comiled into databases where it can be tracked, updated, communicated and analyzed.

Fixed price (lump sum) contract - contract where the amount of payment does not depend on the amount of resources or time expended, as opposed to a cost-type contract.

GMP contract - Guaranteed maximum price contract - cost-type contract (also known as an open-book contract) where the contractor is compensated for actual costs incurred plus a fixed fee **subject to a ceiling price**. The contractor is responsible for cost overruns, unless the GMP has been increased via formal change order (only as a result of additional scope from the client, not price overruns, errors, or omissions). Savings resulting from cost underruns are returned to the owner.

IPD - Integrated project delivery - A project delivery method in which the interests of the primary team members are aligned in such a way that the members can be integrated for optimal project performance resulting in a collaborative, value-based process delivering high-outcome results to the entire building team.

Lean construction - a combination of original research and practical development in design and construction with an adaption of lean manufacturing principles and practices to the end-to-end design and construction process. This approach tries to manage and improve construction processes with minimum cost and maximum value by considering customer needs.

MIS - Management information systems - encompass three primary components: technology, people (individuals, groups, or organizations), and data/information for decision making needed to manage organizations efficiently and effectively.

Prefabrication - the practice of assembling components of a structure in a factory or other manufacturing site, and transporting complete assemblies or sub-assemblies to the construction site where the structure is to be located.

Project Manager - responsible for the planning, coordination, and control of a project.

Project Engineer - the title project engineer is given to new project managers or job site assistants who manage field operations.

Punch List - a contract document used in the U.S. building industry by the architecture and building trades to organize the completion of a construction project.

QA/QC - Quality assurance - the process or set of processes used to measure and assure the quality of a product. **Quality control** - the process of meeting products and services to consumer expectations.

RFI - Request for information - used where it is necessary to confirm the interpretation of a detail, specification or note on the construction drawings or to secure a documented directive or clarification from the architect or client that is needed to continue work.

Superintendent - a supervisor who is responsible for scheduling and monitoring subcontractors on behalf of the general contractor.

1. INTRODUCTION

By taking advantage of recent developments in cloud computing and tablet computers, software firms such as Vela Systems have developed what are known in the AEC industry as field data management tools (Sawyer, 2011) – henceforth FDMT. These software solutions allow data to be synchronized and communicated instantly between the construction site and the office. This new generation of information management tools and services also enables some of the benefits of lean construction, prefabrication, automated data collection technologies and BIM to be realized on the construction site. Currently, FDMT offers contractors, owners and architects the following features:

- Creation of 'punch lists' of damaged building components or problems with installed equipment
- QA/QC and safety checklists.
- Access to construction documents and the ability to mark them up.
- Ability to view and navigate BIMs in the field
- Instantly updatable BIM attributes according to field observations, allowing material tracking and equipment commissioning
- Ability to assign tasks to project team members or subcontractors
- Automatic creation of reports which are sent directly to specified project team members
- Visualization of project data such as open issues or issue owners using infographics
- Analytic reports compiling cross-project data within a firm

FDMT can be considered a type of business process reengineering. According to Davenport and Short (1990), a business process is a set of logically related tasks performed to achieve a defined business outcome. Reengineering a business process means to disregard all the assumptions and traditions of the way business has always been done, and instead develop a new, process-centered business organization that creates time, cost and quality benefits (Hammar and Champey, 1993).

RESEARCH GOAL

The main goal of this research is to provide construction service providers with recommendations for how to achieve time savings and quality gains through their implementation of field data management. By comparing the current use of FDMTs on a number of projects to each other, factors which influence efficiency gains will be identified, making it possible to identify best practices and recommend methods for incrementally improving efficiency through using FDMTs. By comparing the state of field data management on a company-wide level and generalizing these observations where appropriate, it will also be possible to identify where the current approach falls short of the full field data management potential explored in the literature study. This shortfall will form the basis for suggestions as to how construction service providers can fundamentally improve business process efficiency by deepening the adoption of FDMTs.

STRUCTURE OF STUDY

Beginning with a discussion inefficiencies in construction projects due to wasted time and poor quality, the literature survey then investigates a number of existing computerized information management approaches and applications which address these inefficiencies, including lean construction, prefabrication, BIM, automated data collection technologies and innovative project delivery methods. Previous studies into FDMTs are investigated. This serves the purpose of attempting to gauge the potential benefits which FDMT can currently offer to construction service providers, designers and building owners in terms of efficiency gains and quality improvements. It will also situate an innovative new FDMT, Vela, in the context of a number of recently developed business re-engineering processes which have been applied in the construction industry.

Quantitative research is then conducted to measure the efficiency gains achieved by using one such tool within a particular company. By comparing performance from multiple projects, factors will be identified which may influence the extent of these efficiency gains, with the aim of determining best practices and formulating recommendations for how users of FDMT can achieve even higher efficiency.

The final section will highlight any shortfalls between the current state of FDMT implementation observed in the research of 15 Skanska projects, and the potential use of the approaches and tools examined in the literature review. This will help in formulating suggestions for how construction service providers can rethink their approach to information management, and apply the approach in a more comprehensive manner, to achieve deeper quality improvements and efficiency gains in the areas where it is currently being used as well as introducing the FDMT approach to altogether new business processes. These recommendations should be understood within a business process reengineering framework, as they seek to achieve dramatic improvements by fundamentally re-thinking how the organization's work should be done, distinguishing it from process improvement efforts that focus on functional or incremental improvement.

TARGET GROUP

This study is written on behalf of Skanska USA Building, and is primarily intended to assess the state of their use of FDMT and formulate a series of recommendations about how to optimize their implementation of these innovative tools. However, it is also of interest to other construction companies, building owners, and designers, and some of the techniques used to quantify efficiency and/or quality gains can be applied to assess the ROI of other innovative computerization and information management technologies. This study assumes a familiarity with certain construction and engineering specific terms, although a short glossary has been included before the introduction to elaborate some terms which are mostly used in the US construction industry.

PERSONAL MOTIVATION

Chronic problems of efficiency and poor quality have long affected construction projects, causing the building sector to lag behind other industries in terms of productivity and reduction of waste. The recent innovations in tablet computers, BIM and cloud computing are combining to create a number of innovative, smart solutions which address these problems. I believe FDMTs and related data analysis tools will be of major importance to the construction industry in the coming years, and there are regular exciting developments in these technologies. Vela Systems, the maker of the FDMT under investigation in this study, was purchased by Autodesk in June 2012, a leading supplier of software to the building industry, highlighting the growing importance of software and applications for construction site activities.

It is my hope that the recommendations of this essay are taken into consideration by Skanska as they seek to improve both their implementation of FDMTs and optimize their approach towards improving quality and efficiency in general on their projects.

2. LITERATURE STUDY

This section begins by investigating the problems of poor quality and low efficiency in the construction industry, and describes techniques for tracking and monitoring quality and time on projects. It then explores construction management strategies and tools developed to address these problems, namely BIM and automated data collection tools and the lean construction and prefabrication approaches which they enable. Finally it describes the functionality and benefits of Vela, the tool under investigation in this particular study. Vela is situated in the context of other tools and approaches, and previous studies into its benefits are explored.

2.1 INEFFICIENCY IN CONSTRUCTION PROJECTS

Efficiency is defined as the amount of value-adding work processes correctly performed over a certain time period (Helms, 2006). Thus, efficiency is affected by two key variables: time and quality. Efficiency will increase as time per-task decreases and conformance rates (quality) increase.

Data gathered from a number of projects has shown that there is systemic inefficiency and waste in the construction industry. Significant time on construction sites is devoted to performing non-value adding activities, resulting in low rates of efficiency. This includes time spent on quality problems, in rework, in wasted overheads as a result of long breaks between trades in each space, and in safety incidents. Construction labor efficiency in the US has not kept pace with the general pace of industrial efficiency improvement in the economy. In fact, construction costs per dollar of

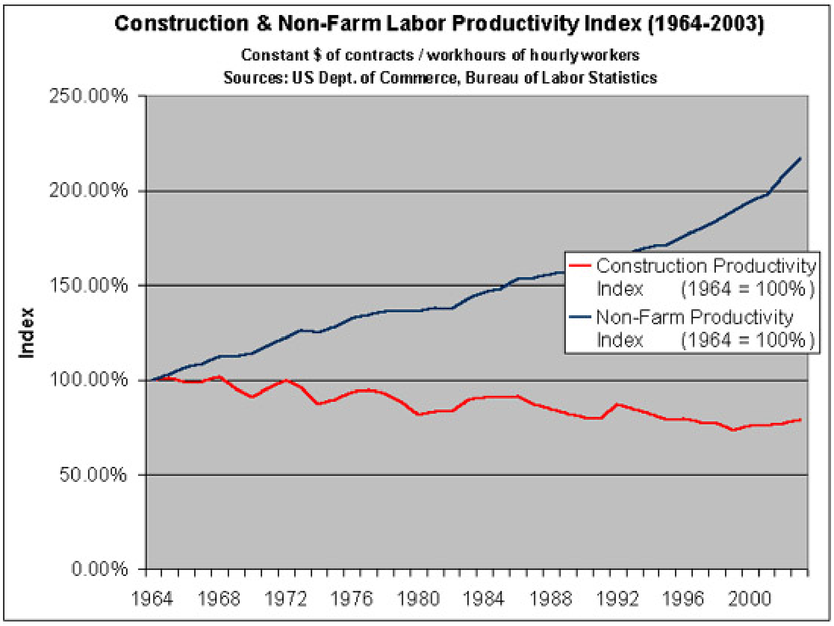


Figure 2.1 Comparison of construction to other industries' productivity over time

investment continue to increase. If construction had achieved the efficiency growth of the overall U.S. economy, labor requirements in 2001 would have been less than half what they were in 1964 (Picard, 2004).

The lack of progress in construction efficiency has five main sources, according to Teicholz (2004):

1. The design-bid-build (DBB) business model fragments phases of a project. Construction knowledge cannot be fully considered during design, and owners often are reluctant to implement innovations as the potential gains are usually not seen as worth the added risk and initial costs.
2. Despite the widespread use of IT, it has not had a significant impact on overall performance because it too is fragmented and often not interoperable. Traditionally, IT tools create paper-based outputs which must be coordinated manually. For example, CAD models are printed for estimators to do quantity take-offs and planners to create product breakdown structures and CPM schedules. Thus, there is time wasted in trying to integrate the outputs of various IT tools.
3. The building industry is characterized by a large number of small clients, designers, suppliers, general contractors and sub-contractors who are often not in a powerful enough position to provide leadership for the adoption of new technology and business processes
4. There is a very low (less than 0.5% of contract volume) investment in R&D by the construction industry as a whole.

5. Construction workers are paid relatively low wages that are declining over time on a constant dollar per hour basis. This means that there is less pressure than in other industries to substitute labor saving equipment for labor work hours.

Proper use of FDMT directly remedies issue 2 and this study makes the case that the other four issues can also be addressed by its benefits.

INEFFICIENCY DUE TO WASTED TIME

Measurements carried out in research by Sacks et al., (2011) showed that the direct waste of non-value adding time was between 13% to 18% of the total working time on projects in Israel. Workers must be paid for this time nonetheless (Picard, 2004).

There is a tendency on construction projects to keep extra manpower ‘in inventory’, waiting for when they are needed on a project. Delays add to the idle time, and are substantial and systemic in the industry. In a study of 5 projects, only 64% of tasks were completed according to the original schedule produced by project planners, while the remaining 36% experienced delays. A full 80% of these delays were caused by lack of design drawings or materials from suppliers (Howell and Ballard, 1994).

A direct consequence of supply network uncertainty and the abundance of delays is the tendency of subcontractors to add material and schedule buffers, in order to ensure steady workflow once their work begins. Buffers provide a workable backlog of construction tasks, by compensating for differing average rates of supply and uncertainty in the actual rates. They also allow differing work sequences by supplier and using activity. However, these buffers result in wasted time, extra labor costs and sub-optimal project schedules. The costs associated with buffers include storage space, double handling, inventory management, loss prevention, buffer fill time, and idle inventory. (Howell and Ballard, 1994).

INEFFICIENCY DUE TO POOR QUALITY

Quality is conformance to specification. The quality of a construction project affect a contractor's overall profitability (Heinloth, 2000). Good quality has short term internal project benefits, including cost reductions through streamlining processes and increasing effectiveness, whereas poor quality has associated expenses, such as the cost of scrapping and re-shipping faulty components, and rework to install items again. Over the long run, a reputation for poor quality can result in a loss of business as well as penalties for late delivery. Conversely, an organization may gain a reputation for high quality, making existing clients more likely to do repeat business with the same contractor again. Contractors that win quality awards have twice the average net income of non-award winners (Huntington, 2010).

A study of nine major engineering projects indicated that, for all projects, quality deviations accounted for an average of 12.4% of the contract value (Burati et al. 1992). Non-conformance costs may be significantly higher on projects where poor or no quality management systems are in place (Abdul-Rahman, 1995).

Rework is defined as: activities in the field that have to be **done more than once**, or activities which **remove work previously installed** as part of the project regardless of source, where no change order has been issued and no change of scope has been identified by the owner (Fayek et al, 2003). Josephson and Hammarlund (1999) reported that specifically the cost of rework on residential, industrial, and commercial building projects ranged from 2% to 6% of their contract values. Love and Li (2000), found the cost of rework to be 3.15% and 2.40% of the contract value for a residential and industrial building, respectively. They also found that through implementing a successful quality assurance system in conjunction with an effective continuous improvement strategy a contractor reduced rework costs to less than 1% of the contract value.

EVALUATING THE COSTS OF QUALITY LOSS

The losses due to not achieving quality targets can be measured in monetary terms by the formula:

$$\mathbf{l = d^2 c}$$

Where: l = quality loss in $

d = deviation from specified production target value

c = cost in $ of countermeasure deployed to fix the problem

This formula is analytical but gives a feel for the real cost of non-conformance (Taguchi and Closing, 1990). It illustrates for example that investing 25% more time in carefully making a connection will pay off by significantly reducing potential non-conformance costs. These costs can be plotted in the quality loss function.

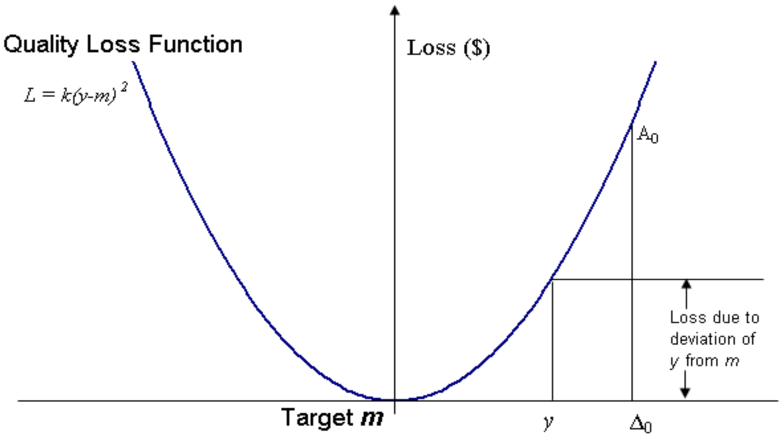


Figure 2.3. Quality loss function

Process Capability is defined as the quality output of any given process in relation to the specified conformance requirements for that component. The capability index is made by comparing the spread of actual production results to the spread between the upper and lower quality specification limits. By decreasing the actual output spread, defects are decreased and the costs of non-conformance are lower.

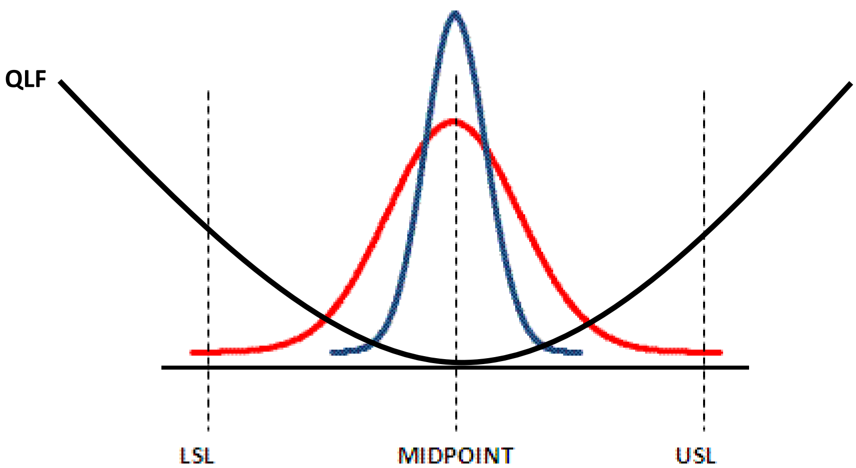


Figure 2.4. – the blue line has a higher process capability index than the red line and thus less costs of non-conformance.

2.2 TRACKING AND EVALUATING PROJECT PERFORMANCE

Since this study aims to assess the costs and benefits of using an innovative technology, it is necessary to orientate any research questions in a framework for measuring construction project performance through accurate, quantifiable measurement techniques.

The classic approach to evaluating construction project performance is based on monitoring performance during construction, up until completion and client handover. The **execution based approach** measures the quantifiable results of time, cost and quality. These can all be measured against baseline estimates and eventually expressed in monetary terms. A project can be considered successful in this way if it was on time, below cost and conforms to quality specifications (Winch, 2010).

However, this approach doesn't consider the full performance of a built asset over its total life cycle. Because the operation phase of a building usually lasts for several decades, it is usually over this time period that the majority of building costs are incurred. This is also often where quality conformance or shortfalls have their biggest implications. Savings can be made by making capital investments in a higher quality of specification to achieve greater savings on running and maintenance costs over the entire facility lifecycle (Holti et al, 2000). These upfront investments can result in a higher value product when successfully implemented. Benefits which clients realize after project handover are harder to quantify and less often tracked and measured, but are important nonetheless. If a contractor consistently invests more in quality and thus reduces operation costs or rework rates, they will gain a reputation for excellent quality and win more project bids (Vaughan, 2011).

In order to assess the benefits of FDMT to contractors, both the execution-based and lifecycle-based approaches to measuring project success should be considered.

2.2.1 SCHEDULE AND BUDGET MANAGEMENT

Earned Value Analysis (EVA) is a commonly used technique to track project progress by measuring actual time and expenditure variances against planned budgets and schedules (Fleming and Koppelman). At any given time in the project, EVA measures three main variables:

- Earned value (EV) – The budgeted cost of the work completed to date.
- Actual cost of work (AC) – The actual expenditure to date.
- Planned value (PV) – The expenditure which *should* have been spent by the project team to date.

To perform analysis, the values for the above factors can be compared:

- Cost variance (CV) – The $ difference between EV and AC (EV-AC)
- Cost performance index (CPI) – A relative measure of budget performance (EV/AC)
- Schedule variance (SV) – The $ difference between EV and PV (EV-PV)
- Schedule performance Index (SPI) – A relative measure of schedule performance (EV/PV)

It should be noted that SV is measured in monetary terms and not actual time, and needs to be measured against a calendar- based Gantt chart.

It is possible to extrapolate actual production rates derived through EVA into the future to predict the impact on the overall predicted budget variance at completion (EAC). This can be done by taking the remaining work (PV at end of project minus EV to date) and dividing by the cumulative

CPI (∑CPI), assuming that existing level of performance continue, resulting an increasing variance between planned and actual performance over time. In formulaic terms:

$$\mathbf{EAC = AC + (PV_{end} - EV) / \sum CPI}$$

This method is preferred, as once a project is running late, many knock-on chain effects of small delays make it difficult to regain the original budget and schedule. However, in some cases budget and schedule problems can be isolated to a particular isolated element in the WBS.

When plotted over time:

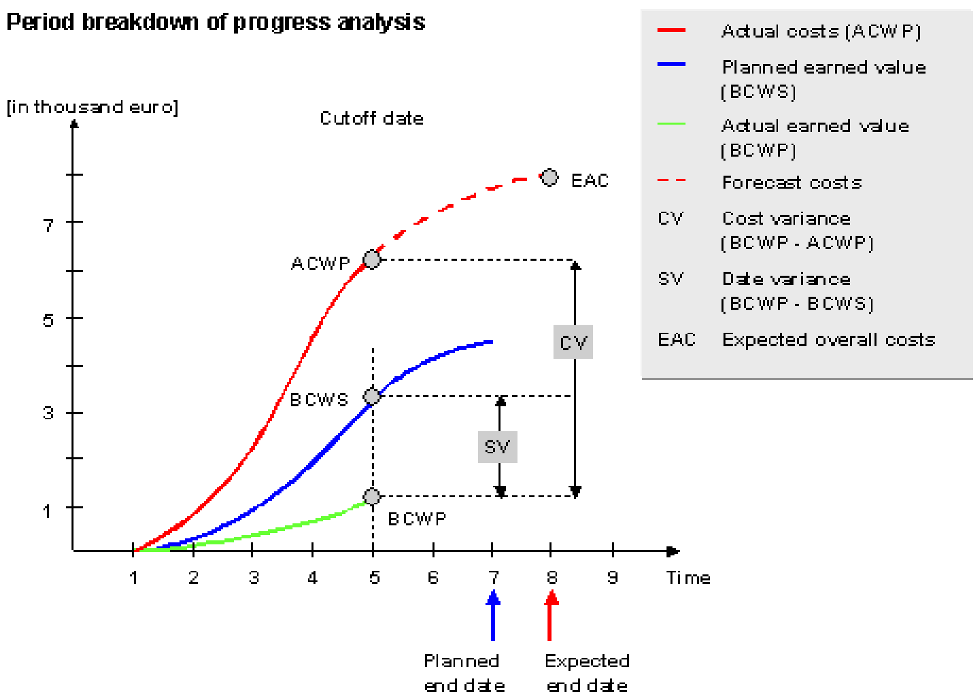


Figure 2.4. Graph of progress analysis over time

In this example, shown in figure 2.4, the project is not performing well. It is behind schedule (SV<0) and over budget (CV<0). The EAC shows the estimated final completion date and cost of the project. The point of this deterministic analysis is to provide an indication of how much needs to be done to bring a project's performance back in line with the original plan, or how much project promises needs to be changed by.

2.2.2 QUALITY MANAGEMENT SYSTEMS

Quality management techniques in construction projects can be classified as reactive or proactive (Winch, 2009). Reactive quality management allows organizations to learn where improvement is needed, by comparing actual performance of key processes with measurable outputs to desired objectives. Proactive quality management, which plans preventive action, can be seen as an investment that saves the cost of correction (Heinloth, 2000). Preventive measures include quality checklists which help raise issues early, for example verifying that sleeves for conduits are inserted in concrete forms before pouring (Huntington, 2010).

There are four basic approaches to quality management systems, identified by Dale et al. (2007). These are not alternatives to each other but rather complements. Thus TQM involves elements of inspection, QC and QA:

1. **Inspection**

   This involves testing components after installation, usually by someone other than those who have carried out the work. There is usually an accept or reject decision, and when a problem is identified, it must be addressed before the task can be considered complete. Often, inspection is carried out by sampling certain components rather than examining them all. This reduces its effectiveness at detecting nonconformance, as some defects may go unnoticed. However, inspection is an important step in the quality process as it ensures that equipment is able to work at required tolerances.

2. **Quality control (QC)**

   This focuses on fulfilling quality requirements by logging and analyzing data collected through inspections. Common tools include cause and effect diagrams, which attempt to ask why a problem has occurred, to avoid similar outcomes in future. Root causes can be plotted in histograms to identify particular problem areas. If data logging is automated, process capability can be measured statistically and discernible patterns over time can be identified.

3. **Quality assurance (QA)**

   QA provides confidence that quality requirements will be fulfilled. It specifies the procedures for QC and inspections. At the firm level, there exists a quality policy, which is applied to individual projects through quality plans.

4. **Total quality management (TQM)**

   TQM focuses on creating a culture of improvement. One of the main strategies in quality improvement programs is empowering those doing installation to carry out their own inspection work and conformance control. This requires that operatives are not blamed for conformance problems, and do not lose pay for stopping a task if a problem arises. This could be encouraged by incentivizing a ‘right first time’ policy rather than simply rewarding volume of output.

2.2.3 ROOT CAUSE ANALYSIS

Root causes of rework can be analyzed at a specific level so that they can be remedied and prevented, driving quality improvement systems. To improve quality it is necessary to understand the basic reason for the existence of rework or set of conditions that stimulate its occurrence in a process (Love, et al 1999). Kauro Ishikawa (1982) developed the “fishbone” diagram or cause and effect diagram as a qualitative tool to visually present cause and effect relationships in a clear way to serve as a basis for developing process improvements. This is a reactive quality management tool.

Fayek et al., (2003) carried out a comprehensive study on the causes and costs of rework on behalf of the Construction Owner's Association of Alberta (COAA). They found that almost all companies have a rework tracking system, although there is variation in these systems and no apparent industry-wide standard. In general, rework can be divided into categories:

- Engineering driven, mostly due to drawing changes, design errors, constructability issues, changes in scope
- Customer driven, mostly due to changes requested by operators; i.e. after construction complete
- Manufacturing and supply, mostly due to poor quality of manufactured equipment
- Construction errors in the field

They determined that 97% of rework on the Syncrude Aurora 2 project in Alberta, Canada was a result of root causes in the Human Resource Capability, Engineering and Reviews and Material & Equipment Supply categories. Accordingly, they updated the COAA's root cause diagram:

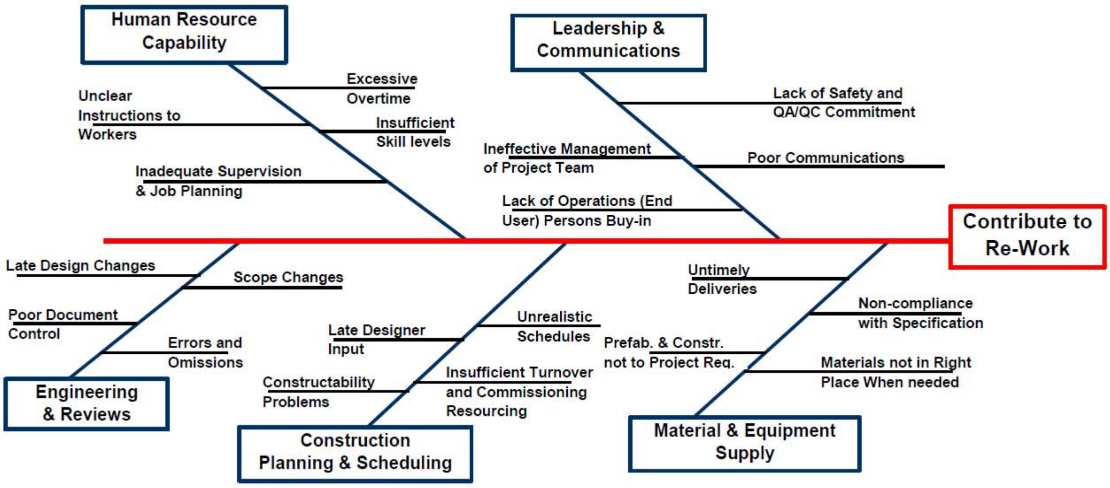


Figure 2.5 COAA's root cause diagram

2.3 LEAN CONSTRUCTION

In Japan in the 1950's, automobile manufacturers developed the Toyota Production System (TPS), a method to reduce inconsistencies, increase value to the customer, level out workload on employees and machinery, and eliminate waste. This production system forms the basis of Just-in-time (JIT) inventory strategy in manufacturing, and for a construction philosophy known as Lean Construction (Howell, 1999), which aims to remedy the high waste and low efficiency prevalent in construction projects.

In traditional managerial methods, such as CPM networks or sequential planning, all activities are treated as though they were value-adding, including many which actually aren't. As a result, there is considerable construction waste, both in labor and materials. Poor planning results in 'fire fighting' crises as they come up, consuming management resources and attention.

Value is the critical starting point for Lean Construction, and can only be defined by the ultimate end customer. The value stream is defined as the set of all the “specific activities required to design, order, and provide a specific product, from concept to launch, into the hands of the customer” (Womack and Jones, 1996).

All activities consume time and resources, but only conversion activities add value to a material being transformed into a product. The focus of lean construction is to re-conceptualize the construction processes into flows and conversions (Koskela, 1992). The first step of this is to focus clearly on the actual object being produced. The second step is to ignore boundaries of jobs or work descriptions and to form a collaborative, lean enterprise which removes impediments to continuous work flows and opts for teamwork. The third step is to rethink specific work practices and eliminate waste and stoppages so that there is less variation in rates of production, design, ordering, etc. (Womack and Jones, 1996).

When successfully implemented, Lean construction can reduce defect and accident rates, and compress cycle times, resulting in imrpoved quality and schedule performance. However, diffusion of the lean philosophy to the construction industry faces some important implementation barriers. The uniquely different nature of each individual construction projects, in which a number of different subcontractors work together on a one-off basis, is an important factor to consider. Furthermore, lean construction requires considerable planning at an early stage, which necessitates a larger up-front investment than in traditional construction management methods.
Continuous statistical monitoring of task durations, root causes for delays and measurements of value-added according to activity performed can play a vital role in improving the productivity on construction projects. Koskela identified four steps which can be used to drive labor efficiency:

- Measure level and variation of the process
- Identify and eliminate causes of variation
- Raise the level of process performance
- Identify events that could disrupt the process

Typically, project controllers measure actual schedule and budget results against planned outcomes for an indication of how a project is performing (Picard, 2004). These ‘lag indicators’ which occur after tasks have been completed are useful to confirm that a change in production levels has in fact occurred as a result of implementing a new management system. However, Kaplan and Norton (1996) recommend using a combination of both outcome measures and ‘lead indicators’ as a way of driving performance and then testing the outcomes. Lead indicators indicate when pre-emptive actions should be taken to achieve desired project goals, and therefore require careful planning progress tracking.

Pappas (1990) differentiates between regular 'push methods' of planning which specify when a task has to start, and the 'pull methods' of lean construction, which give dates by which a task needs to be finished. The Last Planner system (LPS) is a pull method of scheduling aimed at improving productivity and plan accuracy by only allowing assignments which are ready to begin to enter weekly work plans. This lets teams schedule work backward by starting at a target completion date, defining and sequencing works so that their completion releases subsequent tasks. The plan is broken down into varying degrees of granularity:

- Master schedules are limited to phase milestones and items with long lead times.
- Phase schedules contain works which should be completed by a certain date.
- The look ahead plan assesses work which can feasibly be carried out over the next 4-6 week period
- The weekly plan breaks down work into tasks which are ready to begin that week, and gets commitments from responsible subcontractors to complete those tasks.

This makes planning a collaborative effort between schedulers, foremen, superintendents and subcontractors, aimed at improving the reliability of team member's commitments (Seppanen et al., 2010). The reliability of work plans is measured by calculating the percentage of plan completed (see section 2.2 on earned value analysis). For each failed assignment, a root cause analysis is done to prevent the problem from reoccurring (Ballard, 2000). This control and feedback is an important process in improving the *accuracy of the Last Planner system.*

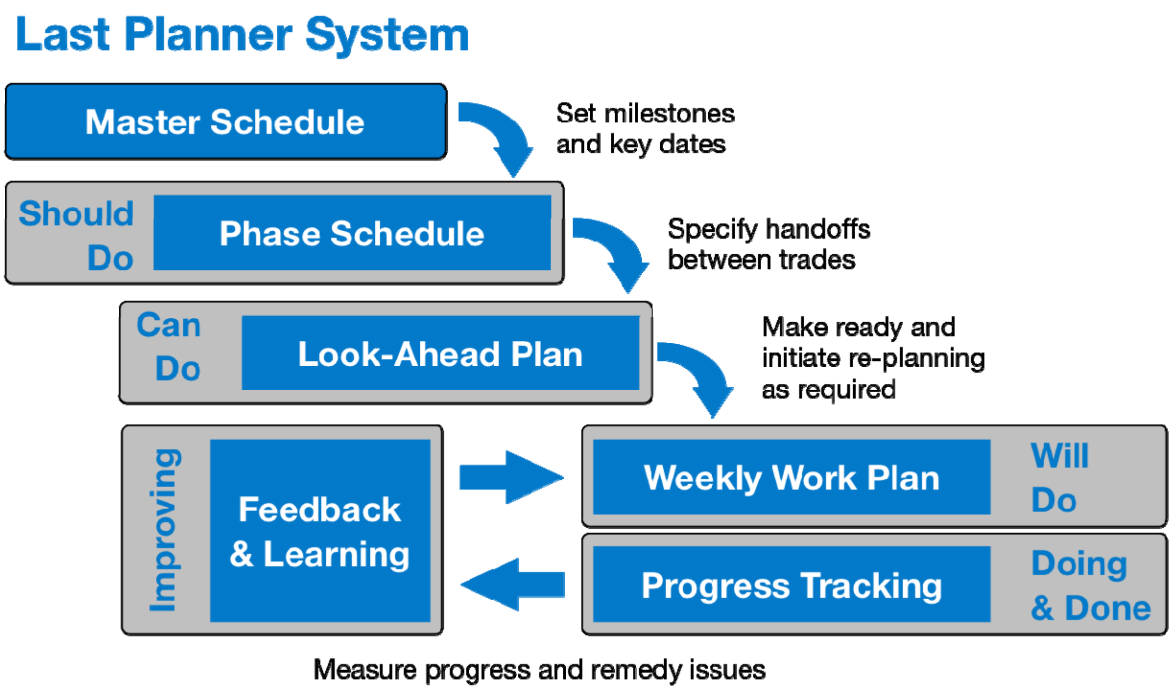


Figure 2.6. The last planner system

Activity-based scheduling methods such as CPM give little indication of space requirements. The Location-based management system (LBMS) is a complementary method of planning to LPS (Seppanen et al., 2010). It integrates the CPM into a physical location breakdown structure such as flowline scheduling, with the goal of optimizing labor flow so that work does not wait for workers and workers do not wait for work. An example of LBMS is Line-of-Balance scheduling, which allows space requirements and work flows to be visualized schematically and distributed evenly, by plotting planned tasks against location and time. This can help identify tasks with high resource needs who may become bottlenecks if a reliable subcontractor is not selected. LBMS requires more data than traditional CPM scheduling, including accurate productivity rates for tasks and quantities by location. The levelling of production spreads activities out over time, reduces costs and delays due to demobilization and remobilization, (Sacks et al., 2010) and optimizes schedules when successfully implemented. In the controlling stages, planned production can be tracked against actual construction, and observed rates can be extrapolated into the upcoming weeks to predict where problems or clashes might occur.

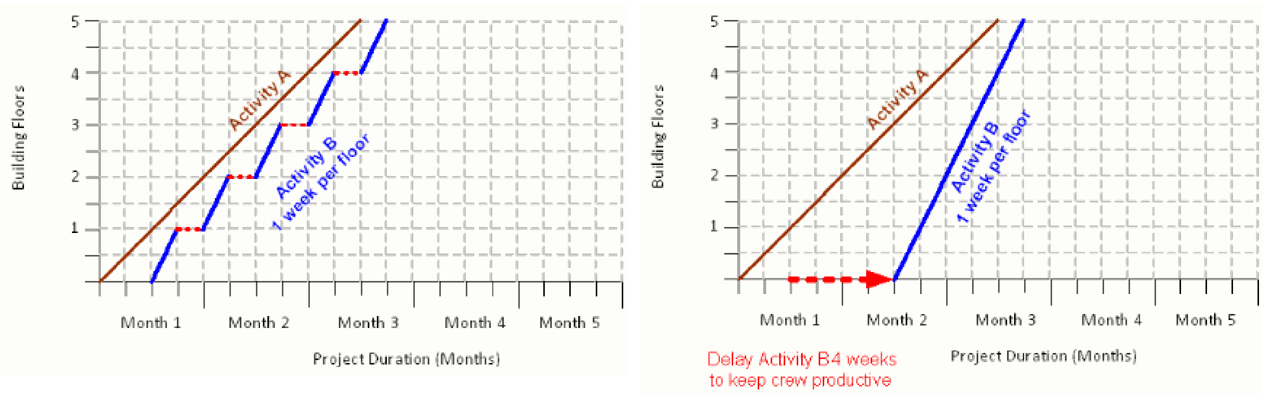


Figure 2.7. Simple flowline chart showing (a) original schedule of 2 activities, in which activity B is forced 2 wait 1 week each floor by activity A (b) optimized schedule in which start of activity B is delayed 4 weeks to ensure continuous production and a shorter individual task duration.

2.4 PREFABRICATION

Prefabrication involves assembling building components offsite and transporting them to where the finished structure will be located. This process benefits the three primary project execution goals: costs, time and quality.

TIME SAVINGS

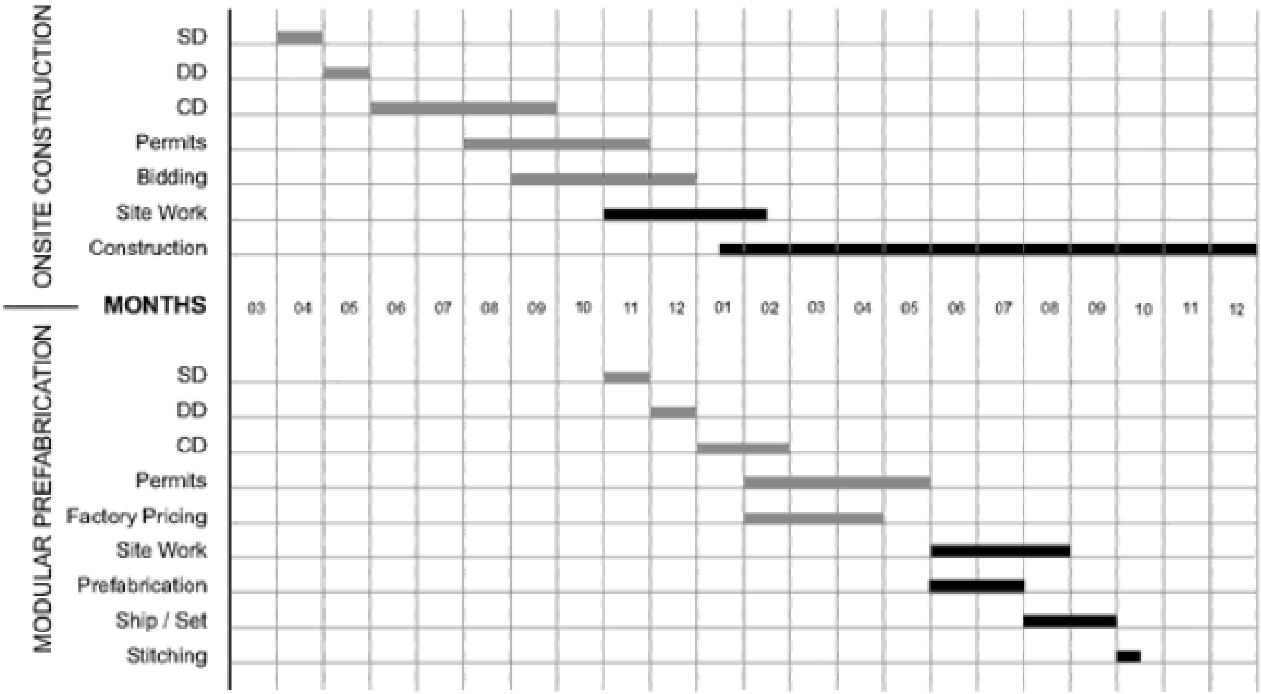


Figure 2.8 Gantt chart showing how design and construction tasks can be overlapped through using modular prefabrication

Preparatory site work and prefabrication activities can be entirely overlapped, as fabrication happens mostly at a separate location. The Gantt charts in figures 2.9 and 2.10 compare the schedules for two similar houses designed by the same Architect (Smith, 2011). They show the dramatic time savings which can be achieved through prefabrication, in terms of design, permitting, pricing and construction.

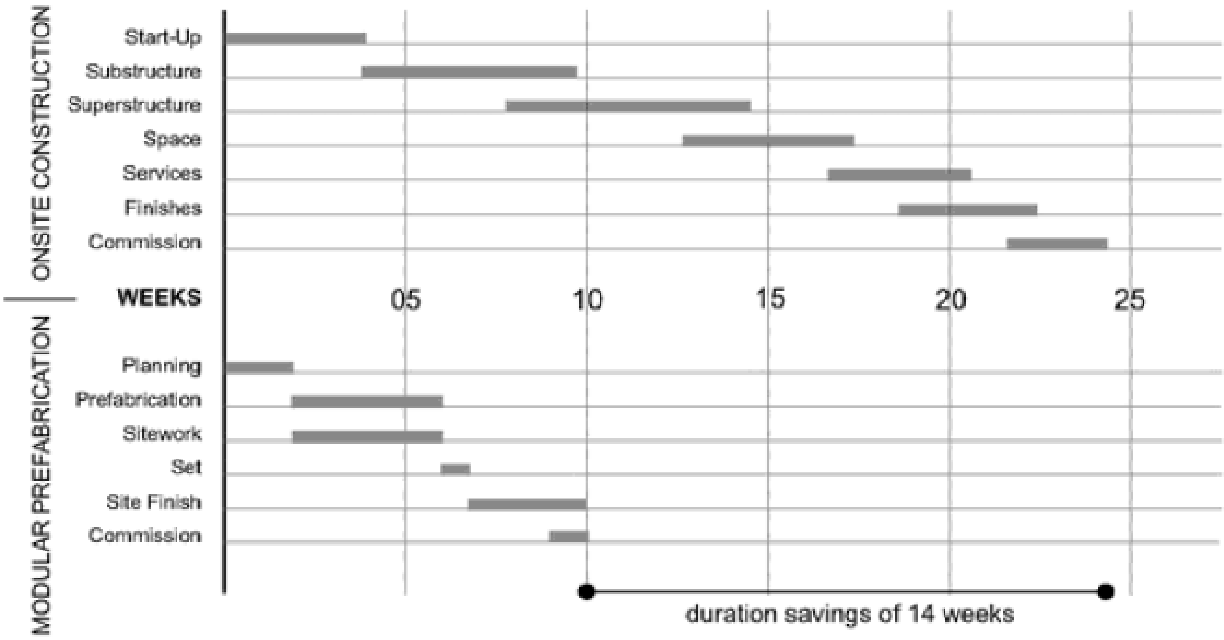


Figure 2.9 Illustration of time savings through use of modular prefabrication

COST SAVINGS

Cost savings due to preassembly of components are mainly realized as a result of time savings. The total benefit of the reduced construction schedule due to prefabrication can be in the range of 5% to 10% of the total building cost in comparison to more traditional site-intensive construction systems (Rogan et al., 1999). These are mainly as follows

- **Reduced rent of site facilities including hire of site huts, offices etc.**

  Typically site overheads are estimated as 8 to 15 % of the total construction cost. Therefore, a reduction in time onsite can lead to a significant saving in overhead cost to the contractor.

- **Earlier return on investment to the client.**

  This depends on the business operation, but the minimum level of this benefit is the saving in interest charges and the average construction cost over the reduced construction period. The maximum level of this benefit is the earning potential of the building when in early operation, and strategic business advantages due to quicker time to market.

- **Reduced loss of the earning potential of the existing facility.**

  This is a real cost to the client that occurs particularly where existing buildings, such as hotels, are extended or modified. A reduced construction period will lead to commensurate savings to the client.

- **Predictability of construction programme (i.e. low risk of over-runs).**

  Prefabrication in a controlled environment is weather independent, unlike many on-site activities, which can be stopped or postponed due to certain weather conditions.

Prefabrication can also achieve economies of scale, which are defined as reductions in unit cost as the size of a facility and the usage levels of other inputs increase (O'Sullivan and Shefferin, 2003). Regular units can be produced to standard dimensions and specifications that are readily transportable. In this case, there are economies of scale, and speed and quality benefits through factory production and pre-testing.

The economy of scale in production leads to the following benefits:

- Greater investment in the production-lines, leading to greater speed of assembly.
- More emphasis on improvement in design by testing, and by rationalisation of details based on ease of manufacture.
- Establishment of strict quality assurance procedures and avoidance of re-work.
- Better design, including the possibility of variants at modest additional cost or difficulty.

- More involvement of specialist suppliers, e.g. services.
- Reduction of waste by efficient ordering and use of materials.

However, it should be noted that:

- The structure may be 'over-engineered' for its normal applications due to requirements for lifting and transportation.
- The need for 'standardisation' means that some economy in use of materials is sacrificed for production efficiency.
- Costs increase with the number of non-standard units in a given project.

In all cases, economies of scale exist with greater standardisation and production line efficiency.

QUALITY IMPROVEMENTS

Process capability can be improved through standardization, which involves using standard components such as door sets and electrical fittings. Through task repetition, there is a learning curve with quality benefits. Preassembly can provide improvements in process capability through providing a more controlled work environment offsite, although the size of objects produced through preassembly is limited by difficulties in transporting and installing large objects. Prefabrication can have a strong influence on quality through the following factors (Rogan et al., 1999):

- Clients often demand a high degree of QA. A single point procurement route for components concentrates the responsibility on the manufacturer.

- Off-site trials can be carried out in a strictly controlled environment to assure conformity of the system before installation. This is especially valuable in highly serviced units such as plant rooms, lifts and kitchens.
- In conventional on-site building, many contractors allow 1 to 2% contingency costs. These costs are considerably reduced when using modular construction.

2.5 BUILDING INFORMATION MODELING

Building Information Modeling (BIM) is defined as the modeling technology and an associated set of processes to produce, communicate, and analyze building models. These models contain the precise geometry and relevant data needed to support the construction, fabrication, procurement operation and maintenance activities needed to realize the building (Eastman, 2011). At least some aspects of FDMTs are complementary to BIM and can be considered to belong to the suite of BIM tools.

BIMs consist of building components that are represented by intelligent digital objects that ’know‘ what they are, and can be associated with computable graphic and data attributes and parametric rules. Components contain data that describe how they behave, which is needed for analyses and work processes, e.g., takeoff, specification, and energy analysis. This data is consistent, non-redundant and coordinated so that changes to component data are represented and coordinated in all views of the component.

Through achieving significant improvements in critical measures of performance such as time, quality and cost, BIM can be considered to belong to the Business Process Re-engineering approaches (Hammer and Champey, 1993) which have long been popular in manufacturing industries. Successful implementation of BIM offers distinct benefits to architects, engineers, contractors, subcontractors, fabricators, building owners and facility managers.

2.5.1 PRE-CONSTRUCTION

CONSTRUCTION PLANNING

BIM can serve as an aide to the scheduling process. 3D objects in a design model can be linked to a construction schedule using 4D scheduling. BIM viewing software such as Autodesk Navisworks Manage enable this by allowing project planners to directly import CPM or Gantt chart project schedule files. This makes it possible to animate the construction process and show what the building and site would look like at any point in time. This visualization of how the building will be constructed on a day-by day basis can reveal potential problems such as space conflicts or safety problems before they occur on site (Eastman, 2011). This scheduling method can enable a continuous and reliable flow of resources through different locations in a project, significantly reducing waste in the form of waiting by crews, rework and disruptions (Jongeling and Olofsson, 2007). 4D modelling allows project managers to compare schedules and track construction progress, by quickly identifying whether the project is ahead of or behind schedule.

4D scheduling is especially beneficial if the model includes temporary construction objects such as scaffolding and cranes, so that these objects can also be linked to schedule activities and reflected in the desired construction plan. They can then link permanent and temporary building components to tasks in the project breakdown structure (Eastman, 2011). This is a key reason why early contractor involvement is beneficial when defining a building model. Temporary structures such as shoring and formwork should ideally be modelled during the design stage. Design-Build projects faciliate this by allowing designers and builders to work together earlier in a project, creating opportunities for constructibility analysis.

Permanent 3D model objects should be detailed to a level of granularity which corresponds to the construction process. For instance, a single concrete slab may be poured in several sections, thus requiring one 3D object per pour (Jongeling and Olofsson, 2007). If a BIM model is made so that objects are created and grouped with a PBS-schedule in mind, the objects can be reused in the construction planning and much less effort will be needed to create a 4D schedule, since double work is essentially eliminated (Tulke and Hanff, 2007).

Safety management has traditionally been carried out separately from the production planning and control process. 4D models aim to improve safety management by allowing teams to identify potentially hazardous site activities and coordinate space use accordingly. These issues would be difficult to identify when different project members view traditional 2D plans in conjunction with CPM schedules (Jongeling and Olofsson, 2007). Using 4D simulation, they can identify spatial conflicts and resolve them before they play out on site. Jongeling and Olofsson (2007) recommend using location-based planning methods such as Line-of-Balance scheduling in conjunction with 4D scheduling.

Despite its benefits, 4D scheduling has a number of limitations. It requires a considerable amount of time effort and collaboration to set up, and as such is still fairly rarely implemented (Tulke et al, 2008). The fragmentation of the construction industry and the related difficulties in operating between varied software infrastructures within projects contribute to this shortcoming.

CLASH DETECTION

Using a single 3D building model as the source for all construction documents reduces design errors caused by inconsistent 2D drawings. Because systems from all disciplines can be brought together and compared in this single model, interfaces between various systems can be easily checked for clashes. This way, conflicts can be identified before the construction begins, rather than once one system is already installed in the field. Coordination among participating designers and contractors is enhanced and errors of omission are significantly reduced. This has significant time savings as the construction process is sped up. The increased quality also reduces costly design changes and the ensuing legal disputes as problems are identified before they become issues in the field (Eastman, 2011).

When all of the major subcontractors participate in using the BIM for accurate detailing their portions of the work there can be great benefits with regards to clash detection. The general contractor must ensure that the building model has sufficient detail for piping, ducts, structural steel, and other components, otherwise a significant number of problems will not be found until the building is constructed, at which time they could be costly and time consuming to resolve. This is another reason why early subcontractor involvement is valuable.

Most BIM software packages contain clash detection features that allow the designer to check for clashes during the design phase. However, contractors often need to integrate various models. This is where poor interoperability of systems can present a major difficulty.

RESOLUTION OF DESIGN ISSUES

If a contractor needs to change a design, modifications can be entered into the building model and changes to the other objects in the design automatically become visible, based on the established parametric rules. The impacts of a change can be assessed in the model, estimated, shared instantly and resolved. This is quicker and more accurate than a paper-based system.

QUANTITY TAKEOFF AND COST ESTIMATING

All BIM tools provide features for automating the estimation of quantities of components, materials, area and volume of spaces, saving considerable time when compared to a manual 2D-document based take-off procedure. These quantities are more than adequate for producing approximate cost estimates during early design phases. Problems may arise however when contractors use components which are not properly defined and are not capable of extracting the full scope of quantities needed for proper cost estimating. For example counting the area of interior partition walls without considering the quantity of studs could lead to an inaccurate estimate.

Thus, BIM is not (yet) a substitute for the knowledge and judgement which estimators can offer. Automatic quantity take-offs from BIM should be used as a part of the estimating process, in conjunction with standard estimating software

IMPROVED PROCUREMENT

The complete BIM provides accurate quantities for most (or all) of the materials and objects in a design. These quantities, specifications, and properties can be used to procure materials from product vendors and subcontractors.

2.5.2 ON SITE ACTIVITIES

ENABLING OF LEAN BUILDING PRINCIPLES

Sacks et al. (2010) have identified 56 interactions between BIM functionalities with lean construction principles, 48 of which are documented by empirical evidence. The principles which are most supported by BIM are:

- reduction in quality variability
- reduction in production variability
- reduced cycle durations

To achieve these project execution improvements, the general contractor and sub contractors must carefully plan and coordinate to ensure that work can be performed when appropriate resources are available on-site. BIMs can be updated as construction work is carried out to track statuses of equipment and measure planned progress with actual progress. This enables just-in-time arrival of people, equipment, and materials, saving time and costs and minimizing waste (Eastman).

SUPPORT OF PREFABRICATION

A design model can be transferred to a BIM fabrication tool and detailed to the level of fabrication objects as a shop model. Shop models contain accurate representations of the building objects for fabrication and construction. The fabrication of components can be automated, because they are already defined in 3D. This has been used successfully in pre-cast components, façades, and glass fabrication, and is standard practice today in steel fabrication and some sheet metal work. Thanks to BIM's increased accuracy, larger components of the building can be fabricated and assembled off-site. There is less likely to be a need for rework once installed and it is easier to predict exact dimensions before other items are constructed in the field.

BUDGET AND SCHEDULE CONTROL

Because BIMs have detailed quantity and other component information that can be linked to other applications, they can play a central role in the control process. Contractors and owners can analyze up-to date project progress and highlight potential or existing problems, using the following techniques:

- **Project Status**: Each component can have a status in the field, which can be updated. Values may include: in design, approved for construction review, shipped, installed, etc. These field statuses can be visually associated with colors so that the team can quickly determine the status of particular areas of the construction and identify bottlenecks or areas that are behind schedule.
- **Procurement Purchasing:** It is possible to make purchases directly using the BIM tool, since objects are broken down into their component parts. Product manufacturers are developing models of their products that can be stored online and accessed via search. Some products provide real - time quotes on doors and windows delivered to the job site based on zip code.
- **Procurement tracking:** The status of procurement activities can be updated, and planners can relate the procurement process to design and construction to identify issues or gaps. By

linking the schedule to BIM, they can visualize where procurement delays are likely to impact construction. For example, if a piece of equipment is scheduled to be installed in two months and the procurement process is not yet complete, the team can address the issue quickly to prevent a chain of delays further down in the schedule.

QUALITY CONTROL AND TRACKING OF CONSTRUCTION ACTIVITIES

Even when a project team creates an accurate model, human error during installation remains a possibility. When errors are found, the contractor must spend further time rectifying them, and catching these errors as they occur or as soon as possible has great value. The building model can be used to verify that actual construction matches the design. An example of this occurred on the Letterman Digital Arts Center (LDAC) in San Francisco, where the project team built a complete model after the project had been designed and subsequently documented a field error in a report (Boryslawski, 2006) as described in the following excerpt:

“During one of the daily rounds of on-site photography, we recognized a critical error shown in the positioning of concrete formwork, which was quickly confirmed by referencing the BIM. This error occurred when the formwork layout person measured from a column that was off the standard grid to the edge of the concrete slab. Pouring more concrete in this complex post – tension slab construction would have had serious consequences not only for the contractor but also for the entire project, as there were three more floors to be built above this floor. The problem was solved just as the concrete was being poured, saving what would have most definitely been a major expense. ”

The above example illustrates that when combined with regular site inspections for validation, intimate familiarity with a building model can help identify field errors before construction activities are carried out.

Tools are being developed which aim to automate certain inspection processes. These include:

- **Laser scanning technologies:** Contractors can use laser measurement devices that create as-built models and compare results with BIMs, to verify that concrete pours are situated in exactly the correct location or that columns are properly located.
- **Machine - guidance technologies:** Earthwork contractors can use machine – guided equipment to support grading and excavation activities driven by dimensions extracted from a 3D/BIM model.
- **GPS technologies:** Contractors can link BIMs to GPS to verify locations.
- **RFID tags:** Radio Frequency Identification (RFID) tags assist the tracking of component delivery and installation onsite. RFID tags have references to BIM components and can automatically update with field scanning devices and provide contractors with instantaneous feedback on field statuses. The use of BIM on site will increase dramatically as mobile devices and software to provide site workers with BIM data becomes commonplace.

2.5.3 WHOLE LIFECYCLE ADVANTAGES

When used as a tool for monitoring construction activities, BIM can also automatically generate as-built 3D models, if the BIM has been accurately updated with all changes made to each building element when it is installed. This provides contractors with a realistic model which can be handed over to the owner, to be used for maintenance and operation purposes (Babic et al., 2009). This single, comprehensive source of information provides a useful tool for managing and operating all systems used in a building. A BIM supports real–time monitoring of control systems and thus provides a natural platform for coordinating sensors and remote operating management of facilities.

The Construction Operations Building Information Exchange (COBIE) is a procedure for streamlining the handover of project documentation which keeps a record of data created during design and updated through construction and commissioning (East, 2012). This saves time, since as-built information about equipment only needs to be recorded once, and also compiles a more accurate database for facilities management. Manufacturers are beginning to provide COBIE data directly to construction contractors, and this information can be used to automatically schedule maintenance or replacement of equipment as required. COBIE is becoming a viable alternative to traditional 2D handover documents.

2.5.4 BIM IMPLEMENTATION ISSUES

LEGAL ISSUES

There is a legal challenge in determining methods and standards by which BIM information is shared by project team members. These mainly concern establishing who owns the design, fabrication, analysis, and construction datasets, who pays for them, and who is responsible for their accuracy. As owners are beginning to accept BIMs as legal handover documents, professional groups, such as the AIA and AGC, are developing contracts which cover issues raised by the use of BIM technology (Eastman, 2011).

PROJECT DELIVERY METHOD

If the architect in a traditional design-bid-build project uses paper - based drawings, then it will be necessary for the contractor to create a BIM from scratch, so that it can be used for construction planning, estimating, and coordination etc. This can add significant costs and time to the project, but this investment is often justified by the added efficiency of using it for planning, detailed design by mechanical, electrical and other subs and fabricators, design change resolution, procurement, equipment tracking etc. The reduction of double work through producing BIMs in the design phase and handing this over to the construction team favors projects delivered through integrated design-build methods which are capable of coordinating all phases of the design and incorporating construction knowledge from the outset.

IMPLEMENTATION

The transformation from a traditional 2D CAD document process to using BIM as the basis of all work processes requires time and training, as is true of all significant changes in technology and work processes. Changes must be made to almost every aspect of a firm’s business. For the conversion to be efficient and effective, firms need comprehensive implementation plans. Eastman recommends the following as general steps that need to be considered:

- Assigning top level management responsibility for developing a comprehensive BIM adoption plan that covers all aspects of the firm's business and how the proposed changes will impact both internal departments and outside partners and clients.
- Creating an internal team of key managers responsible for implementing the plan, with cost, time, and quality metrics to guide and assess their performance.

- Starting to use the BIM system on one or two smaller projects in parallel with existing technology and documentation techniques, and producing traditional documents from the building model. This will help reveal deficits and identify areas for improvement.
- Using initial results to guide subsequent adoption of BIM software and additional staff training. Keep senior management informed of progress, problems, insights, etc.
- Extending the use of BIM to new projects and beginning to work with outside members of the project teams to allow early integration and sharing of knowledge using the building model.
- Integrating BIM capabilities into all aspects of the firms functions and reflecting these new business processes in contractual documents with clients and business partners.
- Periodically re-evaluating the BIM implementation process using the above steps to reflect on the benefits and problems observed thus far, and setting new goals for performance, time, and cost.

The above recommendations focus on implementing BIM from a top-down 'technology push' perspective. However, this involves the challenge of introducing cumbersome work process changes. Research has shown that incremental innovations work better in construction settings than the top-down introduction of disruptive innovations, which some construction managers may see as imposed from above. Hartmann et al. (2011) have empirically demonstrated through 2 case studies that it is preferable to implement BIM tools to organizations in a 'technology pull' manner by creating opportunities for users to apply the technologies on their own, as a result of experiencing the benefits they offer in a first hand way. They used a bottom-up strategy on two projects in the Netherlands, in which BIM was actively adopted by users as they become more familiar with its functionality. In one project, managers discovered the time savings of using BIM for generating automatic quantity take-offs. In the other project, planners used 4D models to vizualize project risks in time and space, assess the risks' implications on schedule, costs and quality, and come up with possible mitigation strategies. In both cases, they could more easily make sense of the benefits with by witnessing improved work processes.

INTEROPERABILITY

If the members of the project team use different modeling tools, then tools for moving the models from one environment to another or combining these models are needed. This can add complexity and introduce potential errors to the project. An important aspect to consider when evaluating the effectiveness of a BIM modelling, viewing or manipulation tool is its degree of interoperability with other systems. An ENR survey of 450 building industry professional identified interoperability as the key concern regarding BIM tools (Sawyer, 2012).

2.6 AUTOMATED DATA COLLECTION TECHNOLOGIES IN CONSTRUCTION

Despite the quality imrpovements which can be achieved through prefabrication of building components, the customized nature of these pieces means that they need to be identified individually and tracked along their supply chain, since most of them are unique (Ergen et al., 2006). Significant resources have been dedicated to tracking and locating components using manual approaches, but these can result in late deliveries, missing components and incorrect installations. To illustrate how these problems can occur, it is useful to consider a typical path of a building component, from manufacture to installation in a building:

- Components are manufacturered, tagged, and transferred to storage areas.
- They must then be located and shipped to construction sites where they are stored based on their destination and delivery dates in laydown yards.
- They must then be located again and moved to the installation area.

Errors are often only detected in the installation phase. The correct component must then be located through a time consuming search. If it still can't be found, it must be re-manufactured at an additional cost (Demiralp et al, 2012). These late deliveries, double-handling and rework lead to schedule delays and increased labour costs.

The heavy reliance on collecting information in a manual fashion is one of the biggest barriers to the adoption of lean techniques in construction projects, as there is an inherent level of error at each step. Several technologies have been developed to improve the identification, tracking, location, and monitoring of building components through construction supply chains, including barcodes, laser surveying, radio frequency identification (RFID) tags, and GPS. They are commonly referred to as automated data collection technologies (ADCTs), as they involve minimum human input. Their three main areas of application are:

- Monitoring of production, storage, delivery to site, installation and quality control of components
- Supporting the erection or installation of components and quality control
- Providing lifecycle information about components and their performance

Through reduction of waste and enhanced visibility of supply chain network, ADCTs can be considered a complement to lean construction techniques (Young et al., 2011). These tools create cost savings through:

1. Quality improvements
    - Reduction in number of missing components, resulting in less need for costly re-manufacturing.
    - Reduction in number of incorrectly shipped components, resulting in less cost of shipping replacements and less cost of trying to install incorrect components if the mistake is not realized until the final stage.
2. Time reductions
    - Reduced activity durations, resulting in less labour costs, for example less need to conduct extended searches.

These savings benefit both manufacturers of components and on-site installers, usually building contractors. Numerous studies have quantified these benefits in terms of time, cost and quality. Grau et al. (2009) measured an 87.5% reduction in time to locate steel components through automation. Yin (2009) calculated a reduction from an average of 25.24 mins to 0.57 mins to locate precast components at a plant. Jaselskis and El-Misalami (2003) estimated 30% time savings using RFID to receive pipe hangers. Nasir et al. (2010) measured 33% labor savings associated with material and information handling tasks due to an automated material location tracking system on site.

The process works by first assigning an ID to each traceable prefabricated piece in the BIM. Then, as each part is produced, the attached RFID tag number is registered to that part in the database. Tags are scanned and transmitted via Bluetooth transmission to a data-entry form. The correct part is selected from a list and associated with the tag ID. From that point on, any time the tag is scanned and linked to a tablet or laptop, the information sheet for the correct part will appear (Sawyer, 2010). In a semi automated RFID-process, workers carry handheld readers which automatically identify components via embedded RFID tags. In a fully automated process, human intervention is minimized as tagged items are automatically scanned by readers attached to locations or equipment such as forklifts or gates.

For ADCTs to be successful, strict performance requirements must be met. Minimal worker input should be involved in accurately identifying and locating equipment, and the tracking technology should be able to withstand harsh site conditions (Ergen et al., 2006). A common feature of ADCT systems is that they all need BIMs to store design information against which actual data can be compared for project control purposes (Eastman et al, 2011).

Demirap et al. (2012) found that using RFID tags for tracking the transportation and installation of 150 prefabricated panels completely eliminated the problem of incorrectly shipped and missing panels at plants and on site. Accumulated durations of delivery and installation activities were found to be 93% less than using manual tracking techniques using semi automated RFID process, and 95% less using a fully automated process. When other activity durations such as manufacture and transportation were considered, these savings accounted for approximately 5% of total time savings between the time of manufacture until installation of the panels. Total costs savings were found to be 3.1% of total project cost, with 65% of this saving occuring due to less remanufacturing, 19% due to less labor cost and 16% due to less material transfers.

The tendency of subcontractors to add time buffers to their tasks results in material stockpiles building up on site, with associated delays and inventory storage costs. Howell and Ballard (1996) showed that projects with heavy pipe-installation requirements accumulate 60% of their pipes in an on-site laydown yard by the time 20% had been installed. Young et al. (2011) demonstrated that by using RFID tags and readers to track a piping supply chain, project managers identified tasks which could be started and completed earlier in the construction schedule. This reduced buffers, meaning tasks such as material fabrication, delivery and installation could be overlapped to a greater extent, as start times were shifted forward. Even with a reduced crew size, this method of ACDT reduced the schedule for the piping task by 10% relative to the initial estimate.

2.7 PROJECT DELIVERY METHODS

Owners can use different methods for organizing and financing design, construction, operations, and maintenance services for a building or facility by entering into legal agreements with one or more entities or parties. The key differences between these methods usually regard how risks and responsibilities are divided. This inevitably affects the contract and payment structure.

Currently, the most commonly used project delivery methods in building construction in the United States are design-bid-build (DBB), design-bid-build with construction management (DBB with CM), design-build (DB), and Construction Manager at Risk (CMAR).

DESIGN-BID-BUILD

DBB is the traditional method for project delivery. It is characterized by separate contracts between the owner and designer and the owner and contractor. There is typically no interaction between designer and contractor during the design phase. Contracts for construction are usually awarded after designers have created tender documents, on which a number of contractors bid. The contractor who makes the lowest bid will be awarded a lump sum construction contract.

In some cases, a construction management agent can be hired to help manage a DBB project (Cunningham, 2005). This is known as DBB with CM. During the design phase, they mainly conduct pre-construction services such as constructability reviews, develop cost estimates and direct value engineering. During construction, the primary task is to manage the owner's quality assurance program, which involves a formal commissioning process, as well as supervise the work undertaken by various trade subcontractors.

DESIGN-BUILD

An alternative to the traditional method which has gained popularity in recent decades is design-build (DB), which lets an owner shift a considerable amount of risk, responsibility and control onto a single third-party DB-entity, who oversees design and construction.

CONSTRUCTION MANAGER AT RISK

CMAR is a project delivery method which borrows aspects of the above project delivery methods. Using the CMAR method, an owner contracts with a single construction manager to provide CM agent services during design, and then provide labor, materials and project management during construction as a general contractor would. The CM takes on performance risk by using a guaranteed maximum price (GMP) or cost guarantee for the work to be performed, which is usually defined when the design is 50% – 100% complete. This makes the CM is fully liable for any costs which exceed the GMP. This reduces risk for the owner, but the owner still retains more control over the final outcome than typically expected in DB contracts, particularily regarding quality control.

Overall, a CMAR contract is more focused on the customer, and emphasizes a collaborative process, with pre-qualifications of CMAR firms and very early contractor involvement. This allows projects to be fast tracked and results in higher quality products, with less likelihood of claims and lawsuits which result from other more adversarial project delivery methods. but can also be more costly.The CMAR contract is thus based on a cost plus fee with a cap.

INTEGRATED PROJECT DELIVERY

Integrated Project Delivery (IPD) is a building delivery system that seeks to align interests, objectives and practices through a team-based approach, primarily involving the Architect, key technical consultants as well as a general contractor and key subcontractors. Rather than each participant focusing exclusively on their part of construction without considering the implications on the whole process, all disciplines in an IPD construction project work as one firm, creating faster delivery times, lower costs, higher quality, less litigation and a more enjoyable process for the entire team. This collaborative approach allows informed decision making and better planning early in the project, where the most value can be created, resulting in maximized value for the owner. The close collaboration and data sharing directly between the design and construction team eliminates waste in the design and a large barrier to increased productivity in construction (Eckblad et al. 2007). IPD is also the ideal project delivery method for maximizing the practical applications of BIM, as it allows a multidisciplinary team to work side-by-side to incorporate all the information needed in the BIM model to estimate, schedule, procure and actually build the project in the field

INCENTIVES FOR REDUCING COSTS BY CONTRACT STRUCTURE

Low bid lump sum contracts have the advantage of using competition between bidders to keep construction costs low for the owner. However, this can also result in a "cheaper is better" mentality amongst the general contractors bidding the project so there is the tendency to seek out the lowest cost sub-contractors, which may be a very low cost indeed in difficult markets. This results in increased contractor risk and can compromise the quality of construction, as cheaper materials and subcontractors are selected. In the long run, this can result in costly delays and cost overruns due to legal disputes and rework.

A GMP contract will include the fees related to general conditions of construction, subcontractor costs, a CM's contingency, plus a CM's fee which typically includes a breakeven labor multiple for key project personnel plus a risk premium of 2-4%. The owner usually retains a separate contingency for construction changes that he/she is likely to make.

Data compiled from school projects completed in Florida using different project delivery methods suggests that the low bid approach saves the owner more money over the GMP system in 80% of cases (Strang,2002). In the other 20%, lawsuits and claims resulting from a low-bid environment created cost overruns and loss of the facility for some time. A separate study showed no significant difference in costs to the owner between GMP and traditional lump sum contracts. A case can be made that a CM has less incentive to reduce costs under a GMP contract, as savings are returned to the owner, whereas a general contractor will retain any savings by reducing their final construction costs to under the amount of their original lump sum bid.

2.8 LINKING INNOVATIVE CONSTRUCTION PROCESSES IN PRACTICE

The innovative processes of BIM, lean construction, prefabrication and ADCT are complementary, as they all seek to significantly improve project execution performance through reduced waste, reduction of unnecessary process stages, concurrent design to reduce errors and rework and shortened cycle durations (Eastman, 2011). A number of examples in the above descriptions show how the processes can be linked and combined, often enhancing each other.

A key driver of lean construction is discerning customers and end users who demand highly customized, high quality products. This involves rapid communication with clients and creates incentives for builders to reduce cycle times in order to be able to react to customer needs more quickly (Womack and Jones, 2003). BIM provides a platform for quick communication and allows clients to assess the impact of last minute changes. Sacks et al. (2010) hypothesized that the full potential for improvement of construction projects can only be achieved when BIM and lean construction adoption are integrated, as they are in the IPD approach.

KANBIM™

Sacks (2010) developed the KanBIM™ system, which integrates BIM with *Kanban*, a pull flow control in lean production, related to J-I-T production (Ohno, 1988). This system supports planning and day-to-day control on construction sites by allowing construction managers to visualize the flow of work in a construction project. KanBIM™ extends the LPS by providing the information infrastructure to reduce the granularity of planning coordination from a weekly to a daily plan. It also lets planners clearly visualize where work is ready to start and where constraints exist on BIM model locations. Via-on site electronic monitoring stations and a single shared BIM, subcontractors can coordinate and plan the number of workers required in accordance with the status of activities and avoid the waste of performing work that is not ready or correct. Proper coordination between crews can greatly reduce the waiting (buffer) periods that crews open up between one another reducing the cycle time of each space. This system currently exists only in a prototype and is not available on the open market, but early empirical tests (Sacks et al., 2011) have shown that the system is capable of achieving closer coordination between work teams than is presently possible. This can significantly reduce construction cost and duration.

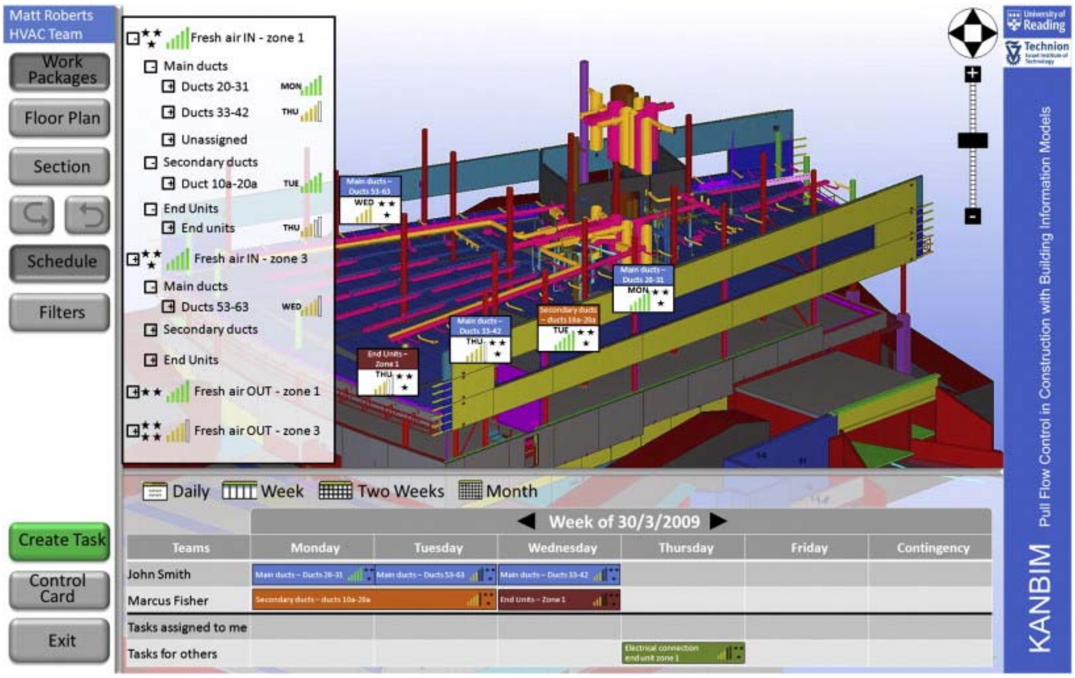


Figure 2.10. User interface for detailing work packages to tasks and compiling the weekly work plan by allocating crews to tasks.

2.9 VELA – THE TOOL UNDER INVESTIGATION

Innovative field data management tools (FDMT) are beginning to bridge the divide between office and site activities by leveraging the advances in mobile devices, wireless connections, software and BIM (Sawyer, 2010). Vela Systems is a software company which has developed a series of FDMTs that allow project information recorded in the field to be automatically uploaded to a central database and communicated with project managers and subcontractors. Quality and safety checklists can be distributed to field personnel via tablet computers and iPads, on which issues can be recorded, and tasks can be assigned to different trades. The data gets stored in a project specific log, and can be compiled automatically into reports. These can be used to analyze delays, RFIs, punch-list items and rework. As Vela is implemented throughout an increasing number of a company's projects, there is a standardization of work-flows over time, as work is done in a more organized, structured and replicable manner, with less variances between operations of project teams. These standard operating procedures (SOPs) also allow information to be easily shared across multiple projects through analytic reporting, which help firms use their data to quantify conformance—how well teams adhere to plans and expectations (Sawyer, 2010). Vela's current set of tools have impacts on the following construction site work processes:

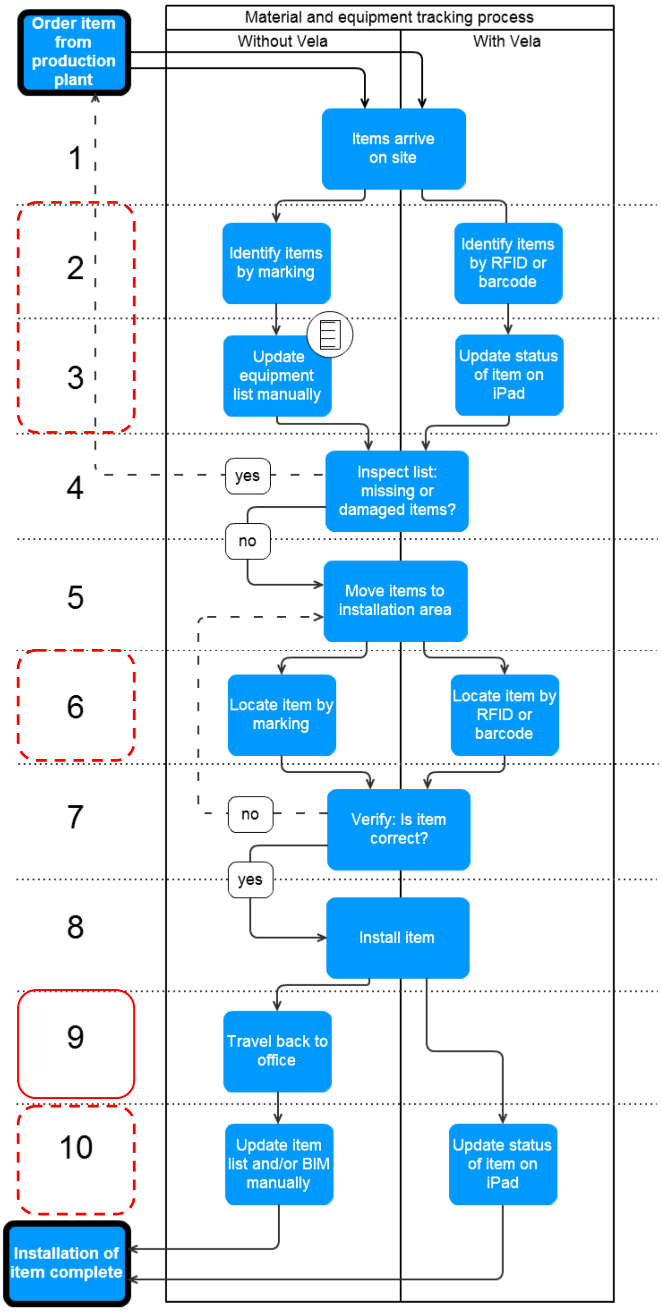
1. Material and equipment tracking
2. Quality and safety checklists
3. Issue notification and tracking
4. Commissioning and owner handover
5. Accessing construction documents

1. Material and equipment Tracking

Vela can be used to track materials and equipment, automating certain tasks in the materials tracking process, thus increasing accuracy, eliminating double work and improving quality. Each piece of equipment or material which is to be tracked can be fitted with a barcode or RFID tag and corresponding equipment list can be imported into Vela. Scanning the tag will bring up the details of the item in Vela, which can then be updated or annotated with remarks. The flow-chart diagram in Figure 2.11 shows a comparison between the existing method and the Vela-enabled RFID method for tracking materials and equipment items.

Tasks 2, 3, 6 and 10 are substantially shortened by using Vela due to near-instant identification and status updating on the iPad. Inspection and verification tasks 4 and 7 will have a higher chance of success since using RFID tags is a more accurate and reliable way of correctly identifying equipment. Task 9 is eliminated altogether, as all updating happens on site. The combined efficiency and accuracy of the Vela and RFID/barcode method result in a shorter process with a higher quality result.

Furthermore, it is possible to link individual equipment and material items from a Vela list back to a BIM model. There, the particular statuses of items can be clearly visualized by using different colors, which results in a 'heat map' of real-time installation progress (see figure 2.12).



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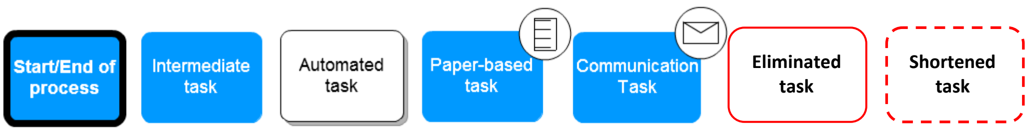


Figure 2.11. Flowchart diagram showing tasks in material tracking process

A number of projects have used the Vela/RFID material tracking method with positive results. A design-build team from Skanska USA Building used electronic identification tags on thousands of pre-cast structural concrete elements while constructing a pro-football stadium to track a just-in-time supply chain, from casting through shipping, delivery and placement (Sawyer, 2008). There was no lay-down yard and only a small holding area for trailers. The 13m by 3m precast elements, weighing an average 20,000 kg, had very limited interchangeability. The information for each component was linked back to a, color-coded, 4D BIM that let the team visualize the status of the 3,200 elements as they were manufactured and assembled to form the bowl of the stadium (figure 2.12). This let them make sure that pieces were produced in the correct construction sequence, which tends to be a problem with pre-casting yards, as they prefer to produce all particular pieces when the specific formwork for each piece is set up.

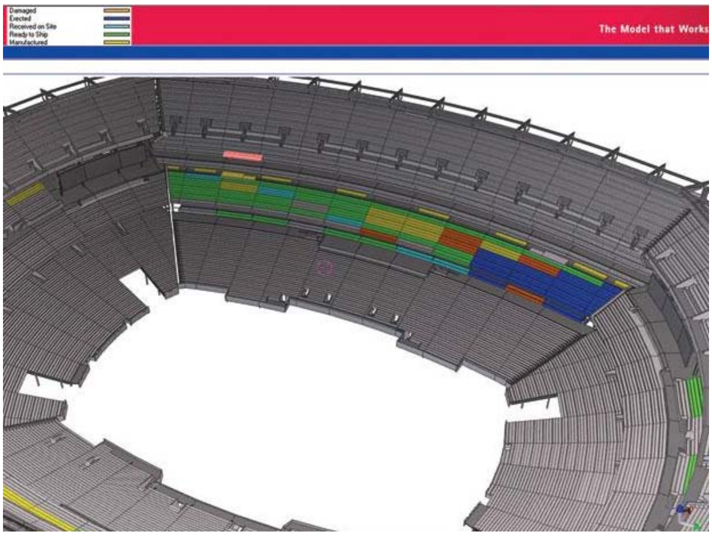


Figure 2.12: Color coding pre-cast items by status to track materials visually

Vela supplied hardware and software for capturing RFID registration tag numbers on individual pieces as they moved from casting to assembly. Vela handled the process by associating metadata with the number on each piece. Each piece could then be identified and its status updated, from ready-to-ship, to shipped, delivered and erected. As the status of each part was updated, the color of the part changed in the Tekla Structures model. Site personnel could add notes about issues affecting individual parts, such as the presence of blemishes, defects or damage. They could also attach sketches, photos and handwritten notes.

Vela's ability to synchronize field data with BIMs has also proved useful in commissioning and handover of building systems in the final close out stage of a project. Mobile technologies can be used to record accurate data in the field which can then be used to set up a facilities management process.

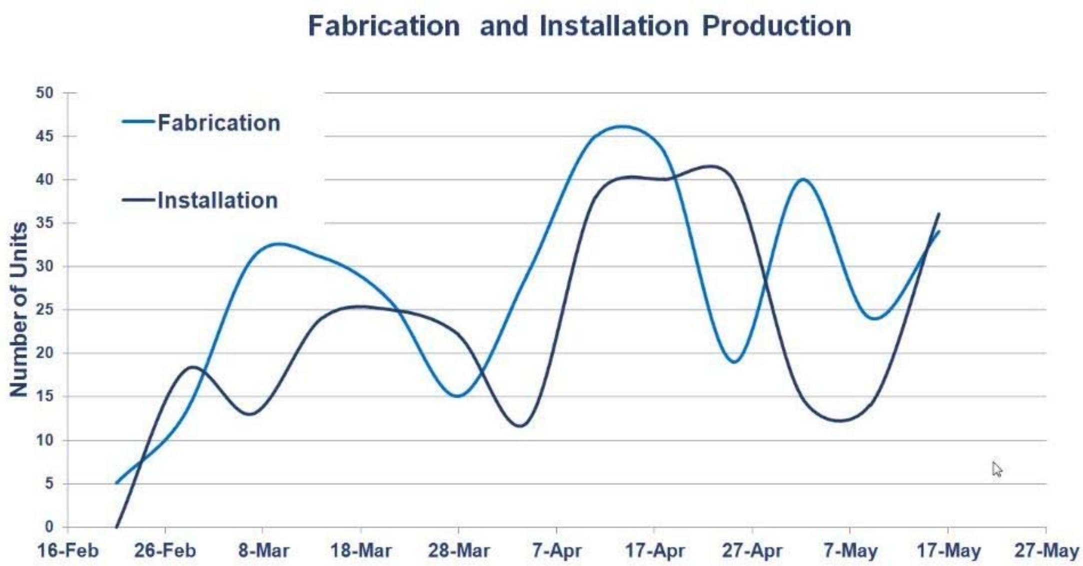


Figure 2.13: Curtain wall unites fabricated and installed over time.

Furthermore, it is possible to keep records of changes in material statuses, copy them into a spreadsheet and create analytic graphs. Figure 2.13 shows how construction managers on the NCSU Hunt Library project were able to plot the fabrication and installation rates of particular pieces of a facade, in order to determine what realistic rates of installation might be at short notice, based on actual fabrication rates.

2. Standardizing QA/QC and safety checklists

Checklists for quality and safety inspections can be created in Vela and saved in a common library, from which they can then be accessed by construction managers, distributed to the assigned users, and filled out on iPads at the location in question. As checklists are completed on site, any non-affirmative answer will automatically prompt an issue to be created (see figure 2.14), which can then be filled out with details and aggregated into a central master list of project issues.

The standardization and easy accessibility of checklists saves time and reduces the possibility that a requirement will be overlooked during an inspection. A record is also made of inspections as they occur, so that it is possible to verify that they are occurring at the right frequency. This enables a pro-active quality management program (Heinloth, 2000).

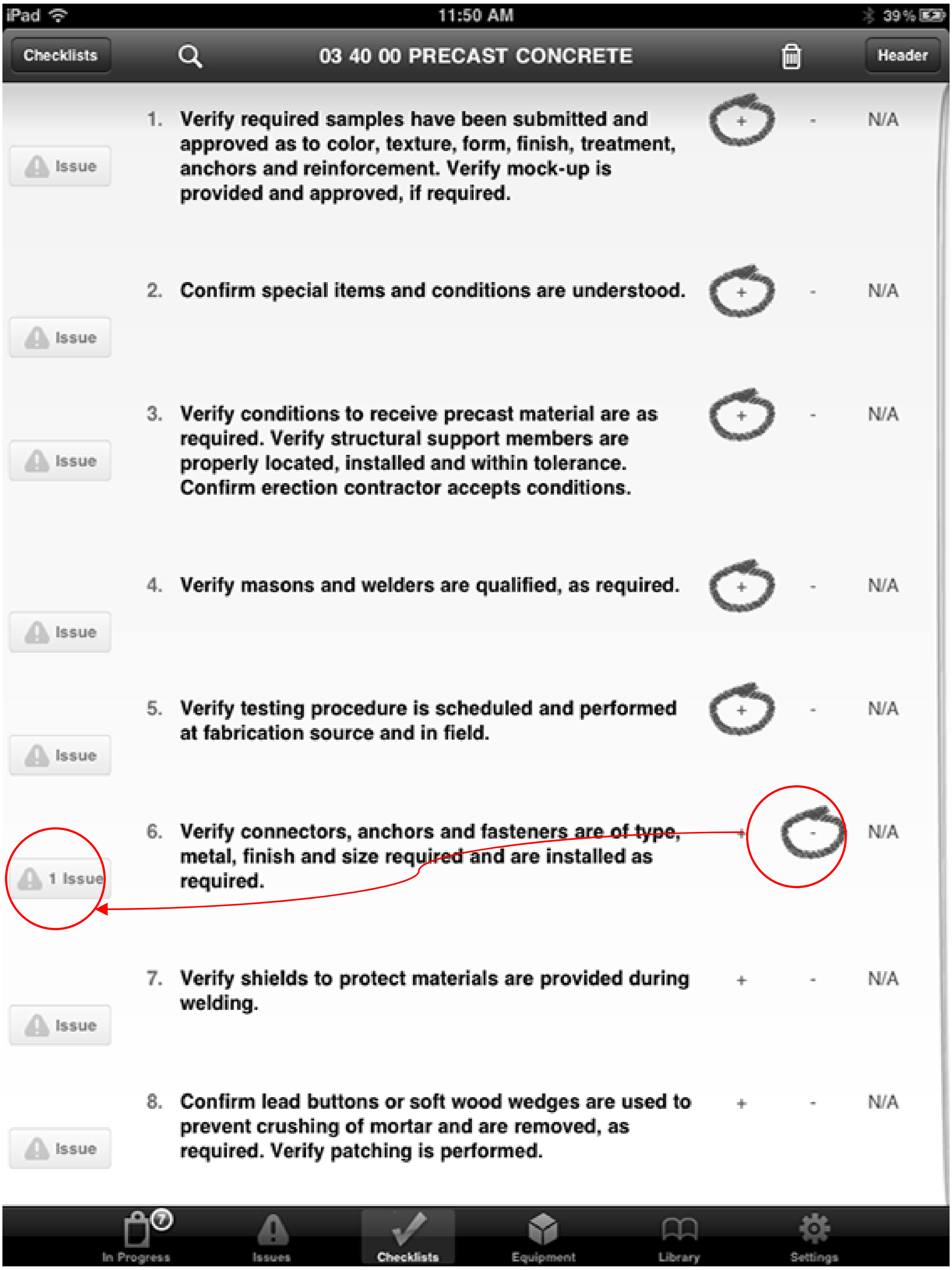


Figure 2.14: Standard Vela QA/QC checklist, with instant issue notification creation

3. Issue notification and tracking

When an issue is identified in the field, Vela users can add it to an existing database of issues stored on the project server. The process of notifying a the party responsible for the issue is illustrated in figure 2.15, and compared to the pre-Vela base case to illustrate how several tasks are shortened, automated or eliminated altogether, saving substantial amounts of time in the process. Step 1 is now standardized, as users simply press: **create new issue** to bring up an issue template. If a photo is attached in step 2, it can be directly marked up and annotated on the iPad. Steps 3 and 4 in the base case are eliminated altogether using Vela, as users no longer have to return to the office and create spreadsheets to record issues on the central project server. Step 7 is also standardized, as users can now drop electronic pushpins onto digital plans to indicate the exact location of an issue to any viewer of the plans. Vela then sends regular automatic notifications to subcontractors, notifying them of their new and outstanding issues, thus removing the need for steps 8, 9 and 10.

Once an issue is communicated to a subcontractor, it must then be resolved (see figure 2.16). Vela also considerably reduces the tasks involved in the process of identifying issues and communicating their resolution back to the general contractor or inspector. With Vela, subcontractors with iPads can view their own issues, and each item with an associated pushpin on digital drawings can be clearly located as shown in task 1. Once the appropriate action has been taken and the issue resolved, the responsible subcontractor can simply change the status of the issue in Vela, for instance, from 'open' to 'ready for inspection', thus eliminating tasks 3 and 5 and automating task 4.

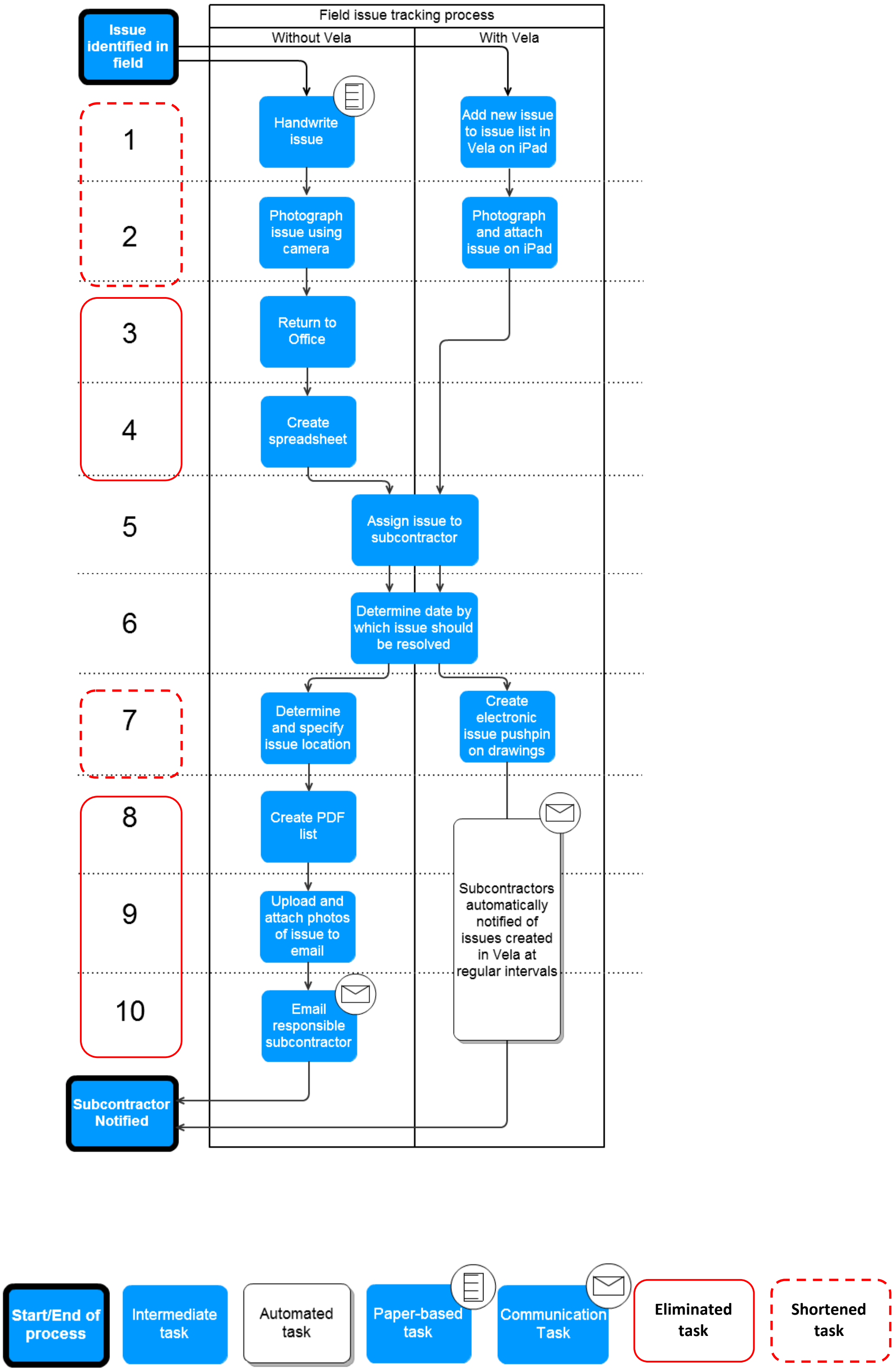
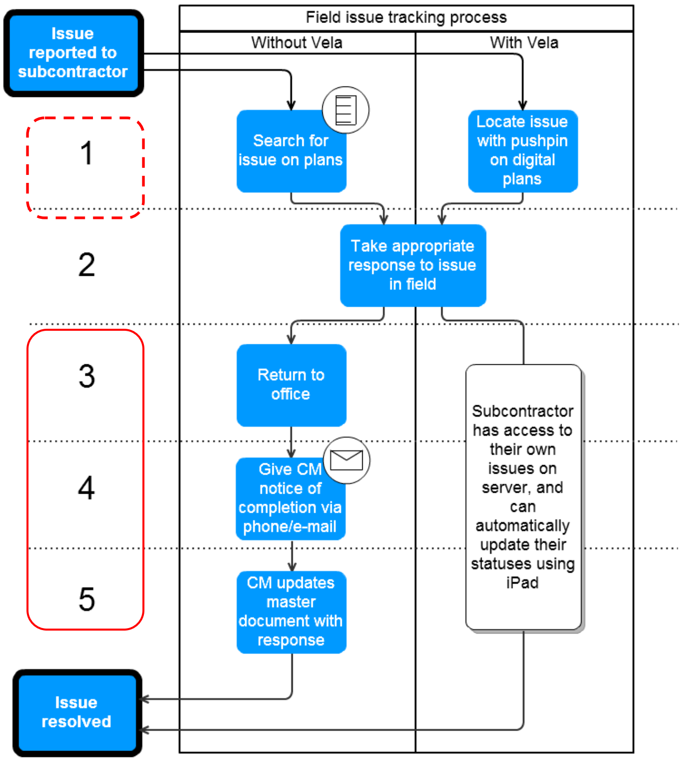


Figure 2.15: Flowchart diagram showing process of notifying subcontractors of issues



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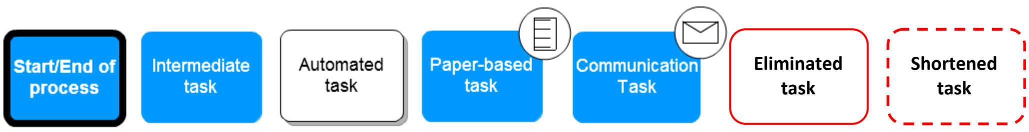


Figure 2.16: Flowchart diagram showing tasks in process of communicating responses to issues

In addition to saving time, the Vela method of logging issues and saving them on a central server makes it considerably more difficult for issues to be ignored reducing the chances of them going unresolved. In the event of a dispute or claim, the electronic data trail created by logging issues in Vela provides an unbiased and transparent look at how an issue was communicated and then dealt with. Furthermore, an important quality benefit is that quicker communication of issues between teams may prevent some items from being installed which would have needed to be removed later, to resolve an issue which was reported too late.

Finally, because issues are logged, analytic data can be viewed for a variety of matters regarding quality issues, such as which subcontractor has the most outstanding, the rate of resolving issues, etc. This can be used to compensate or penalize parties based on their performance, and incentivize quicker responses to issues. Data from multiple projects can also be compared by executives for cross-project performance reviews.

4. Commissioning and owner handover

A recently introduced tool also lets project teams bring BIM visuals and data to the field. The Field BIM-Data product enables users to manipulate BIM objects (e.g., equipment) and their attributes (e.g., name, type, manufacturer) in specific Vela workflows. Data about equipment items is passed from the model to Vela, then back again, adding new attributes to the BIM that are dynamically updated as work and operations progress. End users do not need to see the BIM while in the field - the data are linked to the workflow or equipment list.

One general contractor created a BIM in order to carry out clash detection amongst various subcontractors' systems on the Maryland General Hospital project (Eastman, 2011). Since this model already contained accurate information about MEP systems, it could subsequently be synchronized at the end of the construction process with the field data captured using Vela. All elements in the MEP model were assigned barcode numbers, allowing information pertaining to individual MEP parts to be linked back to the BIM database, similar to the materials tracking process described above. Vela supported the project closeout by collecting information describing equipment locations, statuses, attributes, manufacturer data, warranty information, service information and startup data. Field data could be gathered offline and synched with the database when mobile devices were back in the site office. This helped track commissioning through automatically created 'heat maps' of equipment statuses: onsite, performance testing, startup and client acceptance.

The data logged during this process enabled the creation of a computer maintenance management system (CMMS). This can be used to monitor safety, coordinate inspections, gauge performance and schedule replacement of parts. It compiles vendor work orders and produces automatic reports, and is an advanced tool for building maintenance.

These new process and capabilities around a BIM core has significant advantages over traditional methods of handover and facilities management. Firstly, it automatically creates single, accurate, documentation database in which as-built data is stored and which can be visualized clearly. This includes easy to access warranty and product information for individual pieces of equipment, and automatic scheduling of maintenance and replacement of parts. Secondly, since the data only has to be recorded one time and was stored in a single location, the process saves time and eliminates duplicate efforts associated with paper-based manual retrieval of building information such as searching folders. The client estimated that the system cost of $31,600 (including software licenses, setup and training) would pay for itself through increased savings after only 2-3 months.

5. Access to full digital library of up to date documents

Vela Systems has a document library module which can automatically deliver the most up-to date project documents, documents, plans, RFIs and specifications to all users, including field superintendents, project managers, safety managers, and subcontractors. most up-to-date in Vela Mobile, and can view and annotate them onsite using tablets or iPads. This saves time by reducing trips back to the job trailer to get correct or updated information, and lets teams make better decisions in the field by accessing the latest plans and specifications. An interactive BIM visualization interface also allows a user to put themselves "inside" the model while in the field. Viewpoints are transferred from the model file into Field BIM-Interactive so that users can quickly navigate to a specific location and view actual installations compared to virtual models.

PREVIOUS STUDIES OF VELA BENEFITS

A rigorous assessment of the use of innovative technologies, including BIM, Mobile electronic resource stations and Vela on North Carolina State University's Hunt Library project was carried out by Vaughan (2011). Construction management staff were found to be 8-10% more efficient while using Vela compared to pre-Vela levels, resulting in a reduction in rework which yielded an ROI of 69% on the original investment costs of using Vela.

Through a number of interviews and discussions with construction management staff using Vela on the project, the following qualitative benefits were established in four categories:

1. 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

2. Operations

- 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 generates automated reports for distribution with photos and comments attached
- Creates a clear audit trail for risk mitigation

3. Administration

- 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

4. Quality

- QA/QC checklist 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 through root cause analysis, performance metrics, etc
- Streamlined integration of photo and plan sheet attachments to issues for documentation
- Ability to document construction issues in the field eliminates unnecessary future rework

The increased speed due to communication, operation and administrative benefits and increased conformance due to quality benefits both contribute to an improvement in process efficiency, which was defined in section 2.1 as the amount of value-adding work processes correctly performed over a certain time period (Helms, 2006).

Vela was also found by Vaughan (2011) to address four of the five areas in which root-causes of rework were found to occur by Fayek et al. (2003) (see figure 2.5):

1. Human Resource capability

- Gives more clear instructions to workers by providing subcontractors automatically generated email notifications of issues.
- Improves supervision and job planning by reducing total hours spent on non-value adding tasks
- Reduces overtime

2. Engineering and Reviews

- Improves document control by leveraging instantaneous online information transfer

- Reduces errors and ommissions

3. Material & Equipment Supply

- Easier to find correct materials and equipment due to tracking features combined with bluetooth barcode scanners and RFID readers

4. Leadership & Communications

- More effective management of Project Team
- Imrpoves communication through analytic reporting
- Better Safety and QA/QC commitment

To measure time savings and efficiency gains, Vaughan identified 25 typical management tasks on a construction site, which fit into 4 basic categories. These task divisions were established through interviews with project managers, project engineers and superintendents, with a total of 69 years experience. The cateogries they fit into are:

- **Planning** - reviewing and confirming plans, specifications, schedules, and trade and supplier coordination and communication prior to the actual start of an activity.
- **Assessment** - gathering, organizing, and evaluating appropriate project data in order to make informed decisions about the construction process.
- **Reaction -** time spent addressing issues which have arisen in the field due to inaccurate or incomplete planning or assessment.

- **Administrative** - necessary for communication and the transfer of information and ideas.

Vela users were then surveyed to measure how durations changed as a result of using Vela, compared to a pre-Vela baseline.

One of the study's major findings was that using Vela could reduce non-value-adding hours, and that time spent reacting to field issues could be spent instead on value-adding assessment of work and planning for future work which would focus on addressing root causes of rework. This has important potential implications for Lean Construction, as construction managers can allocate more or their available time to careful planning.

2.10 SUMMARY AND IMPLICATIONS OF LITERATURE STUDY

BIM, ADCT, prefabrication and the lean construction approach are all commonly used on construction projects and can all be considered types of business process reengineering (see introduction), as they fundamentally improve the efficiencies of workflows and processes. FDMT can thus also be considered a business process redesign, as it links and enables these tools and approaches while creating its own efficiency improvements, and allows construction managers to fundamentally rethink how they track and compile information on-site.

The adoption of a field data management approach can be characterized as a computerization process – as it transfers the control of certain processes from a manual, human based procedure to an automated method. However, FDMTs require requires three primary components:

technology, people (individuals, groups, or organizations), and data/information for decision making. As such, this approach can be understood as a type of management information systems (MIS), in that it is used to analyze and facilitate strategic and operational activities in an organization. The regular scheduling of reports based on data extracted and summarized from the underlying issue and equipment tracking activities can be communicated to middle and operational level managers to identify and inform structured and semi-structured decision problems.

Differing rates of adoption of FDMT functionality subsets by construction service providers may be influenced by the dichotomous phenomena of technology push and demand pull. A technology push implies that a new invention is *pushed* through research and development, production and sales functions onto the market without proper consideration of whether or not it satisfies a user need. Users then may implement the innovation in unexpected ways. In contrast, an innovation based upon demand pull has been developed by the R&D function in response to a clearly identified market need (Martin, 1994). Some examples of this phenomenon are explored in section 2.5.4, on BIM implementation issues.

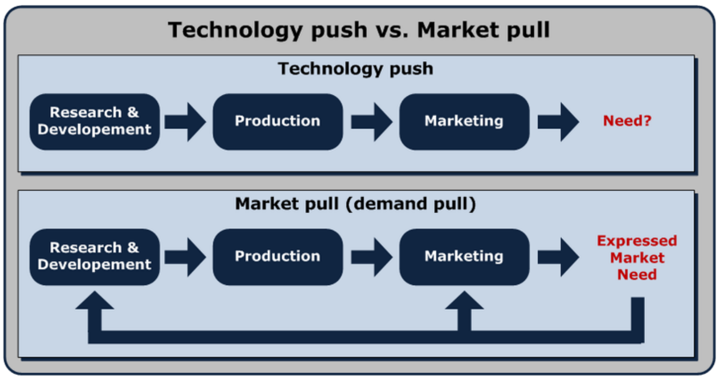


Figure 2.17 Technology push vs demand pull

3. RESEARCH

In light of the information gathered by the literature study on (1) inefficiency and quality problems in construction, (2) the benefits and implementation difficulties of BIM, FDMT, lean construction and prefabrication, and (3) the previous study devoted to measuring hours saved and efficiency gains achieved through using Vela applications, it is now possible to formulate a new research problem, to fill a gap in the relatively recently developed knowledge of FDMT. This study will quantitatively evaluate the time savings and efficiency gains which are attributable to using Vela on 15 of Skanska's projects, collecting data by means of a survey distributed to Vela users. Using efficiency gains as a metric for comparing projects, it determines the extent to which various factors influence the varying increases in efficiency across projects, with the intention of establishing best practices for implementation of FDMTs, and highlighting implementation issues.

3.1 METHODOLOGY

RESEARCH QUESTION

The quantitative research undertaken for this report has the goal of answering the following question: **To what extent do various factors influence the amount of efficiency gains which can be achieved through using Vela applications?**

POPULATION SAMPLE

This research will be carried out on a sample population consisting of Vela users employed by Skanska, a multinational construction service provider, with several thousand continuing projects around the world. It was ranked as the 7th largest contractor in the US in 2012 (ENR, 2012).

At the time of writing (Spring 2012), Skanska have used Vela on approximately 80 building projects in the USA and a few in Scandinavia. This research looks at 15 of their projects, which constitutes somewhere between 15-20% of the total amount of projects on which Vela is being used. The projects were selected by Skanska's director of project controls as a representative sample of projects which demonstrate the diversity of jobs on which Vela applications are currently in use. These projects have a total value of US $1,260 million, with an average contract value of $88 million, ranging from $15 million for the Southern Crescent Technical College to $250 million for the Nemours Children's Hospital Project. The full list of projects is:

1. Bassangkajen project, Sweden
2. CCHS Wilmington Hospital expansion, Delaware
3. George C Young Federal Building, Florida
4. GRU East Operations Center, Florida

5. Merck Lab, New Jersey
6. NCSU Hunt Library, North Carolina
7. Nemours Children's Hospital, Florida
8. NOAA Office and Lab, Maryland
9. Notre Dame Stayer Center, Indiana
10. PPL Data Center, Pennsylvania
11. Southern Crescent Technical College, Georgia
12. St. Francis Hospital, Georgia
13. University of Delaware, Delaware
14. Virginia Tech Academic and Student Affairs Building, Virginia
15. Westin Hotel, Georgia

In total, 38 of Skanska's Vela users from these projects were surveyed. Additionally, 30 non-Skanska Vela users from the projects were polled about their perceptions of Vela's benefits. The respondents had a total of 388 years combined experience in the construction sector and 177 years of experience using project management software, with a mean of 12,9 years construction experience and 5,9 project management software experience per respondent. In total, 16 project engineers, 10 project managers and 10 superintendents participated. It should be possible to generalize the results obtained to the total population of Skanska's Vela users.

Because this research is being done within the widely varied environment of real-world projects, it is difficult to control a number of possible confounding variables when measuring the effect of various factors on efficiency gains. By investigating projects from a single company, it will eliminate some external sources of variation, as there are standard corporate operating procedures which apply to all projects, such as quality programs and the overall corporate culture.

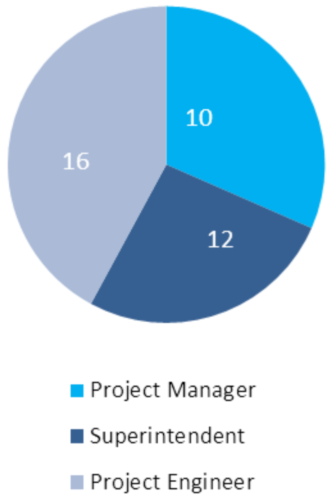


Figure 3.1 Breakdown of respondents

Finally, most of the work processes which are affected by FDMTs are not particular to Skanska, meaning that the findings and implications of this quantitative research can be related to the operations of any construction service providers who want to improve their management of field data. This gives the research a high degree of external validity, because the results of a study can be generalized to other situations and to other companies.

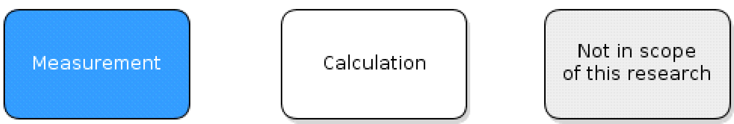
MEASURING VARIABLES AND CALCULATING EFFICIENCY GAINS

The research undertaken for this study fulfils steps 1-3 out of the 6 step comprehensive ROI assessment framework for Skanska and other companies to assess the benefits of Vela and other FDMTs (figure 3.2, overleaf). Because only 3 of the 15 projects under investigation have actually been completed, it is not possible to accurately measure quality improvements and contingency budget savings which may be attributable to using Vela for quality management, as the final cost of rework is not yet known for most projects. However, it is possible to accurately quantify hours saved and efficiency gains, and compare projects using these metrics. See section 4.1 for a detailed discussion of steps 4 - 6 of the ROI assessment framework. Steps 1 – 3 are explained in detail below:

Step 1: Measure influencing factors – independent variables

In order to assess the extent to which various factors affect efficiency gains on projects, it is important to first identify independent variables which could have an influence on performance. A number of potential influencing factors have been identified through interviews with Skanska's Vela users and interviews with Vela Systems' staff, who devote considerable time to determining potential implementation problems and best practices.

To then quantitatively measure these factors on the 15 projects, it is important to operationalize them. This means defining fuzzy terms in a clear way, and creating an experimental design which will allow specific observations of measureable variables, so that they can be tested, compared and replicated. For example, to assess involvement of subcontractors with Vela, participants in the survey were asked to rank the general involvement as well as the rate of response to issues created in Vela on a scale of 1-5.



Key to figure 3.2

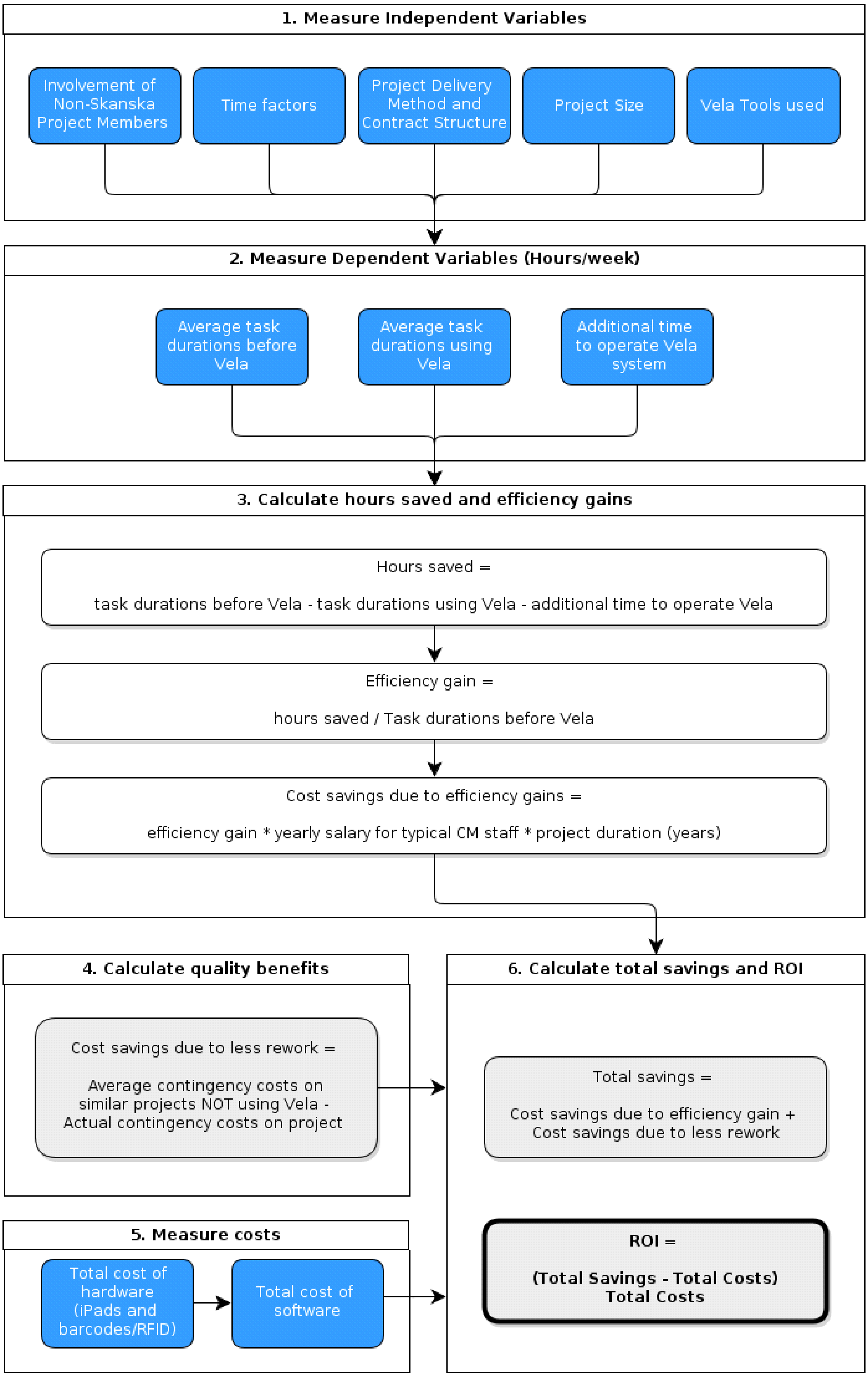

1. Measure Independent Variables
Involvement of Non-Skanska Project Members
Time factors
Project Delivery Method and Contract Structure
Project Size
Vela Tools used
2. Measure Dependent Variables (Hours/week)
Average task durations before Vela
Average task durations using Vela
Additional time to operate Vela system
3. Calculate hours saved and efficiency gains
Hours saved =
task durations before Vela - task durations using Vela - additional time to operate Vela
Efficiency gain =
hours saved / Task durations before Vela
Cost savings due to efficiency gains =
efficiency gain * yearly salary for typical CM staff * project duration (years)
4. Calculate quality benefits
Cost savings due to less rework =
Average contingency costs on similar projects NOT using Vela - Actual contingency costs on project
5. Measure costs
Total cost of hardware (iPads and barcodes/RFID)
Total cost of software
6. Calculate total savings and ROI
Total savings =
Cost savings due to efficiency gain + Cost savings due to less rework
ROI =
(Total Savings - Total Costs)
Total Costs

Figure 3.2 Six-step framework model for determining ROI of FDMT

The following is a full list of potential influencing factors established through interviews, which includes subfactors and the units in which the factors will be measured:

- **Involvement of non-Skanska project team members with Vela Applications (1-5 likert scale, 1 - not involved at all, 5 – very significant involvement):**
    - Subcontractors
    - Architects/Engineers
    - Comissioning Agents
    - 3rd Party inspectors
    - Client/Owner
- **Time factors:**
    - Learning over time (# of previous projects on which Vela admins had used Vela)
    - Depth of knowledge of Vela - is Vela admin on special Vela training team? (yes/no)
    - Stage in project at which Vela was introduced (# of project months elapsed when introduced/total project months*100%)
    - Time using Vela on a particular project (# of months)
- **Project Delivery Method (eg. DB, CMAR)**
- **Contract Structure (eg. Fixed price lump sum or cost plus)**
- **Project size (Millions of US $)**
- **Vela tools used (yes/no):**
    - Quality tracking
    - Safety tracking
    - Worklist

- Punchlist
- Equipment Comissioning
- Equipment Tracking
- Field BIM
- Owner Handover

Step 2: Measuring average weekly task durations with and without Vela - dependent variables

The dependent variables for this study are the average weekly task durations with and without Vela. It is possible to create a baseline against which to measure time savings by asking surveyed Vela users to estimate weekly task durations (in hours), and then getting estimates for durations of the same tasks while using Vela.

Breaking the total sum of weekly activities down into 16 typical tasks in four general categories makes it easier for a user to accurately quantify the number of hours devoted to particular tasks. The list of activities in figure 3.3 is partly based on Vaughan's (2011) list of 25 tasks in four categories, but was further refined and consolidated through discussions with Will Senner from the NCSU Hunt Library Project, to remove certain redundant items Breaking activities down this way also makes it possible to see the extent to which the durations of various tasks are affected by using Vela functionality tools.

Category	#	Task Description
Planning	1	Coordinate with subcontractors for the next weeks' activities
	2	Contact suppliers to verify quantities and delivery dates over next weeks
	3	Determine what productivity for following week must be to stay on schedule
	4	Review Plans/Specs/Shop Drawings/Submittals
	5	CM Team Meeting
	6	Owner/Architect Meeting
	7	Plan for next week's construction/installation
Assessment	8	Go to field to monitor productivity/quality of installation/construction
	9	Quantify productivity of past week/month
	10	Walking with Owner/Commissioning Agent
Reaction	11	Document/Photograph unresolved issues and their location and create notification
	12	Follow up statuses of past week's issues
	13	Conduct Meetings with Sub and A/E on rolling punch list issues
	14	Email/Phone other trades about coordination issues/construction sequence
Administrative	15	Process pay Applications
	16	Update information in the BIM to serve as electronic deliverable to Owner
	17	Vela-related tasks (set-up, uploading docs, hyperlinking RFI's, training users, etc.)

Figure 3.3 Breakdown of typical weekly construction management activities

The 17th task, 'Vela related tasks', is classified under the 'administrative' category and includes activities needed to keep the Vela infrastructure running smoothly, such as initial set up of the system, uploading documents, training new users, creating electronic RFI mark-ups and hyperlinking RFIs on electronic plan sheets.

Step 3: Calculating weekly hours saved and efficiency gains

Subtracting Vela task durations from the baseline will give a weekly time saving result in hours. The main metric by which project performance is measured, and the main benefit which this study aims to quantify are **efficiency gains**. These will be measured by dividing hours saved due to using Vela by weekly hours devoted to the same amount of work before using Vela. The average of users' efficiency gains on a particular project is calculated and assigned to that project as its performance score, which allows it to be compared to other projects.

Although the actual translation of efficiency gains into monetary savings on an individual project basis goes beyond the scope and aim of this study, it is nevertheless possible to calculate savings through efficiency gains due to Vela. Assuming that a reduction in the total hours needed to complete a certain set of tasks translates to less labor requirements, a simple approach to calculate savings is to find the sum of all weekly efficiency gains per user on a project, multiply this by the average yearly wage plus labor burden (healthcare, disability, pension, bonuses and other benefits) of a typical full-time construction manager and multiply this by the duration of Vela use on a project in years. According to Vaughan (2011) the total cost of a CM on a job is approximately \$120,000/year (\$90,000 + \$30,000) on the east coast of the United States.

As an example calculation, the savings due to four CMs using Vela who have an average efficiency gain of 12% for a year and a half on a project, are:

$$\mathbf{4 * 1.5 * 12\% * \$120{,}000 = \$86{,}400}$$

It is important to note that not all these savings are necessarily returned to Skanska. The projects investigated used four different types of project delivery methods with either guaranteed maximum price or fixed price contracts. There are also variations between the same types of contract structure between American states (Tulacz, 2012), not to mention accross borders, as in the case of the Bassangkajen project in Sweden. Therefore, it is not possible to establish a standard way of calculating how much of total savings due to added efficiency are distributed back to Skanska and how much go back to the client or various subcontractors, as renumeration and compensation schemes vary between projects. In addition, it was established through interviews with Vela administrators on some projects that hours saved may not actually translate into less time worked, but may rather be redistributed to other tasks, such as planning of work in the coming weeks.

Project savings due to efficiency gains can form part of a broader ROI calculation, in steps 4-6. See *ROI Assessment Framework* in the section XX (*Recommendations*) for a detailed discussion about the steps beyond the scope of the research undertaken for this study.

One of the fundamental principles of lean construction is the idea that rework can be avoided and waste can be reduced through devoting more time to careful planning and quality management. A significant finding of Vaughan's (2011) study found that using Vela enabled some hours previously spent dealing with quality issues to instead be devoted value-adding assessment of work, and planning for future work which would focus on addressing root causes of rework. A series of interviews and a careful examination of the project performance records of several completed

Skanska projects of similar size and complexity (approximately $100m contract value), determined that an additional 50 hours a week of planning and supervision corresponded to a 33% reduction in the average cost of rework due to managerial and document control errors (Vaughan, 2011), as is shown in figure 11.2.

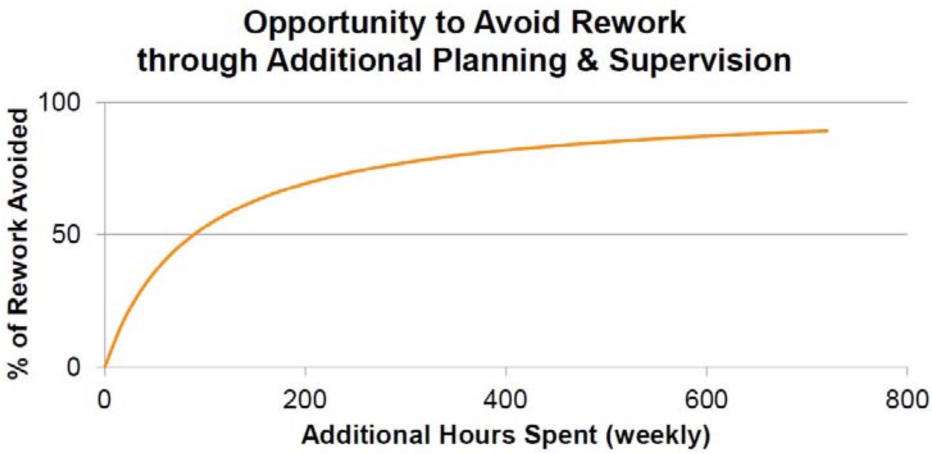


Figure 3.4. Relationship between extra CM planning and supervision and avoided rework

HYPOTHESES

This study tests the following nine hypotheses:

H1. Vela users will save a significant amount of hours performing their weekly tasks.

H2. Vela users will have varying degrees of efficiency gains based on job description. This is because project managers, project engineers and superintendents spend different amounts of time on various tasks, whose durations are affected to varying degrees by the implementation of Vela.

H3. More involvement of other non-Skanska project team members with Vela will result in higher efficiency gains. Since FDMTs essentially store data and communicate it to other project team members a higher level of involvement from non-Skanska project team members will increase its benefits.

H4. Projects whose Vela administrators have previous Vela experience will have higher efficiency gains, due to learning over time and establishment of best practices or how to overcome key implementation difficulties.

H5. Projects with special Vela trainers will have higher efficiency gains, because these trainers have a deeper understanding of successful implementation techniques and special incentives to implement Vela as effectively as possible.

H6. Earlier project implementation will result in higher efficiency gains, as the procedure of effectively using Vela will be more ingrained in the style of working of the construction managers.

H7. Using more functionality tools will result in higher efficiency gains, because more activities will be done using Vela, decreasing more tasks durations.

H8. The project contract structure will affect efficiency gains, due to different incentives for Skanska to save labor hours.

H9. Procurement type will affect efficiency gains, due to different levels of cooperation and coordination between Skanska, subcontractors, owners, designers and other project members.

H10. Project size will affect efficiency gains, due to economies of scale.

3.2 RESULTS AND HYPOTHESIS TESTING

3.2.1 WEEKLY HOURS SAVED

The raw-data metric by which project performance can be compared is the average number of hours saved per project, per week by Skanska's construction management staff using Vela. This was calculated by finding the average difference between the total time spent on management tasks before using Vela and after using Vela. Average weekly time per user spent updating the Vela database with new information, drawings, documents, RFIDs was added to total weekly hours, as well as the time needed to train new users every week was added to the total time spent using Vela (task 17). These additional tasks account for the increase in total administrative time seen on nearly every project, and explains why two projects (St. Francis Hospital Southern Crescent Technical College) saw their weekly hours increase, because they spend more time on these new Vela-related tasks than they save through using the system. However, it should be noted that this does **not** mean that they are not getting any benefits through using Vela. Important quality benefits can still be realised through creating accurate issue databases, and may result in lower rework costs and less contingency budget spending. However, these can only be accurately quantified once projects are completed, so have not been included here.

The table overleaf shows the average of the weekly hour changes, broken down per task, for the 38 Skanska construction management staff who filled out surveys. On average, Skanska's Vela users are saving 9,1 hours per week. The largest amount of hours saved are in reaction tasks, which is expected, as these involve documenting, reporting and following up the statuses of construction issues. This amounts to a 34% total reduction in time spent on reaction tasks.

Category	#	Task	Previous Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change
Planning	1	Coordinate w/ subcontractors for upcoming activities	6,4	5,2	-1,2
	2	Contact suppliers to verify quantities and delivery	2,9	2,7	-0,2
	3	Determine productivity to stay on schedule	3,9	3,6	-0,3
	4	Review Plans/Specs/Shop Drawings/Submittals	6,5	5,8	-0,7
	5	CM Team Meeting	2,4	2,0	-0,4
	6	Owner/Architect Meeting	1,6	1,4	-0,2
	7	Plan for next week's construction/installation	3,5	3,4	-0,1
Subtotal			***27,3***	***24,2***	***-3,1***
Assessment	8	Go to field to monitor productivity/quality	7,0	5,8	-1,2
	9	Quantify productivity of past week/month	2,5	1,9	-0,6
	10	Walking with Owner/Commissioning Agent	2,2	1,5	-0,7
Subtotal			***11,7***	***9,2***	***-2,5***
Reaction	11	Document/Photograph unresolved issues	4,5	2,7	-1,8
	12	Follow up statuses of past week's issues	3,5	2,2	-1,3
	13	Conduct Meetings with Sub and A/E on punch list	4,1	2,9	-1,2
	14	Email/Phone other trades about coordination	2,3	*1,6*	-0,7
Subtotal			***14,3***	***9,3***	***-5,0***
Administrative	15	Process pay Applications	1,6	1,3	-0,3
	16	Update information in the BIM	1,3	0,9	-0,4
	17	Vela-related tasks	0,0	2,6	+2,6
Subtotal			***2,9***	***4,6***	***+1,7***
Total			**56,1**	**47,0**	**-9,1**

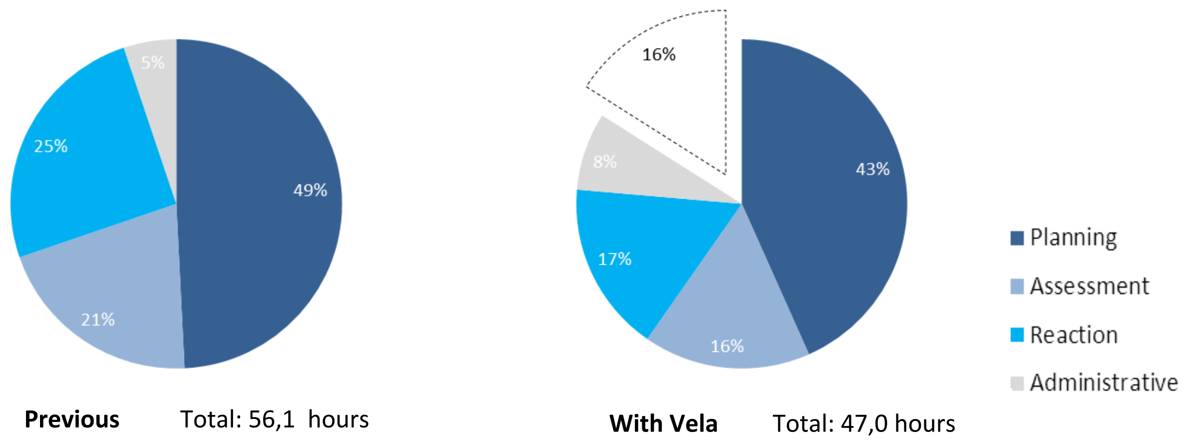


Figure 3.5. Changes in weekly time spent on typical management tasks

The distribution of the 38 individual results *does not follow a normal distribution*. Rather, it follows a Gumbel or Extreme Value Type 1 distribution for the maximum case, which has as its characteristics a bound on the minimum side and a long tail on the positive side (see appendix A for goodness of fit tests). This has two implications:

1. Statistical hypothesis tests such as t-tests, z-tests and ANOVA will not be valid for the data collected for individual Vela users, as they are only applicable normally distributed data.

2. The 'average' users save somewhere around 5 hours using Vela, while 'advanced' users are able to save substantially more time, bringing up the average hours saved and efficiency gains.

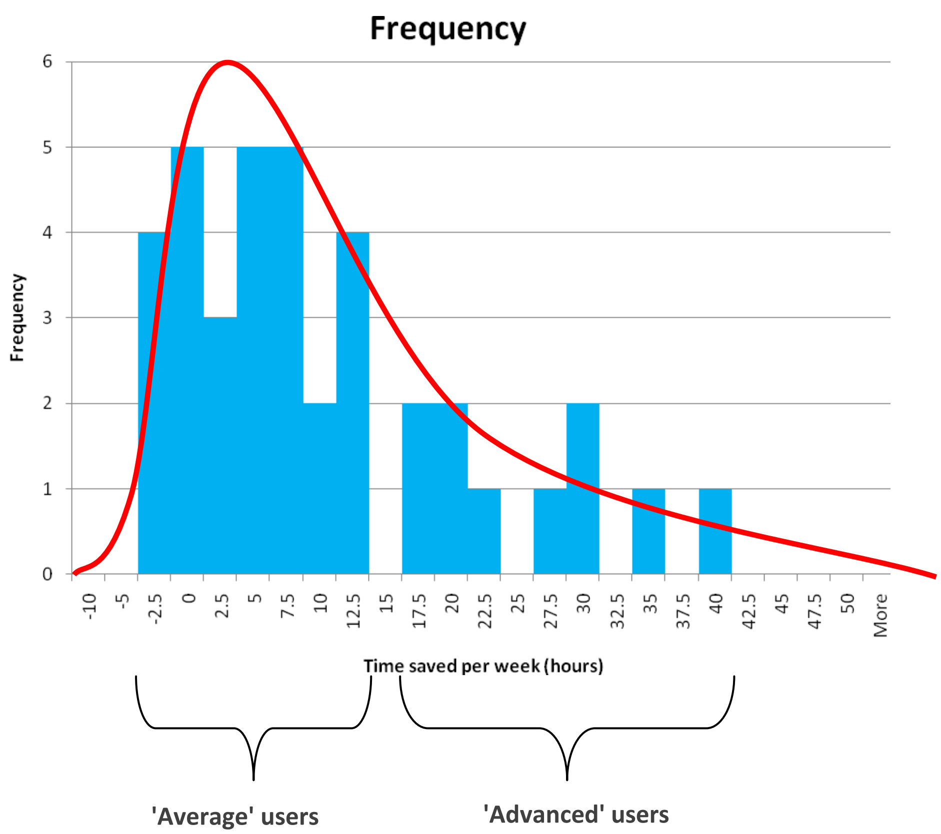


Figure 3.6. Histogram of hours saved per user with Gumbel distribution plotted over it

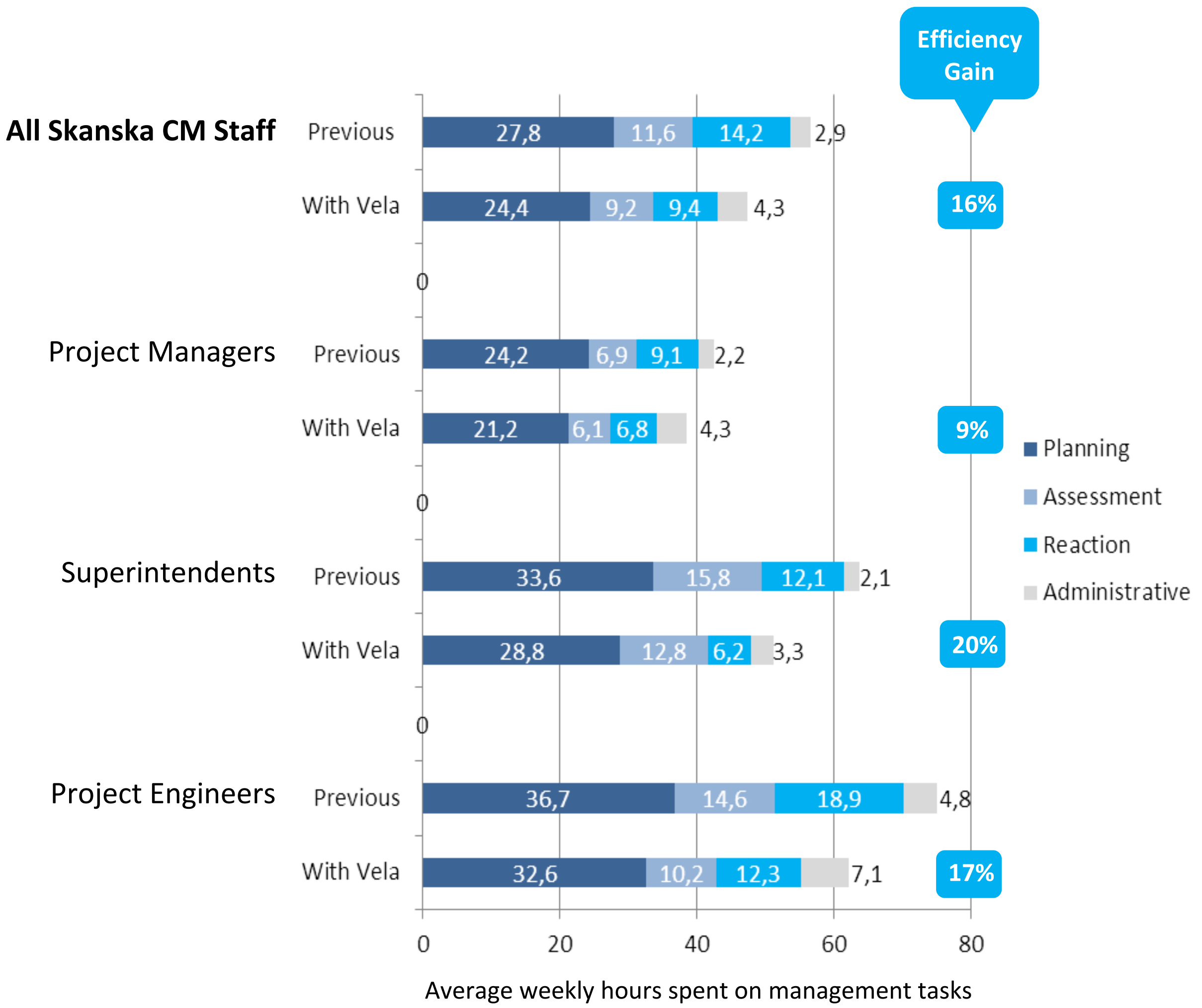


Figure 3.7. Breakdown of time savings by project role and task category

As can be seen above, there were different average hours saved per respondent based on their job function. Project managers save the least weekly hours using Vela, an average of 4 hours a week, with an efficiency gain of 9%. Superintendents and project engineers both save 12,5 hours per week, however, project engineers reported longer hours on average (74,7 hours per week) and so have an efficiency gain of 17%, versus the 20% gain that superintendents experience, on average.

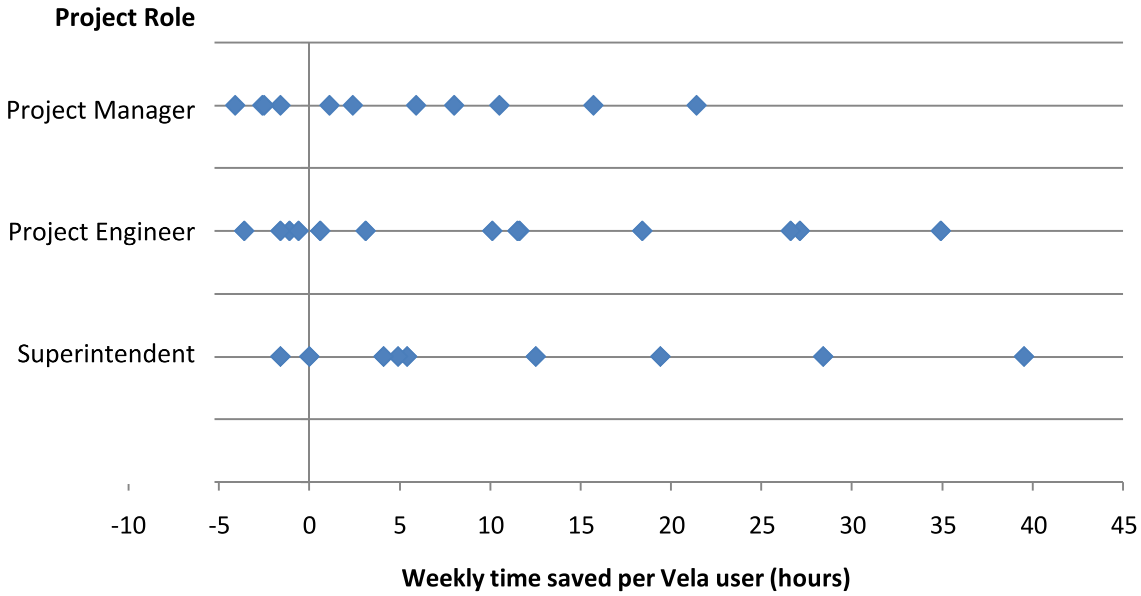


Figure 3.8 Dot diagram showing distribution of results by job description

Again, there is a wide spread of results for each discipline along a gumbel distribution. This can be observed in the dot diagram in figure 3.8 and the histograms in figures 3.9 - 3.11.

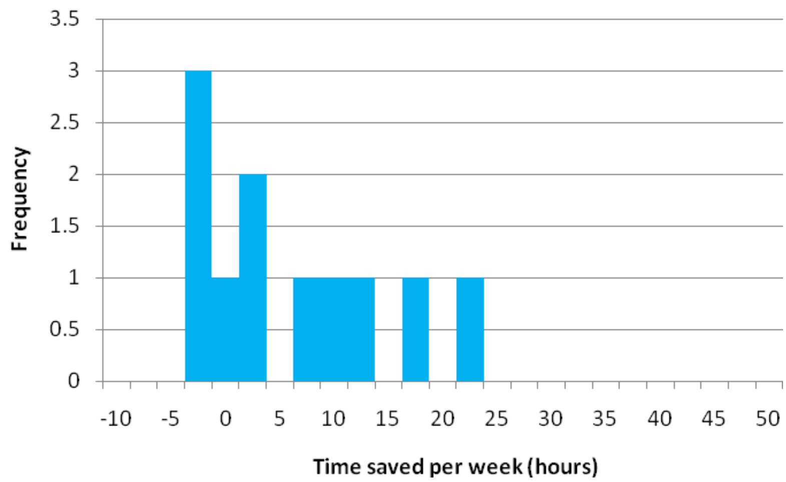


Figure 3.9 Histogram - hours saved per project manager

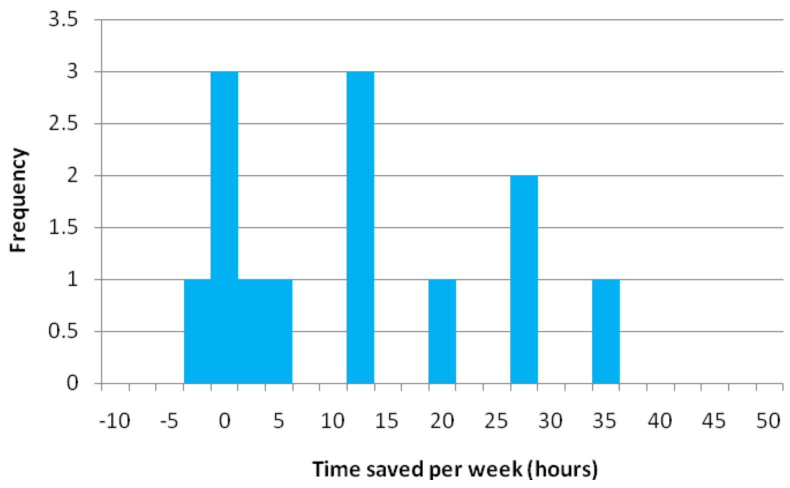


Figure 3.10 Histogram - hours saved per project project engineer

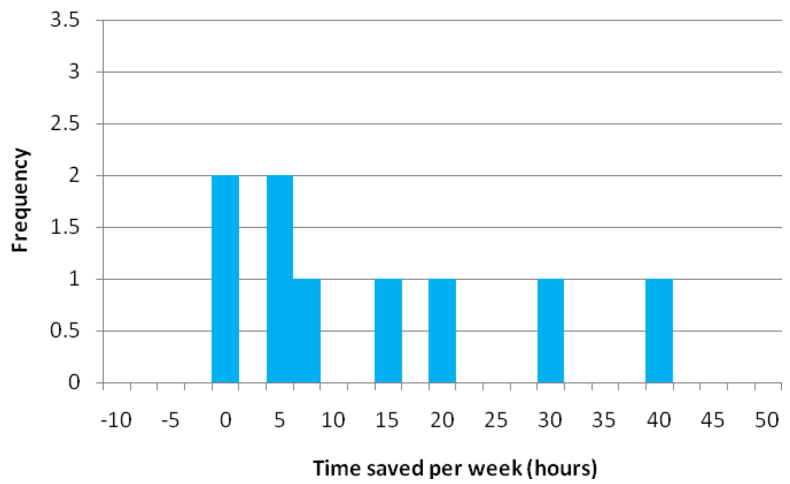


Figure 3.11 Histogram - hours saved per superintendent

These results mean that **H1** (Vela users will save a significant amount of hours performing their weekly tasks) is **not confirmed** due to the sample's Gumbel distribution, but the data suggests it may be true. **H2** (Vela users will have varying degrees of efficiency gains based on job description) is also **not confirmed**, but the data suggests that there is in fact a difference in hours saved as a function of job description.

3.2.2 EFFICIENCY GAINS ACROSS PROJECTS

Efficiency gains are one of the main goals which business process reengineering seeks to achieve through automating existing processes (Hammer and Champy, 1993). They will be used as the primary metric for comparing project performance in all subsequent data analysis and discussion.

Efficiency can be defined for the purpose of this study as the time or effort needed to achieve a certain result. In other words, efficiency gains can be measured by quantifying changes in the ratio of input to output. It was assumed that average output remained constant on a weekly basis, so what changed was the input of average time needed to achieve this steady output. Through dividing the previous total weekly management hours by the new total weekly hours, it was possible to work out a relative efficiency gain per user (or loss) achieved. It is expressed as a percentage, and can be calculated per project as follows:

Efficiency gain = (weekly hours saved using Vela/weekly hours before Vela) * 100

The table and chart in figure 3.12 compare the weekly hours saved per user and average efficiency gains per user for each of the 15 projects investigated. These range from 2,4 extra hours per week and 5% less efficiency on the St Francis Hospital project to the 39,5 weekly hours saved per user on the Westin hotel project, resulting in a 45% efficiency gain. It is important to note that there is a high degree of variance between the time savings recorded per user on each project, which these results are based on. This variance is visible in the dot diagram in figure 3.13.

Project Name	Hours saved weekly	Efficiency gain (%)
St Francis Hospital	-2,4	-5
Southern Crescent Tech College	-2,6	-4
VT ASA	1,4	3
Notre Dame Stayer Center	11,5	7,5
NOAA Office and Labs	4,3	9
NCSU Hunt Library	7,5	12
George C Young Federal Building	8,0	14
Nemours Children's Hospital	15,8	17,5
GRU East Operations Center	15,2	25
Merck Lab	12	26
CCHS Hospital Expansion	8,3	28
University of Delaware	13,6	28
Bassangkajen	15,7	32,5
PPL Data Center	17,1	33
Westin Hotel	39,5	45

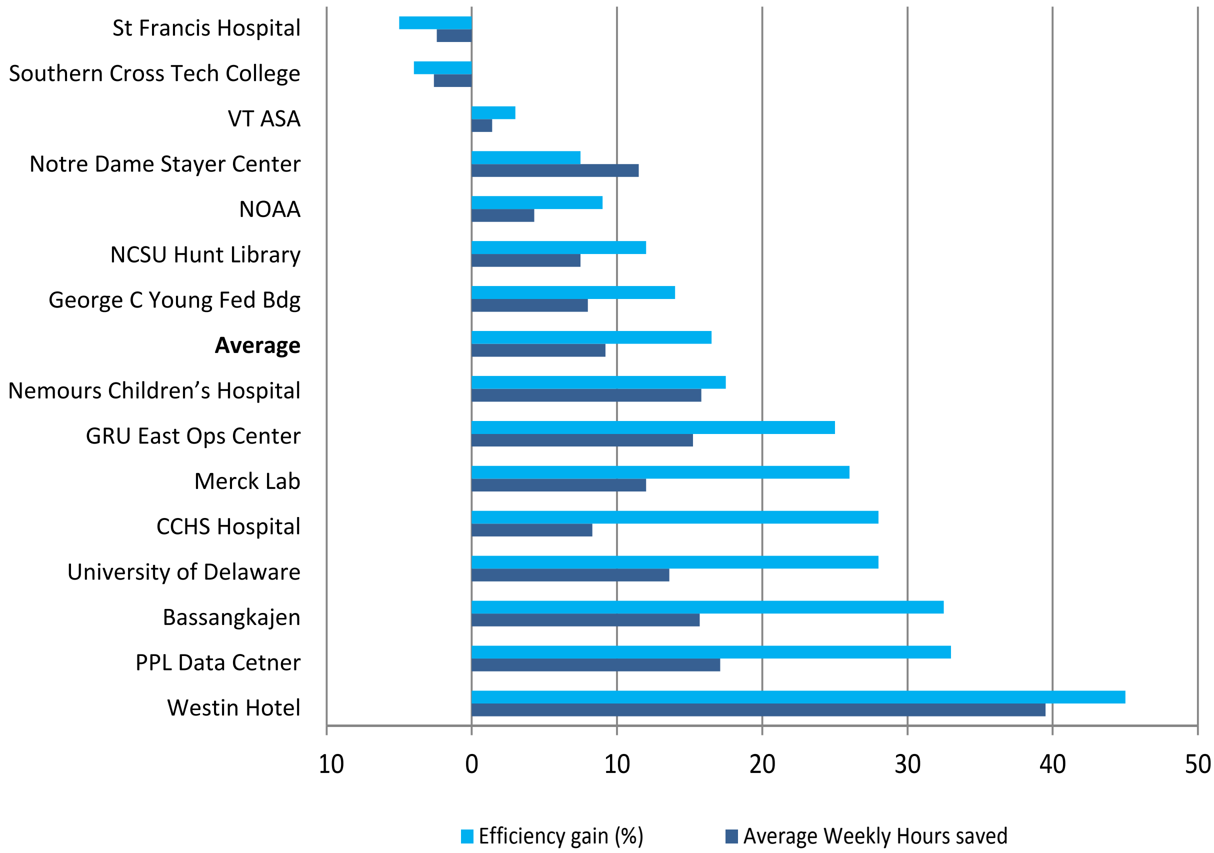


Figure 3.12. Time savings and efficiency gains on all projects

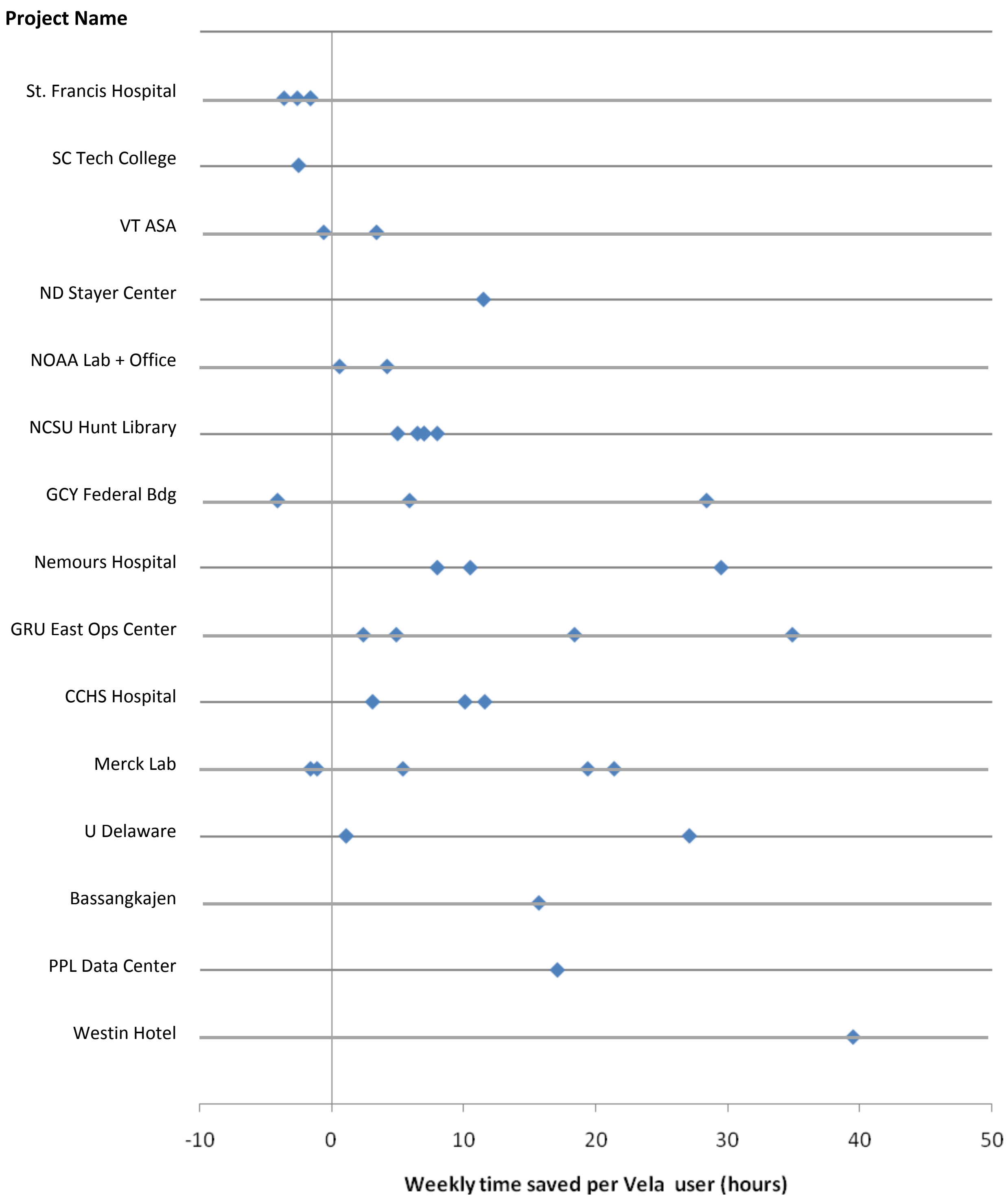


Figure 3.13. Dot diagram showing distribution of results by project

3.2.3 NON SKANSKA USER INVOLVEMENT

Respondents were asked to evaluate the involvement of non-Skanska parties with Vela on a five point Likert scale, with 1 being no involvement and 5 being very significant involvement. The average values of these involvements is shown in figure 3.14 for each of the 15 projects, broken down by discipline. To test the hypothesis that more proactive use of Vela by non-Skanska project team members results in higher efficiency gains, the involvement of each category of non-Skanska users has been plotted against efficiency gains for each project in scatter diagrams in figures 3.15 - 3.20.

Project Name	Average	Subcont-ractor	Architect /Engineer	Commissioning Agent	3rd Party Inspector	Client/Owner
St Francis Hospital	1.3	1	1	1	1	1
Southern Crescent Tech	1.9	2	2	2	2	2
VT ASA	1.6	1	1	1	2	1
Notre Dame Stayer Center	1.6	2	2	1	1	1
NOAA Office and Labs	1.4	1	1	1	1	1
NCSU Hunt Library	2.1	3.2	3.2	1	1	1.6
George C Young Federal	3.1	4.7	4.7	3.7	1	3.3
Nemours Children's Hospital	3.2	4	4	2.3	3	3
GRU East Operations Center	2.9	3.7	3.7	3.3	1	2.7
Merck Lab	2.1	1	1	1	1	3.7
CCHS Hospital Expansion	2.4	1.3	1.3	1	5	1.3
University of Delaware	2.5	2	2	3	2	2.5
Bassangkajen	3.2	1	1	4	3	5
PPL Data Center	2.5	1	1	3	1	4
Westin Hotel	2.9	3	3	3	3	2

Figure 3.14 Degree of non-Skanska project team member involvement with Vela accross all projects

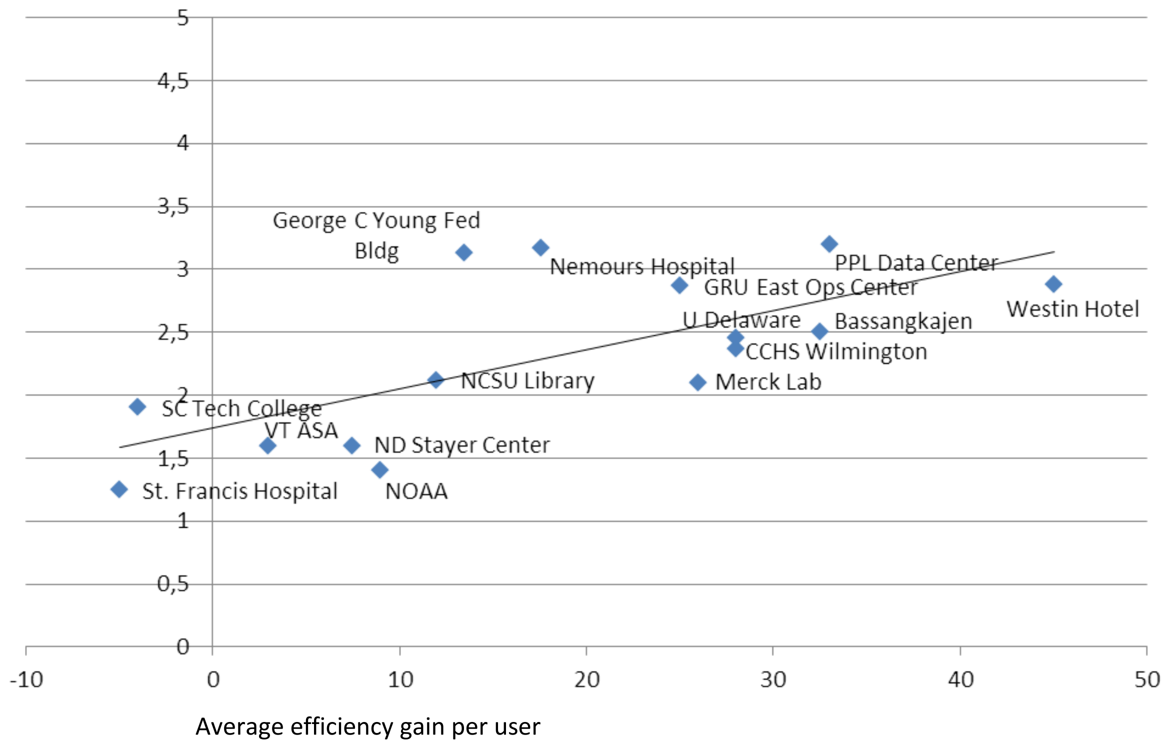


Figure 3.15. Non Skanska user involvement vs. Efficiency gain

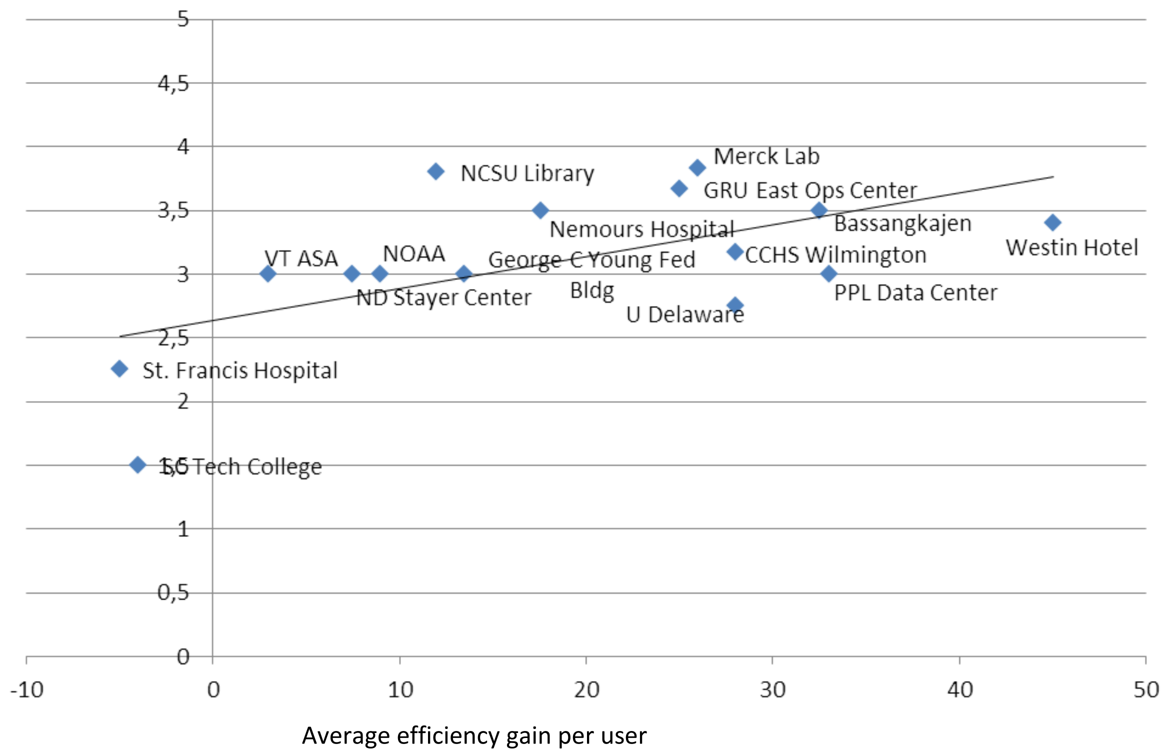


Figure 3.16. Subcontractor involvement vs. Efficiency gain

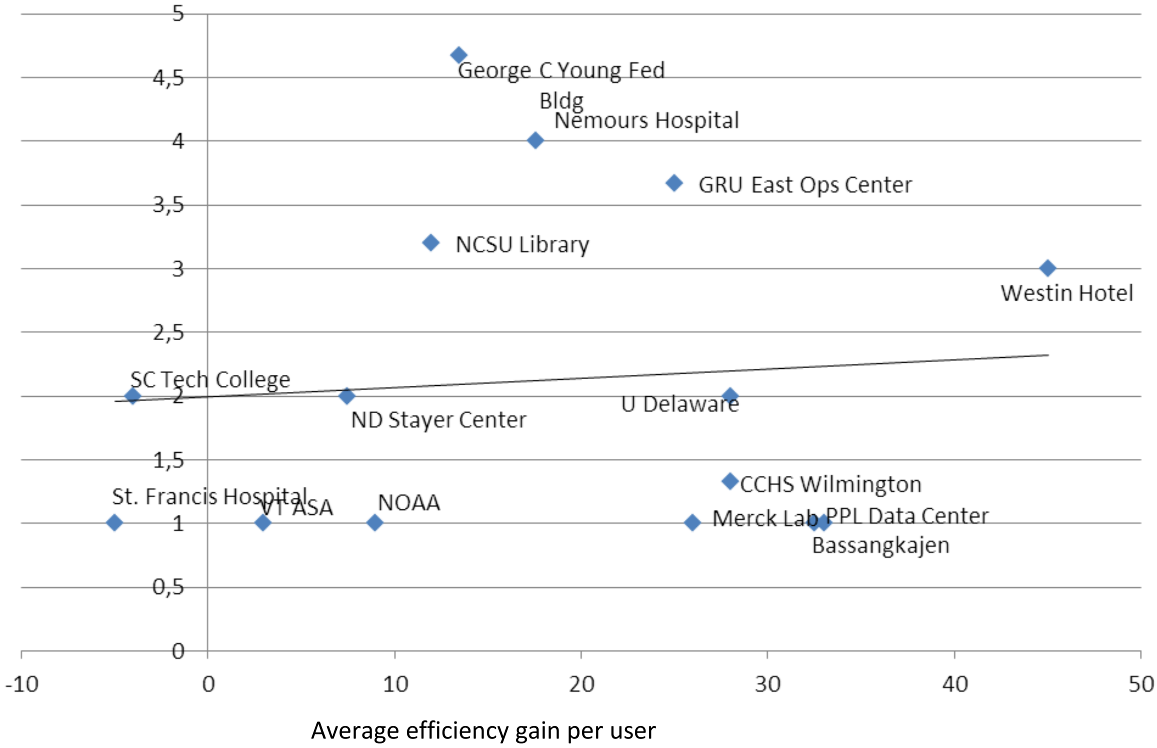


Figure 3.17. Architect/Engineer involvement with Vela vs. Efficiency gain

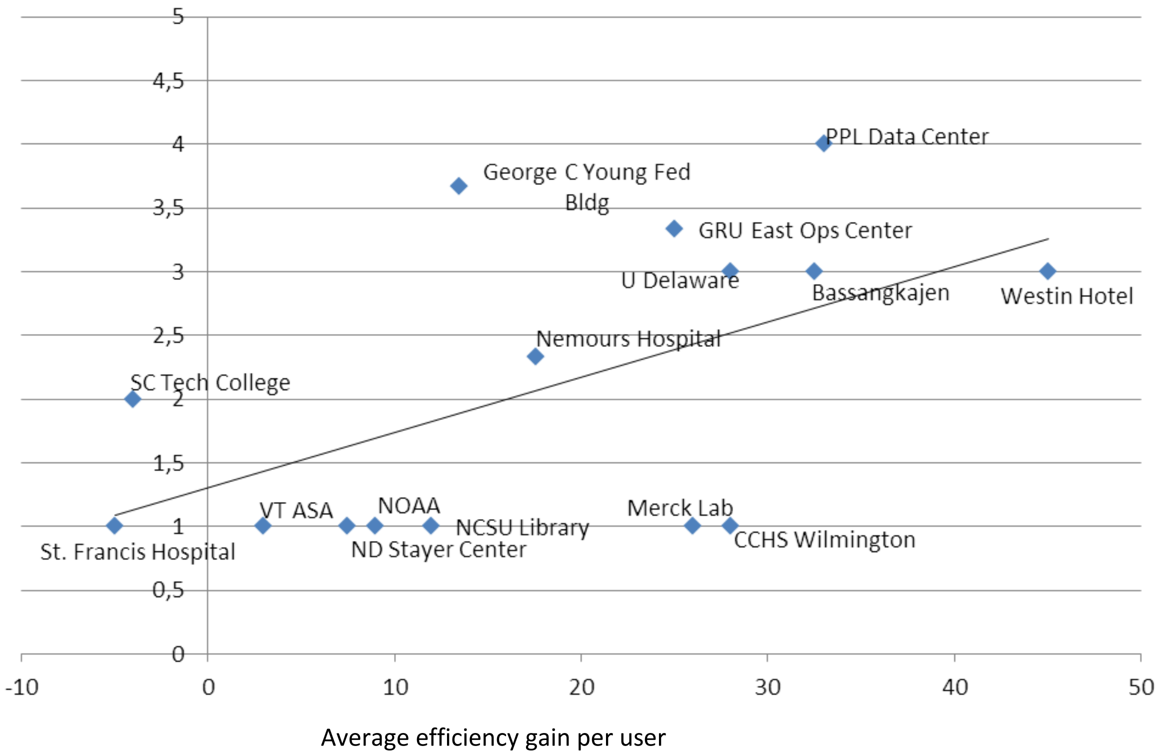


Figure 3.18. Comissioning agent involvement with Vela vs. Efficiency gain

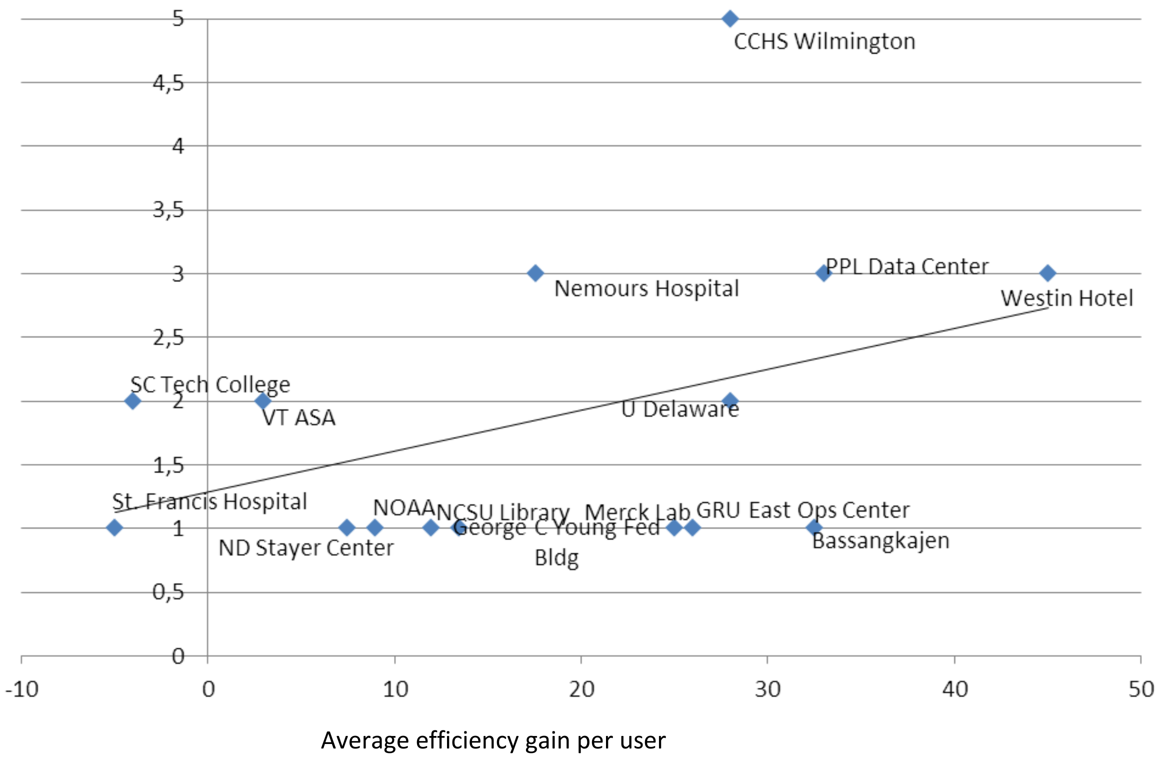


Figure 3.19. 3rd party inspector involvement with Vela vs. Efficiency gain

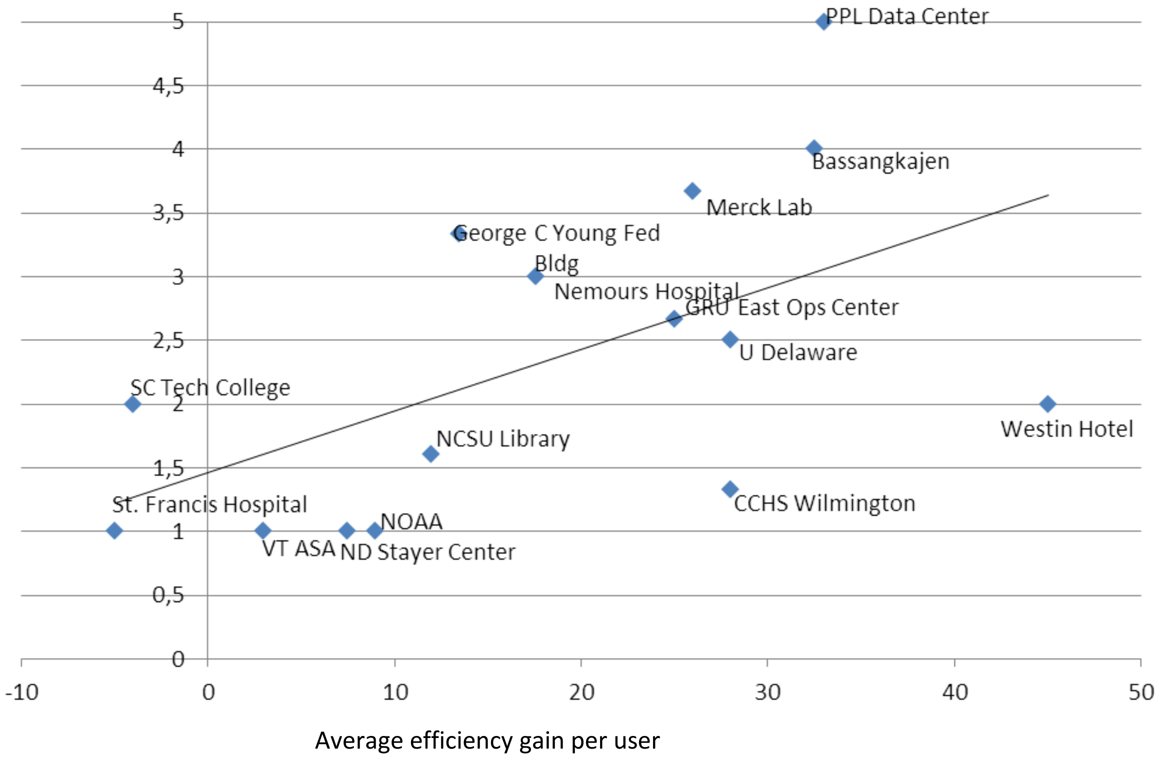


Figure 3.20. Client involvement with Vela vs. Efficiency gain

For all projects, it was possible to identify a positive correlation between levels of non-Skanska project member involvement with Vela and efficiency gains. Figures 3.18 and 3.20 suggest that the correlation between efficiency gains and client and commissioning agent involvement are the strongest, and figure 3.17 indicates that the level architect/engineer involvement has the least effect. Therefore, **H3** (More involvement of other Non-Skanska project team members with Vela will result in higher efficiency gains) is **confirmed** for the involvement of:

- All non-Skanska users combined
- Subcontractors
- Commissioning agents
- Owners/Clients

The results do **not confirm** that greater involvement of Architects/Engineers and 3rd party inspectors with Vela also results in higher efficiency gains (see appendix A1 for statistical correlation testing), but there is a suggestion of a weak positive correlation.

3.2.4 LEARNING OVER TIME

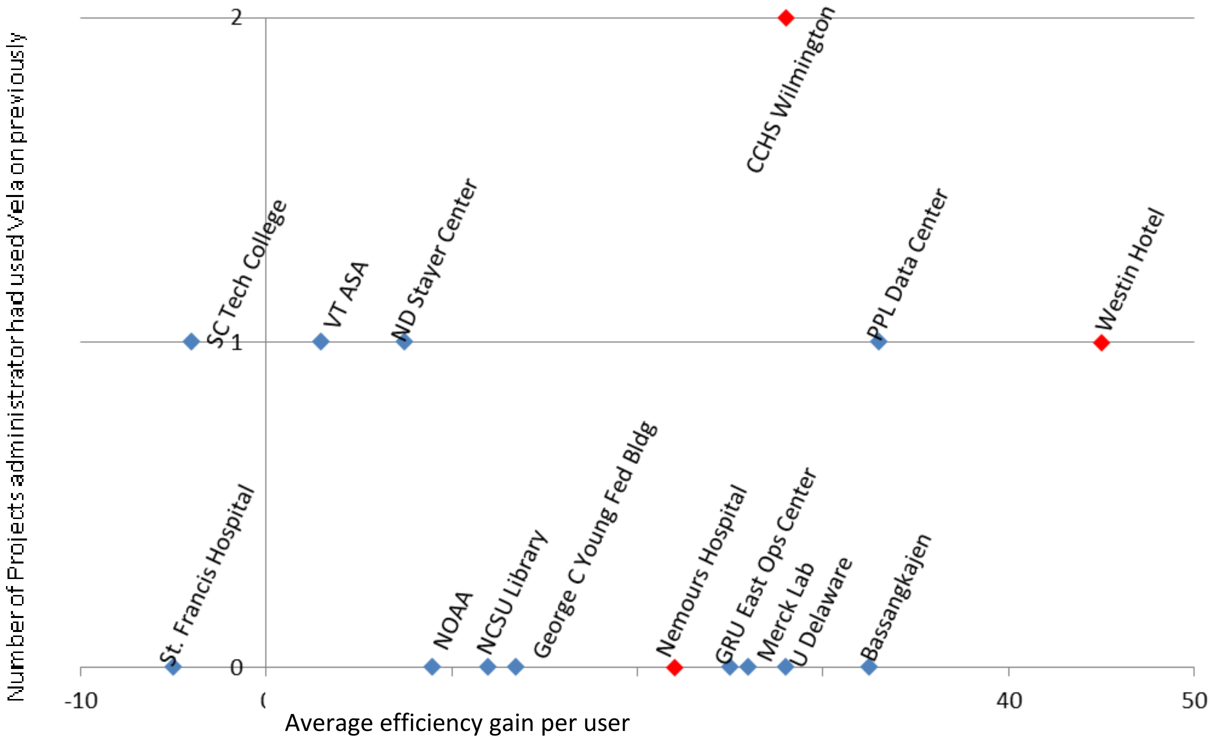


Figure 3.21. Number of previous projects on which admin used Vela vs. efficiency gain (red indicates projects with admins who are Vela trainers for Skanska)

The Vela administrators on each project were aksed how many previous projects they had used Vela on. Projects on which Vela admins had previous experience with using Vela had a 18.5% average efficiency gain. The data suggests essentially no correlation between an administrator's past Vela experience and efficiency gain, so **H4** (Projects whose Vela administrators have previous Vela experience will have higher efficiency gains)is **not confirmed**. However, the administrators of 3 projects are also Vela trainers. These projects: CCHS Wilmington Hospital Expansion, Nemours Hospital and Westin Hotel had an average efficiency gain of 31.7%, statistically different from the remainder at an 85% confidence level (see appendix).This means **H5** (Projects with special Vela trainers have higher efficiency gains) is **confirmed**.

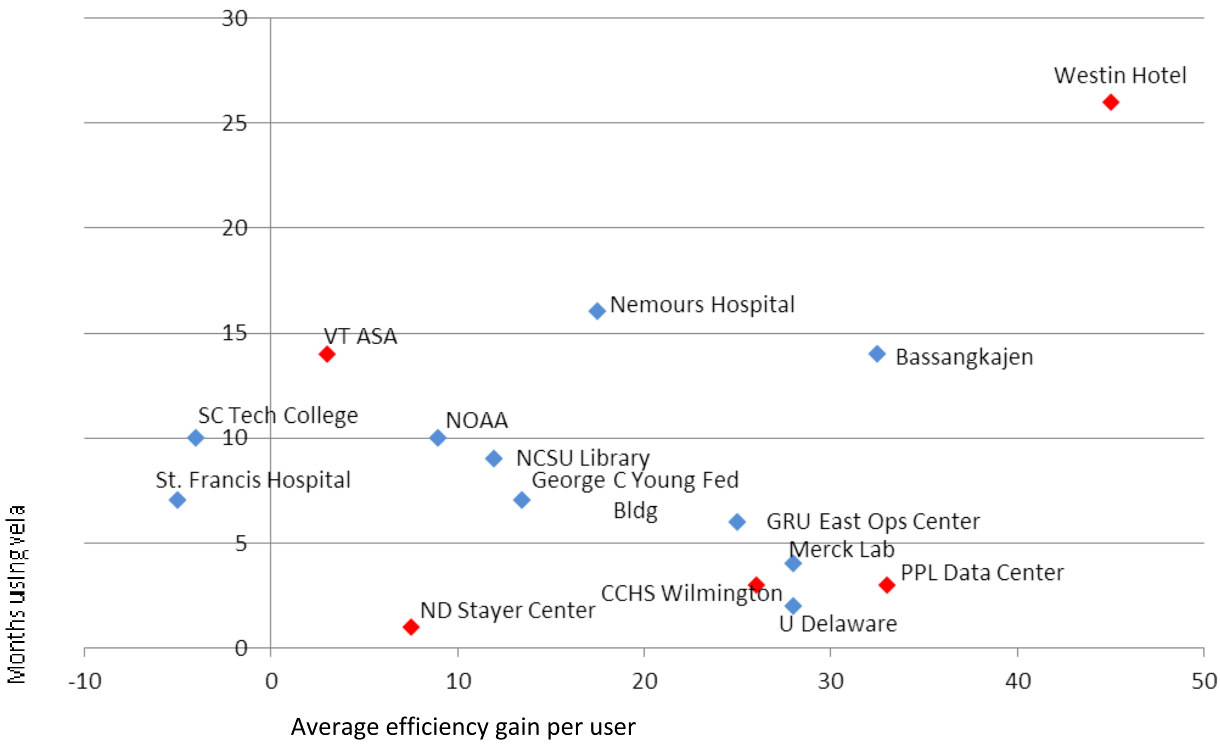


Figure 3.22. Time using Vela vs. Efficiency gain (red indicates project admins who reported previous Vela use)

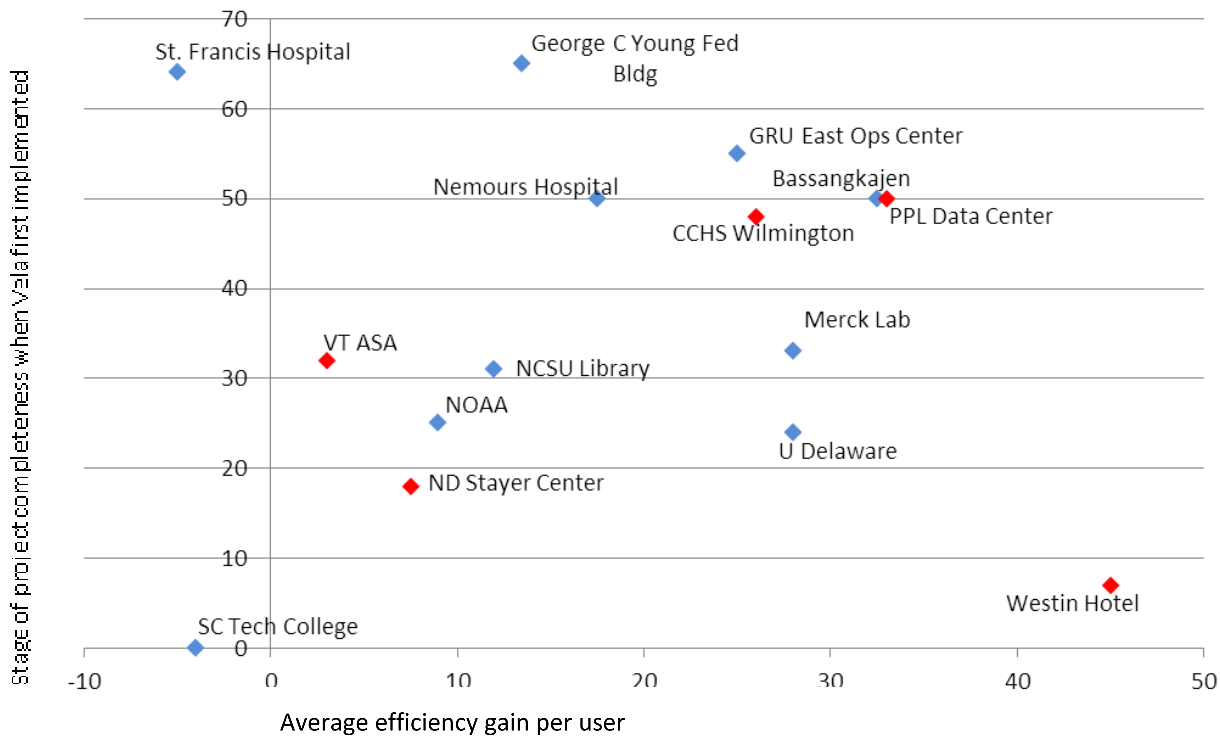


Figure 3.23. Percentage of project completeness when Vela first implemented vs. Efficiency gain

Figure 12.12 plots months which Vela had been used at the time of the survey against average efficiency gain, and suggests that there is a weak but not statistically significant correlation. Figure 12.13 plots percentage of the project complete (in terms of schedule) when Vela was introduced against efficiency gains. This is also an irregular, seemingly random scatter, with no significant correlation. However, the SC Tech College project could be regarded as an usual result in this case, as several subcontractors refuse to use Vela or its outputs, severely limiting the usefulness of the application in terms of increasing task efficiency. If this result is neglected, the remaining results suggest a weak but not statistically significant correlation between the stage of the project on which Vela was introduced and efficiency gains. **H6** (Earlier implementation of Vela in a project life cycle will result in higher efficiency gains) is therefore **not confirmed** by the data.

3.2.5 TOOLS USED

	1					2	3	4	5	
	Quality (Issues /Checklists)	Safety	General Issue Tracking	Work List	Punch List	Equipment/Material Tracking	Equipment Commissioning	Owner Handover	Field BIM	Efficiency gain (%)
St Francis Hospital	✓	✓	✓	✓	✓					-5
Southern Crescent Tech College	✓		✓		✓		✓			-4
VT ASA	✓	✓	✓	✓	✓	✓				3
Notre Dame Stayer Center	✓		✓	✓	✓	✓				7,5
NOAA Office and Labs	✓	✓	✓	✓	✓					9
NCSU Hunt Library*	✓		✓	✓		✓				12
George C Young Federal Building	✓		✓	✓	✓		✓	✓		14
Nemours Children's Hospital	✓		✓		✓		✓			17,5
GRU East Operations Center	✓	✓	✓	✓	✓		✓	✓		25
Merck Lab	✓	✓	✓	✓	✓					26
CCHS Hospital Expansion	✓	✓	✓	✓	✓	✓				28
University of Delaware	✓		✓	✓	✓	✓	✓			28
Bassangkajen	✓	✓	✓	✓	✓					32,5
PPL Data Center	✓		✓	✓	✓					33
Westin Hotel	✓	✓	✓	✓	✓	✓	✓	✓		45

Figure 3.24. Vela functionality subsets used by Skanska CM staff on various projects.

**at time of survey, equipment commissioning and punchlist functions had not been used*

Not all available Vela tools were used on the various projects. All projects used Vela for (1) its core functions of quality checklists, punchlist completion and issue tracking. Projects using Vela for additional purposes reported higher efficiency gains, but not at a statistically significant level. On average, projects which used Vela for (2) equipment and material tracking have a 20,5% efficiency gain, projects using Vela for (3) equipment commissioning have a 21% efficiency gain, and projects using Vela for (4) owner handover had a 28% efficiency gain. None used (5) Field BIM, a relatively new functionality subset, introduced in Spring 2012. The Westin Hotel project used Vela for all four of the above activities and reported a 45% gain. The results indicate a moderate but not statistically significant positive correlation between the amount of tool subsets used and efficiency gains (see appendix A1). Thus, **H7** (Using more functionality tools will result in higher efficiency gains) is **not confirmed** by the results, but the results do suggest that this may be the case.

3.2.6 PROJECT DELIVERY METHOD AND CONTRACT STRUCTURE

Project Name	Delivery Method	Contract Structure	Efficiency gain (%)
St Francis Hospital	DBB with CM	GMP	-5
Southern Crescent Tech College	DBB with CM	GMP	-4
VT ASA	DBB with CM	GMP	3
Notre Dame Stayer Center	CMAR	GMP	7,5
NOAA Office and Labs	DBB	Fixed Price	9
NCSU Hunt Library	CMAR	GMP	12
George C Young Federal Building	DBB with CM	GMP	14
Nemours Children’s Hospital	DBB with CM	GMP	17,5
GRU East Operations Center	CMAR	GMP	25
Merck Lab	CMAR	GMP	26
CCHS Hospital Expansion	DBB with CM	GMP	28
University of Delaware	DBB	Fixed Price	28
Bassangkajen	DBB with CM	GMP	32,5
PPL Data Center	CMAR	GMP	33
Westin Hotel	IPD	Fixed Price	45

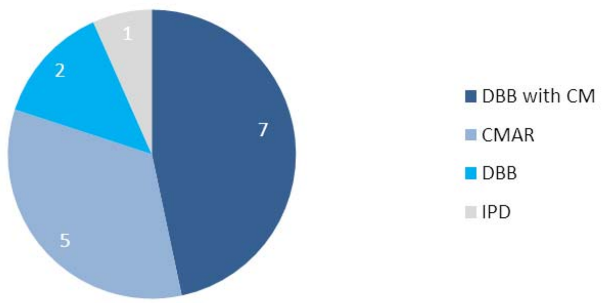


Figure 3.25 Delivery methods of projects

The 7 design-bid-build with construction management projects had an average efficiency gain of 12,3%, the 5 construction manager at risk projects had an average efficiency gain of 19,7%, 2 design-bid-build projects an average of 18,5% and the single integrated project delivery project had a 45% efficiency gain. However, the small size of the sample and variance of results makes any difference not statistically significant at the 80% confidence interval. Fixed price contract stucture projects reported an average of 21,5% efficiency gain, compared to 16% on guaranteed maximum price projects. Thus, **H8** (The project contract structure will affect efficiency gains) and **H9** (Procurement type will affect efficiency gains) are **not confirmed** by the results but some difference is suggested.

3.2.7 PROJECT SIZE

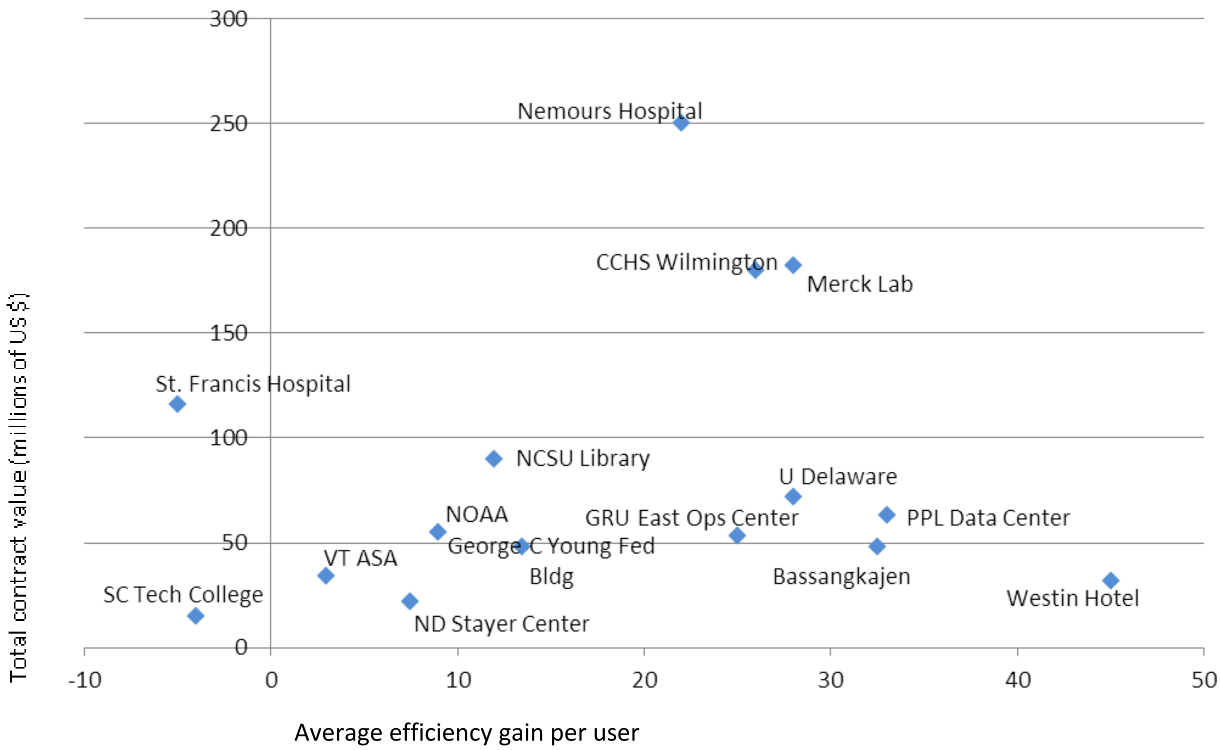


Figure 3.26. Project contract value vs average efficiency gain

Figure 3.26 shows that when plotted against total contract value, average efficiency gains do not demonstrate any significant trend, although there is a weak positive correlation (see appendix). Thus, **H10** (Project size will affect efficiency gains) is **not confirmed** by the results.

3.2.8 PERCEPTIONS OF BENEFITS

Vaughan's (2011) study of Vela on the NCSU Hunt Library project identified 12 main benefits of using Vela (see table in figure 12.17), ascertained by conducting interviews with Skanska staff, architects, engineers, clients and subcontractors, who are the main parties engaged with Vela in any given project. All 38 Skanska employees surveyed plus 27 non-Skanska staff who had used Vela on the projects were asked to rank their perceptions of the relative importance of the 12 benefits. It was then possible to break-up the relative perception of benefits by profession.

Feature #	Description of Benefit
1	Access to construction documents in the field
2	Access to 'real time' information updated daily via 'synching' with Vela server
3	Automatically attach annotated pictures to QA/QC checklists as well as issues and punchlist
4	Automatically generate action items for subcontractors via punchlist and QA/QC checklists
5	Filter punchlist items/issue by type, work area or responsible party for clear distribution to subs
6	Create electronic record and database of all QA/QC checklists
7	Create electronic pushpins to precisely locate an issue, punchlist item etc. on drawings
8	Track quality issues and defects for specific materials
9	View a visual representation of supply chain information through linking material status to BIM
10	Differentiate firm from others in the industry through use of innovative project delivery methods
11	Create new RFI's on electronic plan sheets as questions or concerns arise in the field
12	Provide owner with electronic deliverables linked to BIM

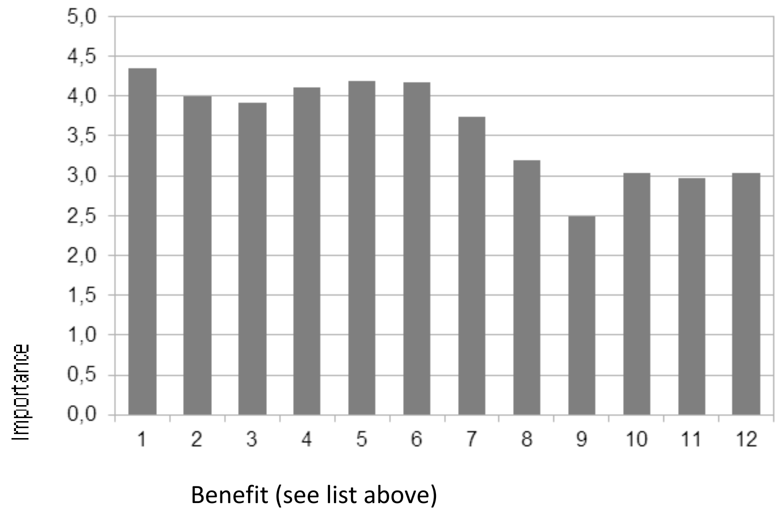


Figure 3.27. Perception of Vela benefits (1: not important, 5: extremely important)

	Benefit #											
Project Role	1	2	3	4	5	6	7	8	9	10	11	12
All users	**4,3**	4,0	3,9	4,1	4,2	4,2	3,7	3,2	2,5	3,0	3,0	3,0
Skanska Staff	4,4	4,3	4,5	**4,6**	4,4	4,4	4,1	3,4	2,8	4,1	3,1	3,3
Owners	**4,5**	3,1	3,6	3,3	3,7	3,3	2,9	2,7	1,5	2,1	2,0	3,0
Subcontractors	**4,3**	**4,3**	3,9	4,2	3,8	4,2	**4,3**	3,7	2,9	3,0	3,8	3,1
Architects/Engineers	4,2	4,3	3,7	4,3	**4,8**	**4,8**	3,7	3,0	2,7	3,0	3,0	2,8

Figure 3.28: Perception of Vela benefits across different project roles. (1: not important, 5: extremely important)

As figures 12.18 and 12.20 - 12.23 show, different professions have varying perceptions of the importance of each benefits. Skanska staff, for instance, found that benefit 4: automatically generating punchlist items for subcontractors, was the most important. Owners found it most useful for benefit (1) immediately accessing and viewing digital drawings in the field, this was in fact ranked as the most important benefit by all project participants surveyed. Subcontractors also found (1) the most significant benefit, tied with (2)accessing up to date information, and (7) locating issues on drawings with electronic ‘pushpins’. Architects and engineers found 5: filtering issues by type or responsible party, and (6) creating a single QA/QC checklist database, to be the most important. On average, all respondents found (9) viewing a visual representation of the building’s supply chain to be the least important benefit.

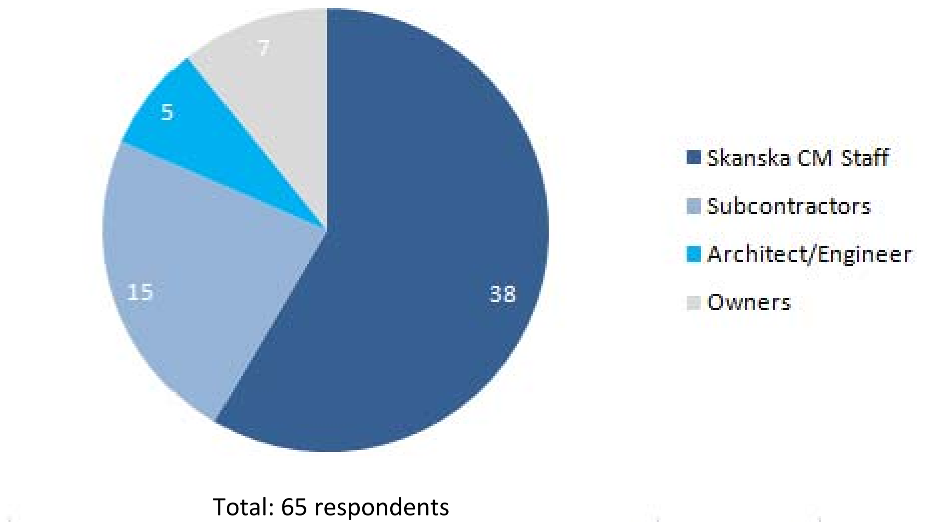


Figure 12.19: Breakdown of respondents

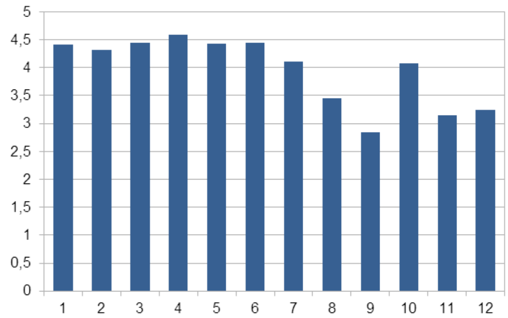


Figure 12.20: Skanska Staff

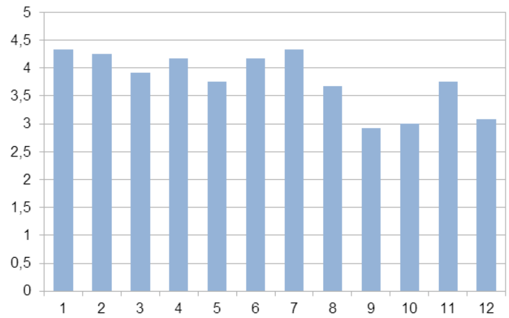


Figure 12.21: Subcontractors

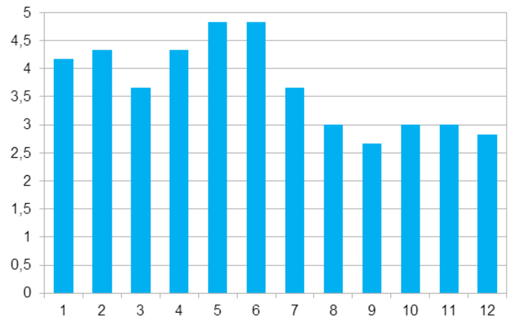


Figure 12.22: Architect/Engineer

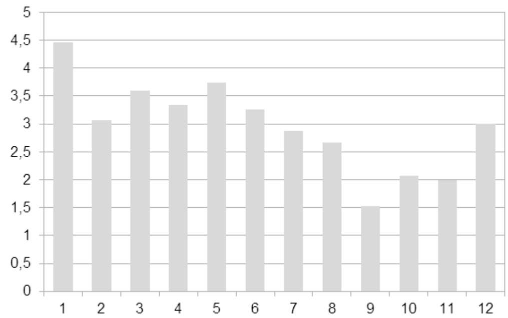


Figure 12.23: Owners

3.2.9 SUMMARY OF HYPOTHESIS TESTING

Hypothesis	Confirmed	Suggested	Rejected
1		✔	
2		✔	
3	✔		
4			✔
5	✔		
6			✔
7		✔	
8		✔	
9		✔	
10		✔	

To summarize, the data **confirms** a significant positive correlation between a project's average users' efficiency gains and the degree to which non-Skanska users are involved with Vela. It also confirms that projects whose Vela administrators are part of a special Vela training team within Skanska have higher average efficiency gains than those who aren't. Although it can't be confirmed statistically, the data **suggests** that Skanska's average Vela user saves a significant amount of hours per week performing typical construction management activities, and that the amount of hours vary depending on job description. The data also suggests without statistically significant confirmation that contract structure and project delivery method have an influence on average efficiency gain. Project size is weakly positively correlated and number of of Vela functionality subsets used is moderately positively to efficiency gains, but neither can be confirmed. According to the data, there is no correlation between an administrator's previous use of Vela on another project or the stage of a project-completeness at which Vela is implemented and higher efficiency gains, so these hypotheses can be **rejected**. There is, however, a weak correlation between months of Vela use and recorded efficiency gains.

3.3 DISCUSSION OF RESULTS

3.3.1 INFLUENCING FACTORS CONFIRMED BY DATA

The significant results of the quantitative research are the identification of (1) non-Skanska project team member involvement with Vela and (2) depth of knowledge of Vela as the two most important factors which influence efficiency gains.

NON-SKANSKA PROJECT TEAM MEMBER INVOLVEMENT WITH VELA

As Vela is in fact mainly used as a tool for communicating information about construction issues, this result was expected and was hypothesised by H3. The other parties are involved with Vela, the greater opportunity there is to communciate in a more efficient manner with them using Vela. A number of examples of successes and failures of subcontractor involvement on individual projects illustrate varying levels of effective communication:

- A proactively involved commissioning agent (involvement rating: 3.3) working on behalf of the owner (involvement rating: 2.7) on the GRU East Operation Center was able to track and commission all equipment at the facility using Vela, and convinced the owner to buy iPads for the final close-out and handover phases of the job.
- A separate Vela account was set up for the most important subcontractors (involvement ranking: 4.0) on the Nemours Children's Hospital project to give them certain administrator rights so that they could utilize the system more efficiently.

- Several subcontractors on the Southern Crescent Technical college (involvement rating: 2.0) refused to use Vela or the results generated from it unless it was explicitly made a requirement by the contract.

DEPTH OF KNOWLEDGE OF VELA

Vela administrators who are also designated Vela trainers have a higher than average depth of knowledge of the tool, and this is demonstrated by the higher efficiency gains recorded on their projects. Importantly, no correlation was identified between number of projects on which Vela administrators had previous experience and efficiency gains on current projects. These two results imply that it is the depth of understanding of the tool, rather than just the exposure to the tool in terms of time which is important in influencing efficiency gains. The projects on which Vela implementation was overseen by a designated Vela trainer also recorded higher levels of non-Skanska user involvement: 2,4 2,9 and 3,4 on the 5 point scale, compared to the average of 2,3. This suggests that the administrators who are also deisgnated Vela trainers have a better than average understanding of how to engage and communicate with non-Skanska project team members using Vela.

3.3.2 INFLUENCING FACTORS SUGGESTED BY DATA

TIME SAVINGS ARE SIGNIFICANT AND VARY DEPENDING ON JOB DESCRIPTION

Without statistical confirmation, the data suggests that the average Vela user saves a significant amount of hours per week performing typical construction management activities compared to their performance before using the tool. This is likely due to the automation of certain tasks and elimination of other activities altogether(see figures, 2.11, 2.15, 2.16).

The data also suggests that the amount of hours saved through using Vela vary depending on job descriptions of construction management staff. For example superintendents recorded an average efficiency gain of 20%, versus the 9% achieved by project managers, on average. Superintendents spend more time on on-site assessment and reaction activities (than project managers, who spend a higher percentage of time planning (see figure 3.7). The majority of tasks shortened or eliminated by Vela are on-site assessment and reaction activities, which may explain why CM staff who spend more time on-site record higher average efficiency gains.

PROJECT DELIVERY METHOD AND CONTRACT STRUCTURE

The data suggests that project delivery method and contract structure have an influence on average efficiency gain.

Interestingly, the Westin Hotel was the only project with an IPD delivery method, and also the only project to use all four of the Vela functionality subsets available. This supports the idea that the collaborative environment of an IPD project enables a fuller, more effective use of BIM's potential applications (see literature study, section 2.8).

The three projects with fixed price lump-sum contract structures had an average of 21,5% efficiency gain through using Vela, which is 5,5% higher than the average efficiency gain of the remainder of projects, which had guaranteed maximum price contracts. This difference may be due to more incentives for Skanska to save labor hours with fixed price contracts, as any savings are returned to Skanska. In GMP contracts, savings are often shared between contractor and owner, or returned to the owner outright.

VELA TOOLS USED

The data collected indicates a moderate positive correlation between the number of available tool subsets used and efficiency gains. More construction management tasks and activities will be shortened or automated as more tools are used for tasks such as equipment tracking and commissioning and owner handover, so this result is expected.

3.3.3 POSSIBLE SOURCES OF ERROR

In measuring the independent and dependent variables, there were numerous sources of error, which the following section will discuss. The experimental design tried as far as possible to mitigate these sources of error.

GENERAL SOURCES OF ERROR

Performance in terms of time, quality and cost on complex multi-million dollar construction projects is prone to myriad influencing factors. This research has tried to identify the most important and relevant, but is entirely possible that an important factor was overlooked and therefore not measured

To control for confounding variables, all Vela administrators interviewed in the survey were asked to comment on any quality or efficiency enhancing programs or initiatives other than Vela being used uniquely on their own project (and not on all Skanska projects). None were noted in the responses.

All data is based on responses in the forms of estimates by subjects who were generally enthusiastic about participating but also busy with other tasks. Therefore, there is no doubt differing degrees of concentration and efforts at creating accurate responses behind the 38 sets data collected from each survey completed. Furthermore, 5 of the users' estimates for weekly task durations pre-Vela and using Vela (from the NCSU Hunt Library) were incorporated into this study by using data from a previous study (Vaughan, 2011), collected using a significantly different method. The previous study found the average of 20 weeks worth of time duration estimates using Vela. This averaging of more data collected over a longer period of time probably leads to lower errors, which is reflected in the lower variance of the results than in other projects (see figure 2.3.10). However, Vaughan's 2011 study found time an average savings of 8 hours per week and an efficiency gain of 12%, which is consistent with this study's mean results of 9.1 hours saved per week with an efficiency gain of 16% for all 38 participants surveyed.

INVOLVEMENT OF NON-SKANSKA PROJECT TEAM MEMBERS

When survey participants rank the involvement of various Non-Skanska parties in terms of their use of Vela, their answers are subject to their own perceptions. The 5 point likert scale specifies that 1 means no involvement and 5 is very significant involvement, but it is still possible that respondents have different perceptions of what these values mean, and some may have witnessed different events in relation to this topic, which will influence their perception of other parties' involvement. Furthermore, it is possible that the phenomenon of biased interpretation has led to a higher degree of positive correlation between scores of non-Skanska project team memebers' involvement and efficiency gains. For example, a Vela user who experiences a relatively high degree of efficiency gain and time savings may be more likely to favorably comment on the degree to which others were involved with using Vela, as he or she finds the tool more useful than those who experience lower efficiency gains.

TIME FACTORS

It is easy for Vela administrators to accurately recall the date when their projects started and when Vela was first implemented.

Regarding previous experience using Vela, some users who claimed to have previous experience with using the applications may have been using an older, significantly different version of the software, which did not have the same user interface or functions. In addition, only Vela administrators were asked if they had used Vela on previous projects, with the assumption that all other users had no prior experience. However, some users may have used Vela or a similar FDMT on previous projects, which could have had an effect on their recorded efficiency gain.

Because a weak (but not significant) positive correlation was found between efficiency gains and the number of months Vela had been used on a project at the time of the survey (see figure 3.22 and appendix A2), it suggests the presence of a slight learning curve, which means that some users who had been using Vela for a shorter time at the time they completed the survey may not have been achieving their full eventual efficiency gains.

VELA TOOLS USED

It is possible that some respondents did not include all Vela functionalities they had actually used when filling out the survey's checklist. Furthermore, some may have included tools that were not used yet, but that they were planning to implement at a later stage in the project. Where possible, actual Vela tools used on each project were verified during interviews with Vela administrators over the phone.

ESTIMATION OF TASK DURATIONS

While estimating task durations to the nearest half hour, respondents had to rely on memory. Due to limitations of time and long-distance communication, it was not possible to monitor and record actual task durations on a weekly basis, which would have returned more accurate results. The wide range of results for total hours worked in a typical week, from 5,5 to 149 (there are 168 hours in a week) suggest that some of the estimates were not entirely accurate. Partly for this reason, efficiency gains expressed as a relative percentage which represents the ratio between task durations pre Vela and using Vela has been used as a metric by which to compare performance between projects. To make estimates more reliable, it was important to break tasks into specific, easy to estimate activities with specific descriptions which construction management staff could clearly tell apart from each other.

3.3.4 EXTERNAL VALIDITY OF RESULTS

The results and implications of this study should have a high degree of generalizability to other construction service providers considering a variety field data management approaches. Although the sample size of users (38) and projects (15) is relatively small, it is the largest study of such a type conducted on measuring the efficiency gains achieved through using FDMTs. The findings fall within the range of results obtained by a previous study (Vaughan, 2011), suggesting that the experimental set-up is replicable. Perhaps most importantly, the research quantitatively measures efficiency gains in typical site tasks conducted by construction managers on projects of varying scales around the world. Thus, the results can be characterized as having external validity, and should be valuable for various construction firms considering the adoption of FDMT.

4. RECOMMENDATIONS TO SKANSKA AND CONCLUSION

This last section begins by laying out a comprehensive cost/benefit assessment framework model, which construction service providers will be able to use as a guide for evaluating the full quantifiable ROI of FDMTs, as well as determining which factors influence final ROI. It includes a discussion of important costs and long-term benefits which are infeasible to accurately quantify but which should be considered nevertheless.

A series of proposals are then presented to Skanska which explain how their implementation of FDMTs can be optimized. These are based on observations from the quantitative research, and the factors which were identified as key influencing drivers of performance with FDMTs. Finally, the current state of FDMT implementation observed in the research of 15 Skanska projects is compared to the full theoretical potential of the approaches and tools examined in the literature study, and some suggestions are made for how to Skanska can deepen their adoption of these innovations to fundamentally improve process efficiency in a number of key business areas.

Although these proposals are aimed at a single company (Skanska) based on studying the use of a particular FDMT (Vela) on specific projects, it should be possible to generalize most of the recommendations making them of interest to any construction service provider considering their management of field data.

4.1 RECOMMENDATIONS

4.1.1 ADOPT A FULL ROI ASSESSMENT FRAMEWORK TO EVALUATE BENEFITS OF FDMTS

One of the barriers to the adoption of FDMTs and other innovative tools by organizations is the difficulty of assessing the potential return on investment (ROI). The research and analyses done for this study has focused solely on measuring **hours saved and efficiency gains** on 15 projects, as an accurate metric for comparing performance. A method for translating those efficiency gains into dollars saved has been proposed (see step 3 in section 3.1). However, this is only one of the two major types of savings offered by Vela and other FDMTs. It was beyond the scope of this project to measure quality savings through reduced rework due to using Vela, but this is a significant and possibly more substantial benefit in terms of final dollars saved on a project. This section proposes a logical continuation of the research procedure model explained in the Research Methodology section (Steps 1-3 of Figure 3.2). As a comprehensive whole, this will serve as a guide for quantifying the ROI of FDMT implementation to Skanska and other construction service providers.

Here, steps 4-6 of the ROI assessment framework model in figure 11.1 will be explained in detail:

Step 4. Quantifying quality gains

Vaughan (2011) suggests a hypothetical metric for calculating savings through reduced cost of rework, based on information compiled by Skanska on a number of previous projects. Historical data suggests that typically as Skanska projects add extra construction management staff, the result is a reduction in the final cost of rework, with exponentially decreasing returns (see figure 11.2), presumably due to more staff available to carry out careful planning. It was therefore assumed that some of the hours saved by using Vela could be redistributed and devoted to more lengthy, careful planning, resulting better quality and less rework expenses. However, any attempt at quantifying this amount in dollar terms would be *extremely speculative* and prone to error, and because each individual project is built only once, it is not possible to accurately compare final build quality and cost of rework with and without the use of Vela on a particular project.

Therefore, this ROI assessment framework suggests another approach to measuring quality gains. It is possible to compile the averages of actual historical data about rework costs and compare it to actual performance from finished projects which have used Vela. To measure quality savings from using Vela, Skanska would first need to track rework costs as a percentage of final total costs on projects which do not use Vela. There is usually a fixed contingency budget set aside for rework and a record is kept of actual contingency expenditure spent on rework. By establishing a typical baseline for rework costs on particular types of projects, based on complexity, size, contract amount, type (eg. Hospital, Educational, Data Center, etc.), Skanska would then need to measure the percentage of final rework costs on all completed projects on which Vela was used. In a similar way to the way that hours saved by using Vela were calculated in this study, typical savings due to reduced rework by using Vela could be calculated by subtracting the average rework costs by project type using Vela from the pre-Vela baseline estimates:

Reduced rework cost% = Average rework cost% without Vela – Average rework cost% with Vela

The final reduced rework costs can thus be calculated:

- **Per project** by subtracting the actual result from the historical baseline estimate for similar projects (subject to a lot of error as it is difficult to know how much reduction in final rework cost is attributable to Vela or other factors)
- **Per project class** for example, difference between average rework cost of college dormitory expansions under 50,000 ft^2 not using Vela and the average rework cost of such projects using Vela (more accurate, as including a larger number means the sum of the errors due to non-Vela influencing factors should approach zero).
- **For all projects using Vela**. Most accurate because it is based on largest amount of data.

A simple example (using fictitious values) of how reduced rework costs attributable to Vela use could be calculated is below:

Project Type	Without Vela (baseline)	With Vela	Reduced rework costs
Hospital Expansion	8,00%	5,50%	2,50%
University	6,00%	4,00%	2,00%
Data Center	3,00%	2,50%	0,50%
Government	4,50%	3,00%	1,50%
Total	**5,38%**	**3,75%**	**1,63%**

Based on the final reduced rework costs, dollar savings can be estimated per project by multiplying final project cost by the percentage of educed rework cost:

Savings through reduced rework = reduced rework cost % * Total final project costs

This study asked the 38 participants to estimate typical rework costs on previous projects they had been involved in, with answers ranging from 0,5% to 30%, and an average estimate of 7,5%. This wide range of past experiences suggests that rework costs vary substantially between projects, as figure 4.1 shows:

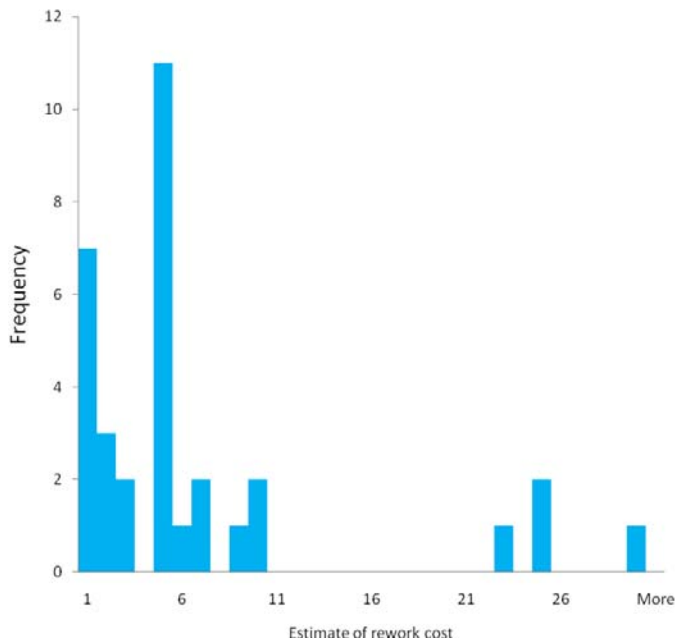


Figure 4.1 Estimate of typical rework costs of surveyed Vela users

5. Calculating direct costs

The surveys distributed by this study asked Skanska's Vela administrators to estimate the time spent training new users, uploading documents, hyper-linking RFIDs and performing other tasks related to keeping the Vela database up and running on their projects. These are indirect costs, measured in hours, added to the total amount of hours spent on weekly tasks while using Vela. However, there are also direct dollar costs for purchasing Vela software and hardware (iPads, barcode printers and scanners, mobile on-site resource stations).

The 15 Vela administrators surveyed were asked to fill out estimates for software license and hardware equipment costs, but in many cases they did not know the actual expenditures. Furthermore, without accurate details about quality savings, it is not possible to work out a useful estimate of ROI so the direct costs figures have not been used in this research. However, it should be fairly easy to obtain accurate data on FDMT related expenses.

6. Calculate total savings and ROI

Total quantifiable savings are the combined sums of savings due to efficiency gains and savings due to reduced rework.

These total savings minus direct purchasing costs of software and hardware divided by the direct costs give a simple ROI figure, which can be used to judge the quality of investing in FDMT:

ROI of FDMT = ((time savings + quality savings) – direct costs) / direct costs

NON-QUANTIFIABLE COSTS AND BENEFITS

The ROI assessment framework describes how to convert quality and efficiency gains into dollar savings. However, there are a number of other costs and benefits which are virtually impossible to accurately quantify, but which still may have significant affects on the total final ROI of using FDMTs. These factors should taken into account by Skanska when evaluating the use of Vela.

TEMPORARY LOSS OF EFFICIENCY WHILE LEARNING VELA

An indirect but real cost of implementing any new working method is the loss of efficiency that CM staff will experience while learning how to work in a new way, relative to the previous efficiency.

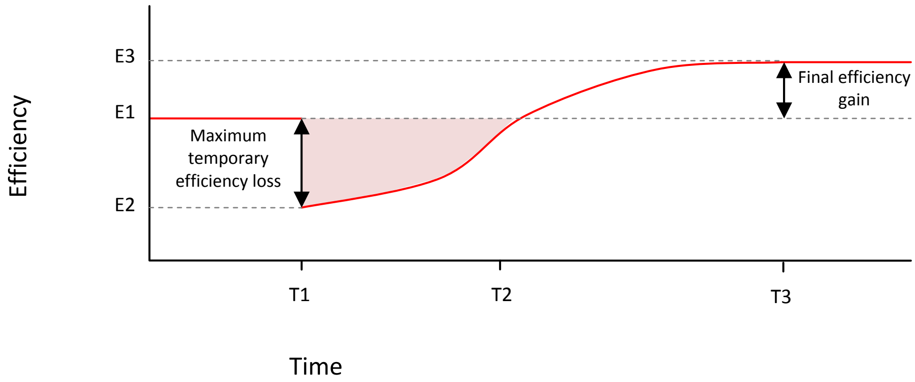


Figure 4.2 Temporary efficiency losses while learning

In figure 4.2, the time prior to T1 shows a constant average level of efficiency achieved by carrying out activities with using an established working method. This is a schematic representation of the efficiency recorded by the pre-Vela baseline. At T1, there is a sudden loss of efficiency due to the introduction of a new working method or tool (such as Vela), which users are not experienced with. The efficiency between T1 and T2 is lower than the previous level, as users learn how to effectively operate using the new working method. This lost efficiency is a cost (represented by the shaded area), but it is very difficult to accurately quantify due to the difficulty of establishing a measurable point at which the baseline efficiency is reached (T2). Beyond T2, the introduction of the new method begins to pay off, as efficiency using the new method is higher than the previous one. Finally, a maximum average level of efficiency is reached at T3. The difference between T3 and T2 is the efficiency gain measured by the research undertaken by this study.

LONG TERM BENEFITS

The use of Vela on construction projects may result in benefits which are realized after the project is completed and handed over to the client:

1. Higher number of contracts awarded

A general contractor which consistently makes use of innovative technologies such as FDMTs to deliver projects with quicker schedules, lower costs and higher quality than their competitors will develop a reputation for good performance amongst clients. This reputation may result in more contracts being awarded to the contractor, particularly when the award criteria are not based on lowest bids.

Subcontractors who use FDMTs in an effective manner will be able to deliver their work packages with substantial cost savings. Over time, they will be able to reduce their cost estimates and bid prices due to these consistent savings. General contractors can also figure these lower costs into their bid prices when tendering on new projects, increasing their chance of winning a contract, particularily when it is awarded on a low-bid basis.

Both phenomenon described above have the substantial benefit of a higher overall turnover for the general contractor in the long term.

2. Benefits due to more use of prefabrication

When used properly, the material and equipment tracking capabilities of Vela make it possible to accurately and effectively track prefabricated, modular components. This makes the use of prefabrication on a project more feasible. As Vela and other FDMTs gain a reputation for improving the process of material tracking on site, project teams may begin to reconsider the logistics of procuring materials and equipment. Design teams aware of FDMTs' tracking capabilities may be able to consider a wider range of possible design alternatives, with more components assembled and manufactured off-site. The increased use of prefabrication has benefits in terms of schedule, costs and quality of the final built product, although it is very difficult to quantify the monetary savings as a result.

These types of benefits are considered by lifecycle-based approaches to measuring project success, (described in section 2.2)

4.1.2 RECOMMENDATIONS FOR INCREASING EFFICIENCY GAINS

The research undertaken for this study identified a number of factors which influence efficiency gains. Focusing on these factors in the right way can maximize the efficiency gains that Skanska's construction management staff achieve through using Vela, resulting in higher savings and greater ROI.

Because of the savings to Skanska through higher efficiency of Construction Management staff (see section 3.1), it is in the interest of the company to use Vela as effectively as possible in order to further increase efficiency gains. This means shifting the distribution of time savings through Vela use to the right, as shown in figure 4.3, so that more users start achieving time savings and efficiency gains in the 'advanced user' category.

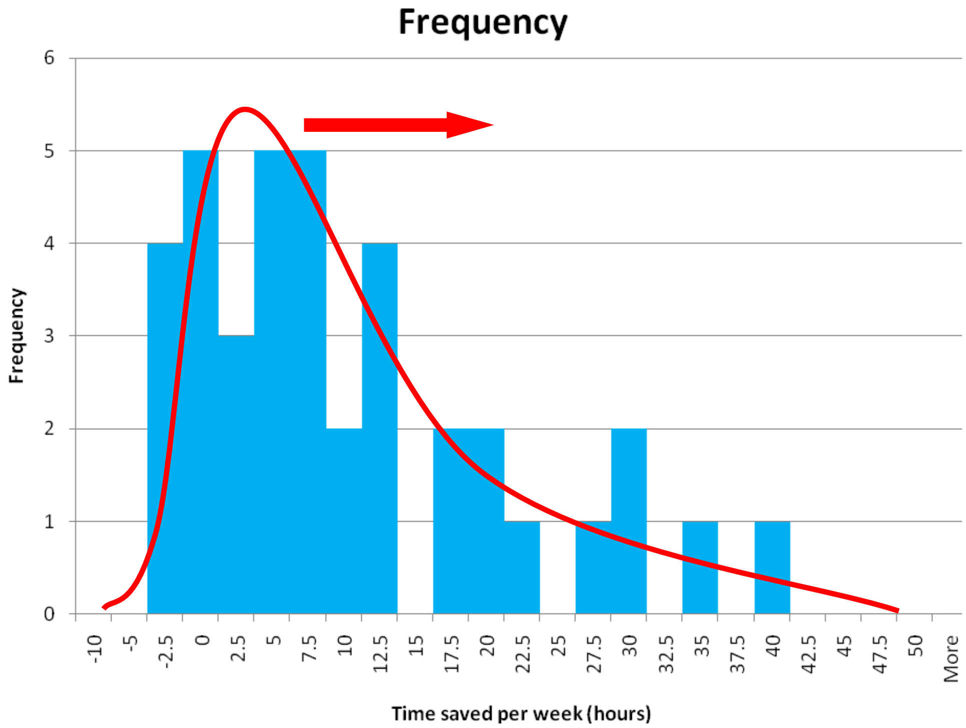


Figure 4.3 Shifting distribution of hours saved per user to increase average savings

A significantly higher level of efficiency gains were recorded on projects whose Vela administrators who are also designated Vela trainers. The difference between them and the rest of the Vela administrators surveyed is most likely a deeper level of understanding of Vela and more incentives to making sure it is properly implemented on their project. Skanska may want to consider training all Vela administrators to a level of proficiency with Vela comparable to these designated trainers, and incentivize higher levels of performance, either through efficiency gains or quality improvements. The cost of the extra training or performance-bonuses should be seen as an investment which could pay off for Skanska through cost savings due to higher efficiency and less rework.

When Vela administrators are trained, it should be stressed that the factor with the most significant influence on efficiency gains is the involvement of Non-Skanska project team members with Vela. It is vital that subcontractors, commissioning agents and owners of projects are properly introduced to Vela and that its benefits are clearly explained to them. In some projects investigated for this study, Skanska's team had bought iPads for owners or important subcontractors, so that they could use Vela on site, and in some cases seperate Vela accounts were set up for non-Skanska parties so that they could have administrator rights. This substantially increased the level of their involvement with Vela, and paid off by making communication quicker and more accurate between Skanska construction management staff and their important project collaborators. A $700 dollar iPad purchased for a vital subcontractor could pay for itself through efficiency gains alone over quite a short period if it substantially shortens communication time and increases accuracy. Other parties are more enthusiastic about using Vela if they observe direct benefits (see section 2.6.4). The findings of section 3.2.8 (Perceptions of benefits) can be used to encourage different construction project participants to use Vela and FDMT to communicate with other project team, by emphasizing the most important potential benefit to other parties.

In one project it was observed that a low rate of subcontractor participation with Vela was attributable to several subcontractors refusing to use the system for communication regarding issues unless it was explicitly written into contract requirements. Certain important contracts could have terms written into them requiring subcontractors or other parties to actively respond to issue notifications, or track certain pieces of equipment or materials using FDMTs. Furthermore, it may be possible to incentivize higher response rates or information sharing by creating performance-based rewards for subcontractors with the fastest or most consistent rates of closing out issues, since they are traceable and easy to view in infographics with Vela.

Although there was no correlation found between earlier implementation of Vela on a project and the efficiency gains that users eventually achieve, it makes sense to implement it earlier rather than later, so that users can be more efficient for as more of the project as possible, and have more opportunity to make use of the various subsets.

Projects using IPD as a delivery method could be seen as 'laboratories' for trying new functionality subsets, such as the recently released Field BIM function, as the high degree of collaboration and risk sharing allows designers to create detailed BIMs which can be used in the construction phase.

All projects are using Vela for issue tracking and the related QA/QC checklists. Most are also using Vela to either track or comission materials and equipment. However, only three are using it for owner handover, and only one is actually using Vela for all of the above mentioned functions. The surveys of Vela users' relative perceptions of benefits (see section 3.2.8) indicates that benefits 1-7, which relate more to isssue tracking and reporting, are more appreciated than benefits 8-12, which relate more to material tracking, equipment comissioning and owner handover. There is no extra direct cost to use additional functionality subsets once it has been purchased, yet two administrators interviewed in this study were not aware that it is possible to track equipment using Vela. It is important that that administrators are made aware of **all** functionality subsets during Vela training, and trained in how to use them.

4.1.3 RECOMMENDATIONS FOR INCORPORATING THE CURRENT FDMT APPROACH INTO MORE CONSTRUCTION ACTIVITIES

Most Skanska projects are achieving substantial and quantifiable time savings, efficiency gains and quality improvement through using Vela. Mainly, it is being used to track quality issues, while a number of projects teams are also using it to update information pertaining to particular pieces of equipment, linked back to a BIM model. However, there is a significant shortfall between Skanska's current approach to using FDMTs and the full available potential of such tools, elaborated in the literature review. Skanska may benefit from considering this shortfall and ways to increase the depth of their use of innovative field data management systems, which can be combined with other tools.

Essentially, FDMTs' functionality subsets all have a common methods of managing field data:

1. **Create a small digital file pertaining to a piece of information on the construction site (eg. issue or piece of equipment).**

2. **Save file on central database, accessible by multiple project participants.**

3. **Update meta-data (status, specifications, hisotry) relating to file so that it can be tracked.**

This simple approach can have profound effects on efficiency and quality, and a wide range of applications which are currently not being taken advantage of.

RE-USING DATA OUTPUTS OF VELA PROCESSES

The information generated by the Vela processes illustrated in figures 2.11, 2.15 and 2.16 can be 'recaptured' and used to support several of the methods for evaluating project performance and planning for lean construction (see sections 2.2 and 2.3):

Root cause analysis

It is currently possible for Vela users to record the root cause of a quality issue when they create an issue notification. Analytic reports which Vela automatically generates can also show statistics on these root causes. However, none of the Vela administrators on the 15 projects noted that cross-project analytic reports were being used for quality purposes. With the outputs of Vela work processes, Skanska can capture detailed information on a very large number of root causes of issues, which is an invaluable tool for root cause analysis (see section 2.2.3), as trends can be spotted, highlighting improvements or problem areas.

Progress Tracking

Data logged in Vela pertaining to the manufacturing, delivery, installation and startup of materials and equipment can also be used analytically. As illustrated in figure 2.13, this was already used to create realistic estimates of facade panel installation rates for accurate scheduling and coordination of activities in the coming weeks on the NCSU Hunt Library project. Previously, the effort and costs of accurately recording and keeping track of installation rates of materials were a significant hindrance to introducing the lean construction scheduling method of the last planner system (see figure 2.6). With FDMTs material tracking, however, this information is readily available and there is no extra cost to generate it, as it has already been used for tracking prior to installation. The location based management system (LBMS) of optimizing labor flow, another key component of lean construction, is also enabled by using this data. Therefore, Vela's and other FDMT's outputs can be seen as complementary tools to lean construction processes.

This data can also be used as inputs for EVA (see section 2.2.1), an important and widely used calculation technique for determining project progress and identifying when work has run behind schedule or over budget.

USING FDMT TO INCREASE USE OF PREFABRICATION AND SUPPLY CHAIN TRACKING

Accurate and reliable information about material locations and delivery times are vital components of just-in-time delivery, which enables prefabrication (see section 2.4). Most of the projects investigated in the research used a delivery method in which Skanska had some involvement in the design stage, such as design-bid-build with construction management in which the contractor often gives the client advice on constructability. In future projects, it during the design of a building, Skanska could make designers and clients aware of the FDMT enabled techniques which enable more efficient use of prefabrication, to specify more modular and prefabricated components, which can result in compressed construction schedules and higher quality.

Consistent use of material and equipment tracking linked to BIM models could provide Skanska with a strategic advantage over other construction service providers in terms of supply chain logistics. Proper use of FDMT material tracking, in cooperation with key suppliers and subcontractors provides an important step forward in reducing the uncertainty of material supply.

This could bring the building sector one step closer to the important efficiency, reliability and waste reductions achieved by manufacturing and retail industries by tracking inventory and obtaining accurate delivery times.

FIELD VERIFICATION WITH BIM

The newly developed Field BIM functionality subset allows site personnel to view BIM models at the point of construction, with important implications for verifying conformance. These capabilities could be incorporated with GPS, laser scanning, and machine guided technologies to increase the accuracy of installations and automate certain measurements on site.

BENEFITS BEYOND PROJECT DELIVERY

Accurate data about equipment and building systems can be logged using Vela during the owner handover phase by commissioning agents. This is useful to building owners, tenants and facility managers for a number of years after a project has been completed, as it provides as-built information about actual performance and specifications and can be linked to a BIM model to create a computer maintenance management system (CMMS), described in section 2.9. In addition to its usefulness for monitoring safety, coordinating inspections and scheduling maintenance or replacements, this accurate data can be used to analyse performance of key building systems and optimize energy efficiency. Over years, small adjustments enabled by more accurate information can add up to major savings in utility bills for building owners. Additionally, clients with a very large portfolio of buildings and real estate can incorporate information on building systems into an asset management strategy which can help determine the best times for replacing certain components and subsystems in order to maximize energy efficiency. Building energy auditors are beginning to use tablet-based applications such as EcoInsight™ and kWhOURS™ to record operating data on key pieces of equipment in the field which can then be compared to make recommendations for facilities managers. The barcodes or RFID tags placed on items of equipment during the tracking stage could be used after project completion to provide facility managers with instantaneous feedback on performance and maintenance history, saving further time during the operation phase of a building's lifecycle.

As the COBIE method of owner handover becomes more widespread, it will become more routine to deliver as-built BIM-linked information about building systems. Clients who are convinced of the longer term benefits of using FDMTs to log data at project closeout may even be willing to reimburse Skanska for the entire cost of hardware and software needed to perform commissioning and startup, in which case ROI will be near infinite, as there are no direct costs. This was the case on the GRU East Operations Center, in which the client was in fact a utilities company who had a deep understanding of the importance of accurate information regarding buildings systems for optimizing consumption and performance. This is a further benefit of closely involving a client with FDMTs.

4.1.4 RECOMMENDATIONS FOR FURTHER RESEARCH

As FDMT is a recently developed toolset and approach to construction site management, there is relatively little research into its effects and factors which influence it. The research undertaken by this study could be augmented by looking more deeply into several areas, for purposes of generating more data to make it easier to statistically confirm or reject hypotheses which are suggested by the relatively limited amount of data collected in this study.

Particularly, effects of contract structures, remuneration schemes for contractors, incentives for labor redutions and division of cost savings or contingency overruns could be interesting influencing factors to test in more detail, as this study found a slightly higher average efficiency gain from Vela use on projects with fixed price contracts, where savings go back to the contractor.

It would also be interesting to further investigate the extent to which efficiency gains vary between different types of construction management staff based on job description (ie. superintendent, project manager, project engineer) to determine if certain site personnel who devote most of their time to tasks not affected significantly by Vela use (such as planning and scheduling of work or procurement of materials) do not in fact benefit from using Vela, so as not to invest training time and resources on these staff.

The effectiveness of a top-down versus bottom-up (see section 2.5.4) FDMT implementation strategy could also be a valuable subject for further research which could have applications for the introduction of any innovative IT tool or new construction approach. It was observed that users on the PPL Data Center project were more likely to use Vela after they discovered the time-saving benefits of recording quality issues using an iPad themselves, rather than being taught how to do so in a training session. It could be worthwhile to determine how more opportunities for self-discovery of benefits could be created.

A major component of Vela's total benefits is quality improvements, quantified by reduction of rework costs. A study into these benefits and the factors which influence their magnitude is needed to evaluate how significant they actually are. A similar approach to measuring differences baseline and post-Vela performance as was done in this study could be used, and the influence of various factors could be gauged.

Finally, a recurring observation of Vela administrators interviewed for this project was that younger construction management staff seemed to use Vela more enthusiastically and effectively than older users, likely because of different levels of technology savvy. The influencing factor of age or entrenchment with an existing work method could be measured through a series of surveys.

4.2 CONCLUSIONS

In light of the information gathered by the literature review and quantitative research carried out for this study by surveying Vela users on 15 Skanska projects, it can be concluded that FDMTs are a powerful new method of conducting issue, equipment and material tracking. In its current state, a well-implemented field data management approach achieves quantifiable monetary savings for construction service providers through time savings and quality improvements.

A total of 38 surveyed users save on average 9,1 hours a week using Vela, resulting in an average efficiency gain of 16% while conducting typical construction management tasks. These average efficiency gains vary substantially between users and projects, due to a number of important influencing factors.

The most important factor influencing efficiency gains identified by the quantitative research was the involvement of non-Skanska project participants with Vela, namely subcontractors, clients and commissioning agents. Another significant finding was that Vela administrators who are also designated Vela trainers within Skanska work on projects whose users recorded a higher efficiency gain, suggesting that the depth of knowledge of how to use an FDMT is an important factor influencing efficiency gains.

Although it could not be confirmed, mainly due to a small sample size of 15 projects, the data suggests that there are higher average efficiency gains in projects with fixed-price lump sum contract structures which return savings to the contractor, and that it is possible to achieve higher efficiency gains by using more of the available Vela functionality subsets.

Thus, by focusing on increasing the depth of administrator knowledge and the involvement of subcontractors, owners and commissioning agents with FDMTs, construction service providers should be able to incrementally increase the efficiency gains which they achieve through using FDMTs.

In the future, it should be possible for Skanska to make use of the full ROI assessment framework for FDMT developed in this study, to include quantitative measurements of quality improvements when evaluating the benefits of introducing innovative construction approaches. This framework serves as a guide for companies to quantify costs and savings due to quality and efficiency improvements, and will help them evaluate implementation of new tools as a strategic decision making aide.

FDMT enables the use of BIM and ADCT tools as well as innovative lean construction and prefabrication approaches, but currently applications like Vela are mainly being used as a tool in a set of quality management techniques. This may be due to the phenomenon of demand pull, as the most strongly expressed market need: improved quality issue tracking system is the feature which is utilized the most effectively, above the other functionality subsets.

At best, the proper management of field data can be a comprehensive method for coordinating supply chain management, construction activities and building maintenance post-completion. In addition to incremental efficiency improvements, a thoughtful consideration of the full potential use of FDMTs can help construction service providers such as Skanska fundamentally increase the efficiency of their operations business processes and give them a distinct competitive advantage with clients. The observations of this study show that although the current field data management approaches of Skanska achieves considerable benefits; it does in fact short of its full potential uses. Skanska is widely considered one of the most innovative firms in the industry, with regular innovation grants and a devoted R&D manager for each business unit (Dewick, Miozzo, 2004), so this shortfall is likely the case with other construction companies as well. The suggestions in the recommendations section should be heeded by companies wanting to get even more benefits out of this important new set of IT tools for the construction industry and deepen the impact of adopting a field data management approach. The benefits observed at the moment may turn out to be the tip of the iceberg of the savings that FDMTs can offer.

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APPENDIX A - STATISTICAL TESTS

A.1 GOODNESS OF FIT TESTS

TEST OF SAMPLE 1 - WEEKLY HOURS SAVED BY 38 VELA USERS

The following is the results of the goodness of fit test for a normal distribution:

Distribution check Goto General Content List Goto input of parameters or data
Remove the two smallest and the two biggest values | Normal distributed | Goto cell A1

Anderson-Darling Goodness-of-Fit test on F(theoretical)= Normal distributed ; After removal of some outliers ; n = 32
Alpha one-sided (%) 5.00 50 α = level of significance H0: Data are distributed as Normal distributed
α(one side 0.05 H1: Data are NOT distributed as Normal distributed
*) #NUM! means: calculation is not possible, or remove outliers
A(critical)= 0.732 A^*_{data}= 1.176
H0 is rejected at the 5% level.

Kolmogorov-Smirnov Goodness-of-Fit test on Normal distributed (Two-sided test) ; After removal of some outliers ; n = 32
F(empirical data) = k/n with k = rank number of ordered data. Highest and lowest outliers have been removed
H0: Data are distributed as Normal distributed H1: Data are NOT distributed as Normal distributed
Maximal vertical distance D(n) between empirical and hypothetical PDF= 0.179 Alpha two-sided = 0.025
Critical value D(32,0.05)= 0.235 Alpha two-sided (%) = 2.50 **H0 is accepted at the 5% level.**
This means a 95% confidence interval overlapping the cdf-curve, thus a two-sided 2.5% type I error.

Chi-Square Goodness-of-Fit test on F(theoretical)= . The test is based on the histogram data, see the cells [X10:AH29].
Degrees of freedom = 12 Alpha one-sided (%) 5.00 H0: Data are distributed as Normal distributed
χ2 = 29.192 $\chi 2_{test}$ = 21.026 α = 0.05 H1: Data are NOT distributed as Normal distributed
H0 is rejected at the 5% level.

Both the Anderson Darling and Chi Square tests **reject the null hypothesis that the data are normally distributed.** I then ran the test for Gumbel type 1 distribution:

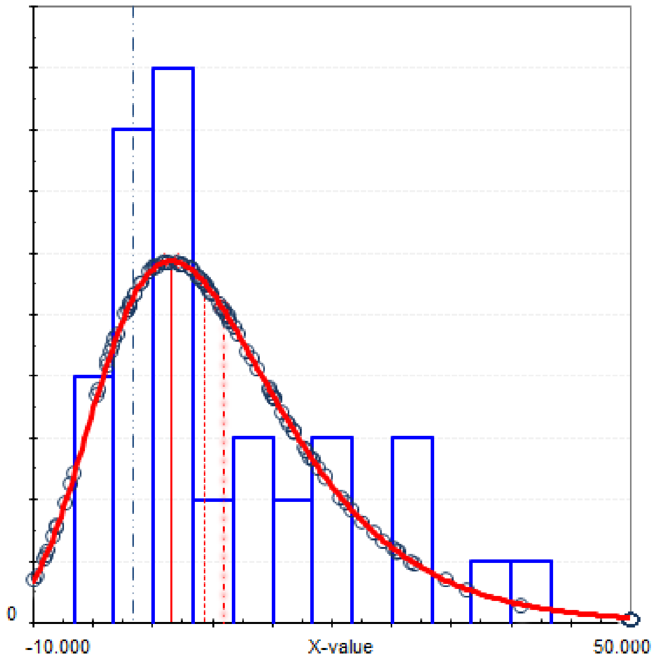
Distribution check Goto General Content List Goto input of parameters or data
Remove the two smallest and the two biggest values | Gumbel type I distribution of maxima | Goto cell A1

Anderson-Darling Goodness-of-Fit test on F(theoretical)= Gumbel type I distribution of maxima ; After removal of some outliers ; n = 32
Alpha one-sided (%) 5.00 50 α = level of significance H0: Data are distributed as Gumbel type I distribution of maxima
α(one side 0.05 H1: Data are NOT distributed as Gumbel type I distribution of maxima
*) #NUM! means: calculation is not possible, or remove outliers
A(critical)= 0.757 A^*_{data}= 0.629
H0 is accepted at the 5% level.

Kolmogorov-Smirnov Goodness-of-Fit test on Gumbel type I distribution of maxima (Two-sided test) ; After removal of some outliers ; n = 32
F(empirical data) = k/n with k = rank number of ordered data. Highest and lowest outliers have been removed
H0: Data are distributed as Gumbel type I distribution of maxima H1: Data are NOT distributed as Gumbel type I distribution of maxim
Maximal vertical distance D(n) between empirical and hypothetical PDF= 0.088 Alpha two-sided = 0.025
Critical value D(32,0.05)= 0.235 Alpha two-sided (%) = 2.50 **H0 is accepted at the 5% level.**
This means a 95% confidence interval overlapping the cdf-curve, thus a two-sided 2.5% type I error.

Chi-Square Goodness-of-Fit test on F(theoretical)= . The test is based on the histogram data, see the cells [X10:AH29].
Degrees of freedom = 12 Alpha one-sided (%) 5.00 H0: Data are distributed as Gumbel type I distribution of maxima
χ2 = 16.934 $\chi 2_{test}$ = 21.026 α = 0.05 H1: Data are NOT distributed as Gumbel type I distribution of maxima
H0 is accepted at the 5% level.

All tests confirm at 95% level that the data is **distributed along a Gumbel type 1 distribution for the maximum case:**



TEST OF SAMPLE 2 - AVERAGE EFFICIENCY GAINS OF USERS ACCROSS 15 PROJECTS

The following is the results of the goodness of fit test for a normal distribution:

Distribution check Goto General Content List Goto input of parameters or data

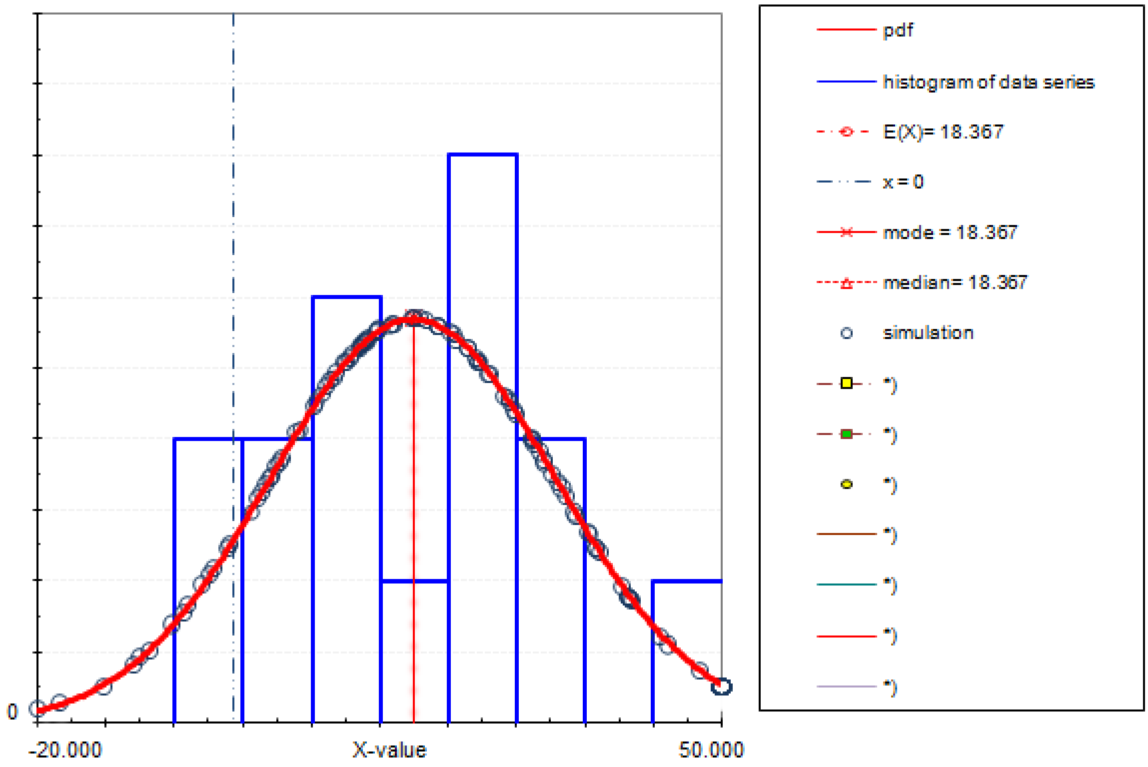
Don't remove any data point | Normal distributed | Goto cell A1

Anderson-Darling Goodness-of-Fit test on F(theoretical)= Normal distributed ; Based on all input values ; n = 15
Alpha one-sided (%) 5.00 50 α = level of significance H0: Data are distributed as Normal distributed
α(one side 0.05 H1: Data are NOT distributed as Normal distributed
*) #NUM! means: calculation is not possible, or remove outliers
A(critical)= 0.709 A^{*}_{data}= 0.289
H0 is accepted at the 5% level.

Kolmogorov-Smirnov Goodness-of-Fit test on Normal distributed (Two-sided test) ; Based on all input values ; n = 15
F(empirical data) = k/n with k = rank number of ordered data. Test is based on all data
H0: Data are distributed as Normal distributed H1: Data are NOT distributed as Normal distributed
Maximal vertical distance D(n) between empirical and hypothetical PDF= 0.097 Alpha two-sided = 0.025
Critical value D(15,0.05)= 0.335 Alpha two-sided (%) = 2.50 **H0 is accepted at the 5% level.**
This means a 95% confidence interval overlapping the cdf-curve, thus a two-sided 2.5% type I error.

Chi-Square Goodness-of-Fit test on F(theoretical)= . The test is based on the histogram data, see the cells [X10:AH29].
Degrees of freedom = 7 Alpha one-sided (%) 5.00 H0: Data are distributed as Normal distributed
$\chi2$ = 5.352 $\chi2_{test}$ = 14.067 α = 0.05 H1: Data are NOT distributed as Normal distributed
H0 is accepted at the 5% level.

All tests accept the null hypothesis at the 95% level that the data is normally distributed:



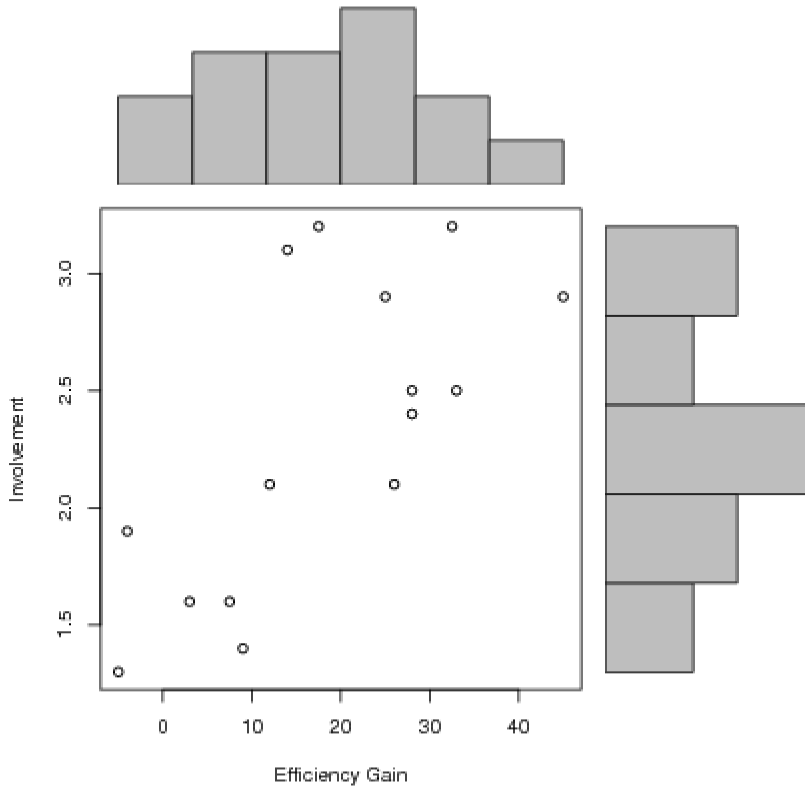
A.2 CORRELATION TESTING

The interpretation of a correlation coefficient depends on the context and purposes. A correlation above 0.5 may be regarded as significantly high in this case, where the environment is difficult to control and there is a large contribution from complicating factors.

Correlation	Negative	Positive
None	−0.1 to 0.0	0.0 to 0.1
Weak	−0.3 to −0.1	0.1 to 0.3
Moderate	−0.5 to −0.3	0.3 to 0.5
Significant	−1.0 to −0.5	0.5 to 1.0

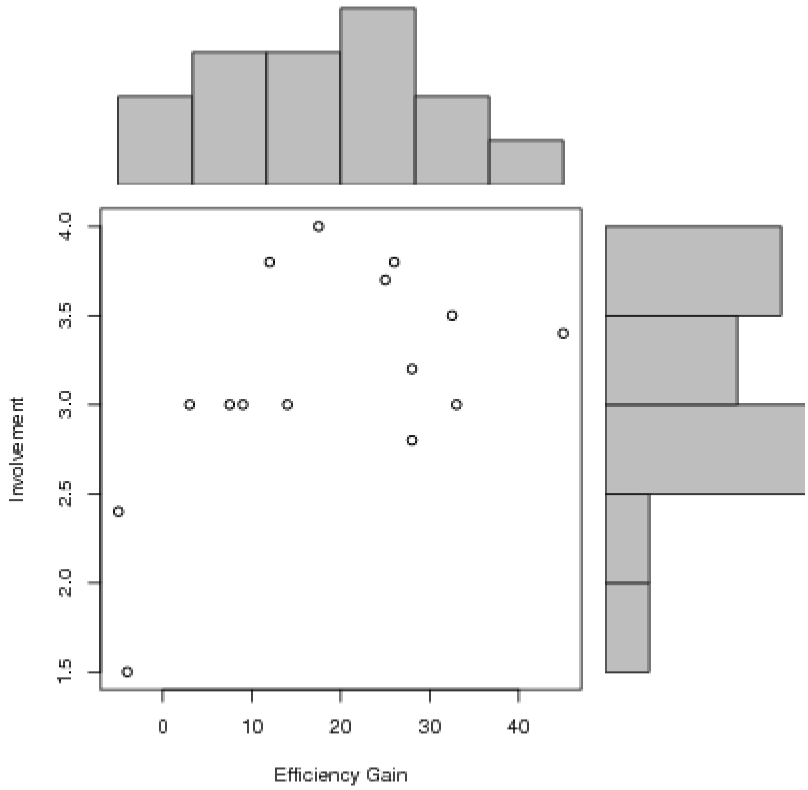
EFFICIENCY GAINS VS INVOLVEMENT OF ALL NON-SKANSKA USERS

Pearson Product Moment Correlation - Ungrouped Data		
Statistic	Variable X	Variable Y
Mean	18.1	2.31333333333333
Biased Variance	197.24	0.406488888888889
Biased Standard Deviation	14.0442158912486	0.637564811520279
Covariance	6.65214285714286	
Correlation	**0.693388297220747 - Strong**	
Determination	0.480787330722687	
T-Test	3.46956911413838	
p-value (2 sided)	0.0041493180032286	
p-value (1 sided)	0.0020746590016143	
Degrees of Freedom	13	
Number of Observations	15	



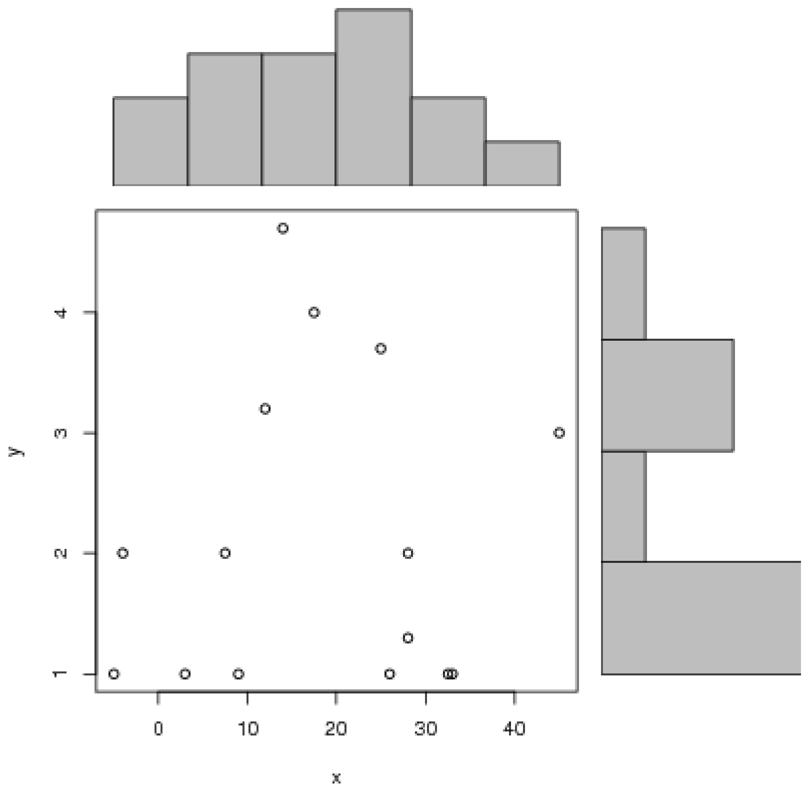
EFFICIENCY GAINS VS INVOLVEMENT OF SUBCONTRACTORS

Pearson Product Moment Correlation - Ungrouped Data		
Statistic	Variable X	Variable Y
Mean	18.1	3.14
Biased Variance	197.24	0.371733333333333
Biased Standard Deviation	14.0442158912486	0.609699379475929
Covariance	5.04571428571429	
Correlation	**0.549979094398553 - STRONG**	
Determination	0.302477004275453	
T-Test	2.37431640265158	
p-value (2 sided)	0.0336634929227151	
p-value (1 sided)	0.0168317464613575	
Degrees of Freedom	13	
Number of Observations	15	



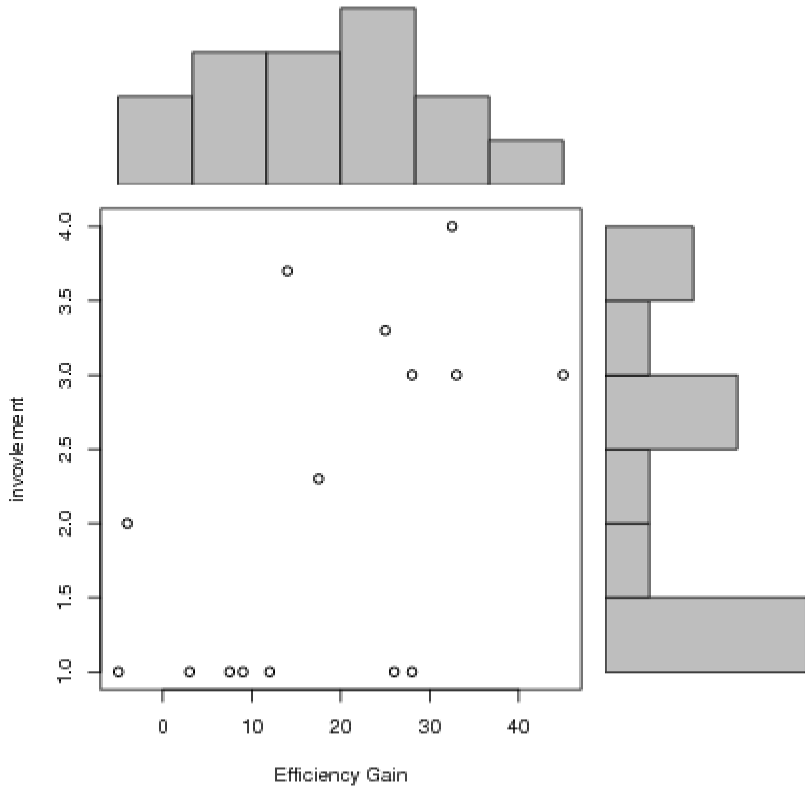
EFFICIENCY GAINS VS INVOLVEMENT OF ARCHITECTS/ENGINEERS

Pearson Product Moment Correlation - Ungrouped Data		
Statistic	Variable X	Variable Y
Mean	18.1	2.12666666666667
Biased Variance	197.24	1.52462222222222
Biased Standard Deviation	14.0442158912486	1.23475593629762
Covariance	1.58642857142857	
Correlation	**0.0853844292586927 - None**	
Determination	0.00729050075983271	
T-Test	0.308986330757629	
p-value (2 sided)	0.762228146139479	
p-value (1 sided)	0.381114073069739	
Degrees of Freedom	13	
Number of Observations	15	



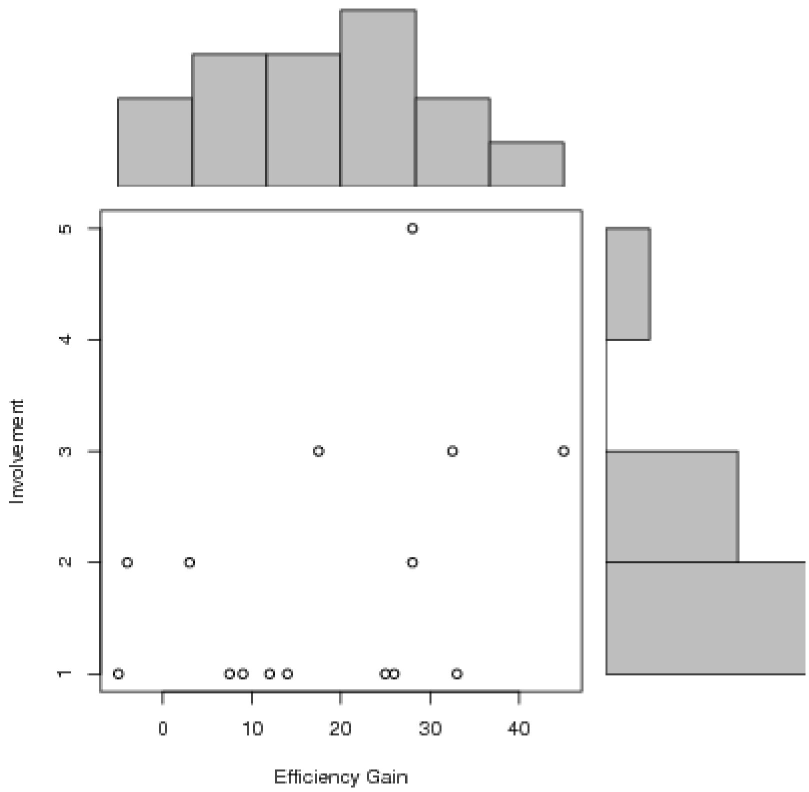
EFFICIENCY GAINS VS INVOLVEMENT OF COMISSIONING AGENTS

Pearson Product Moment Correlation - Ungrouped Data		
Statistic	Variable X	Variable Y
Mean	18.1	2.08666666666667
Biased Variance	197.24	1.23715555555556
Biased Standard Deviation	14.0442158912486	1.11227494602529
Covariance	9.18	
Correlation	**0.548491379209997 -STRONG**	
Determination	0.300842793067685	
T-Test	2.36512480452065	
p-value (2 sided)	0.0342462130375267	
p-value (1 sided)	0.0171231065187634	
Degrees of Freedom	13	
Number of Observations	15	



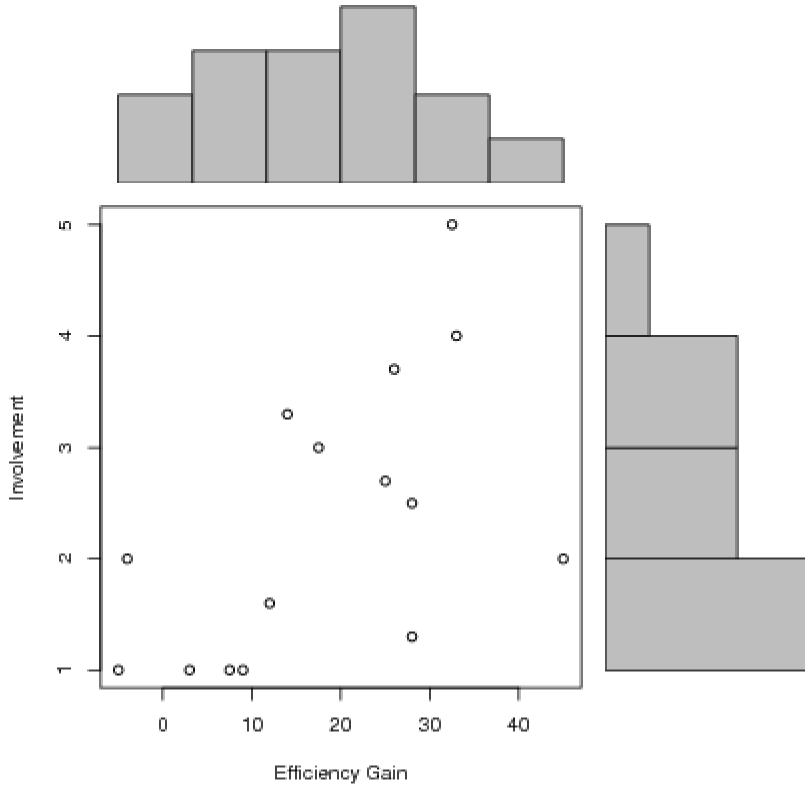
EFFICIENCY GAINS VS INVOLVEMENT OF 3RD PARTY INSPECTORS

Pearson Product Moment Correlation - Ungrouped Data		
Statistic	Variable X	Variable Y
Mean	18.1	1.86666666666667
Biased Variance	197.24	1.31555555555556
Biased Standard Deviation	14.0442158912486	1.14697670227235
Covariance	6.69285714285714	
Correlation	**0.387789672084266 - Moderate**	
Determination	0.150380829775222	
T-Test	1.51689584974032	
p-value (2 sided)	0.153228314086781	
p-value (1 sided)	0.0766141570433907	
Degrees of Freedom	13	
Number of Observations	15	



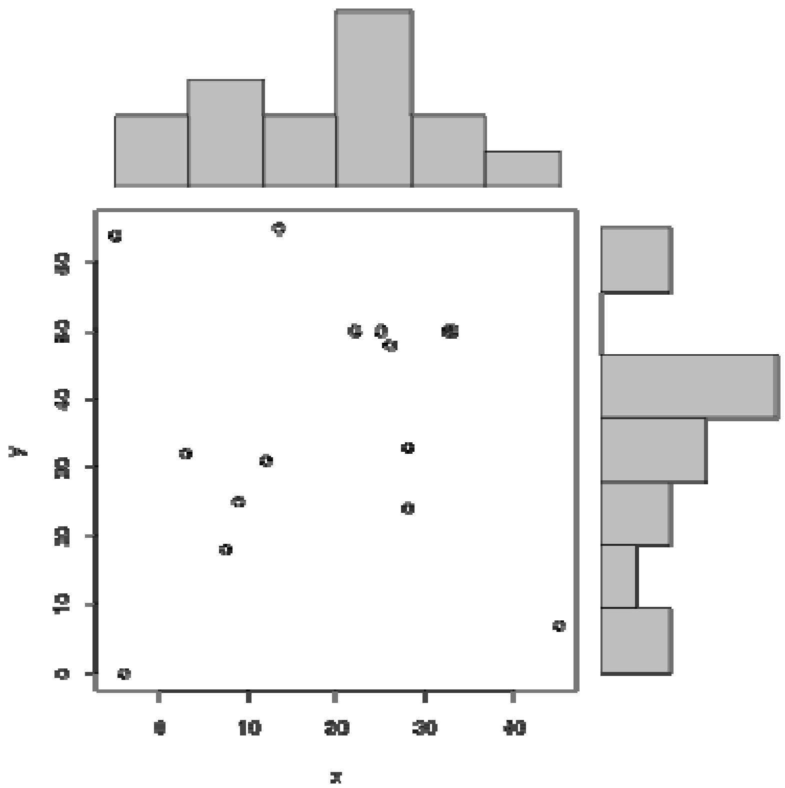
EFFICIENCY GAINS VS INVOLVEMENT OF OWNERS

Pearson Product Moment Correlation - Ungrouped Data		
Statistic	Variable X	Variable Y
Mean	18.1	2.34
Biased Variance	197.24	1.4824
Biased Standard Deviation	14.0442158912486	1.21753850041795
Covariance	10.2635714285714	
Correlation	**0.560215454799341 - STRONG**	
Determination	0.313841355796032	
T-Test	2.43845357905703	
p-value (2 sided)	0.029853459480299	
p-value (1 sided)	0.0149267297401495	
Degrees of Freedom	13	
Number of Observations	15	



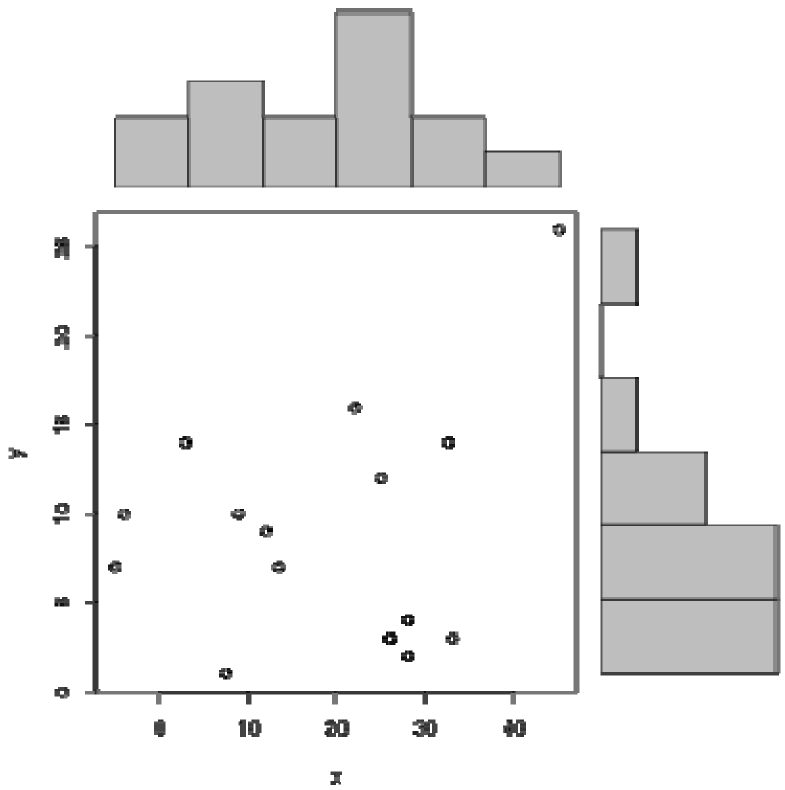
EFFICIENCY GAINS VS % OF PROJECT COMPLETE WHEN VELA IMPLEMENTED

Pearson Product Moment Correlation - Ungrouped Data		
Statistic	Variable X	Variable Y
Mean	18.3666666666667	36.4666666666667
Biased Variance	198.448888888889	355.048888888889
Biased Standard Deviation	14.0871888213685	18.8427410131565
Covariance	8.78095238095238	
Correlation	**0.030875214527234 - None**	
Determination	0.000953278872102719	
T-Test	0.111375267621079	
p-value (2 sided)	0.91302000259467	
p-value (1 sided)	0.456510001297335	
Degrees of Freedom	13	
Number of Observations	15	



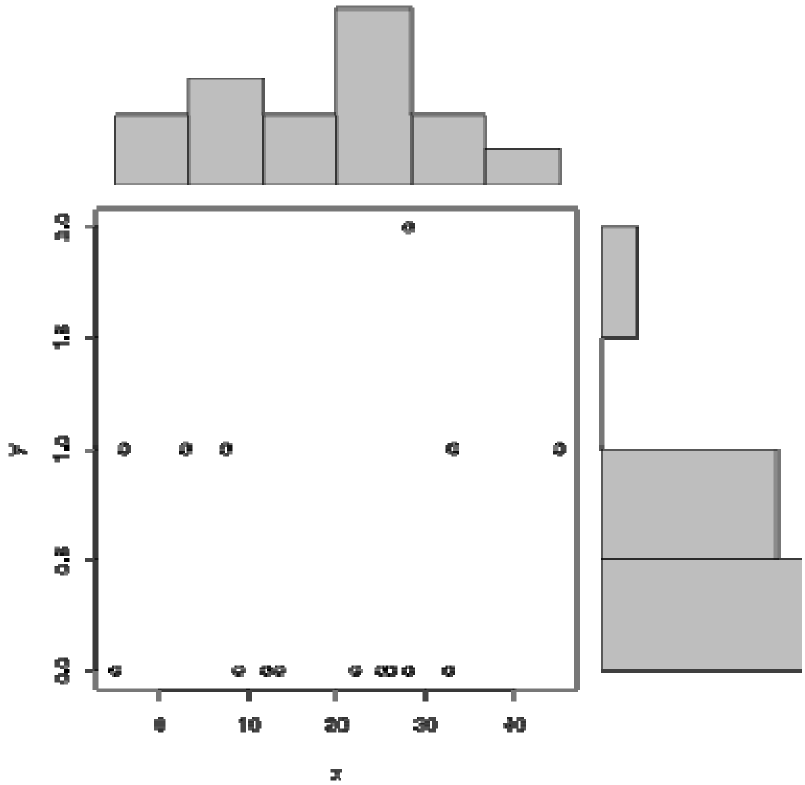
EFFICIENCY GAINS VS MONTHS OF VELA USE

Pearson Product Moment Correlation - Ungrouped Data		
Statistic	Variable X	Variable Y
Mean	18.3666666666667	9.2
Biased Variance	198.448888888889	41.0933333333333
Biased Standard Deviation	14.0871888213685	6.410408203331
Covariance	25.3142857142857	
Correlation	**0.261632946859669 - Weak**	
Determination	0.0684517988824743	
T-Test	0.977375488573055	
p-value (2 sided)	0.346221664211421	
p-value (1 sided)	0.17311083210571	
Degrees of Freedom	13	
Number of Observations	15	



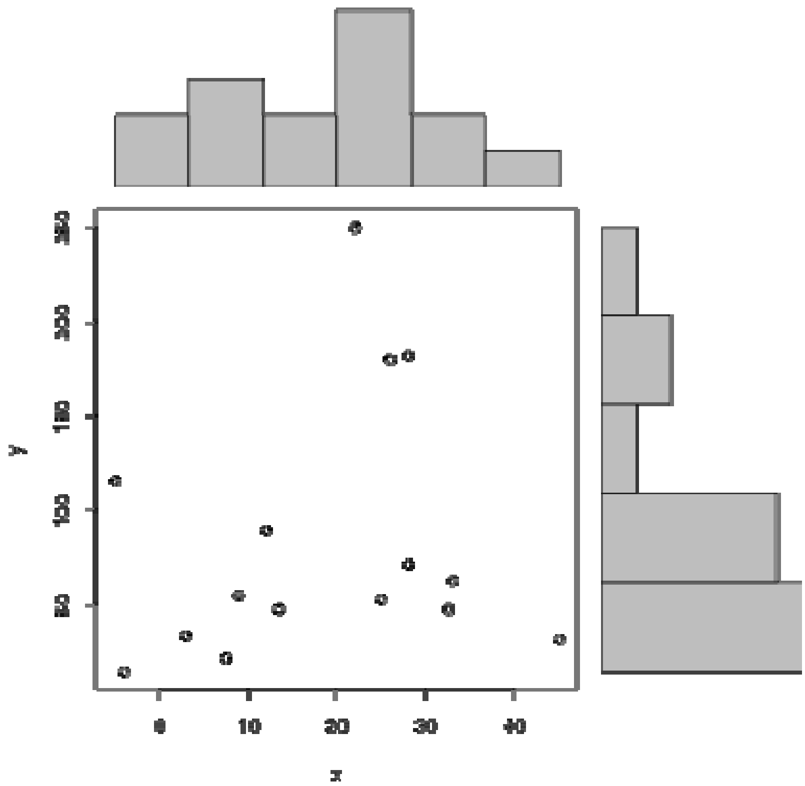
EFFICIENCY GAINS VS NUMBER OF PREVIOUS PROJECTS ADMIN USED VELA ON

Pearson Product Moment Correlation - Ungrouped Data		
Statistic	Variable X	Variable Y
Mean	18.3666666666667	0.466666666666667
Biased Variance	198.448888888889	0.382222222222222
Biased Standard Deviation	14.0871888213685	0.618241233033047
Covariance	0.852380952380952	
Correlation	**0.0913457215070793 - None**	
Determination	0.00834404083764889	
T-Test	0.330734403786219	
p-value (2 sided)	0.746115108421761	
p-value (1 sided)	0.373057554210881	
Degrees of Freedom	13	
Number of Observations	15	



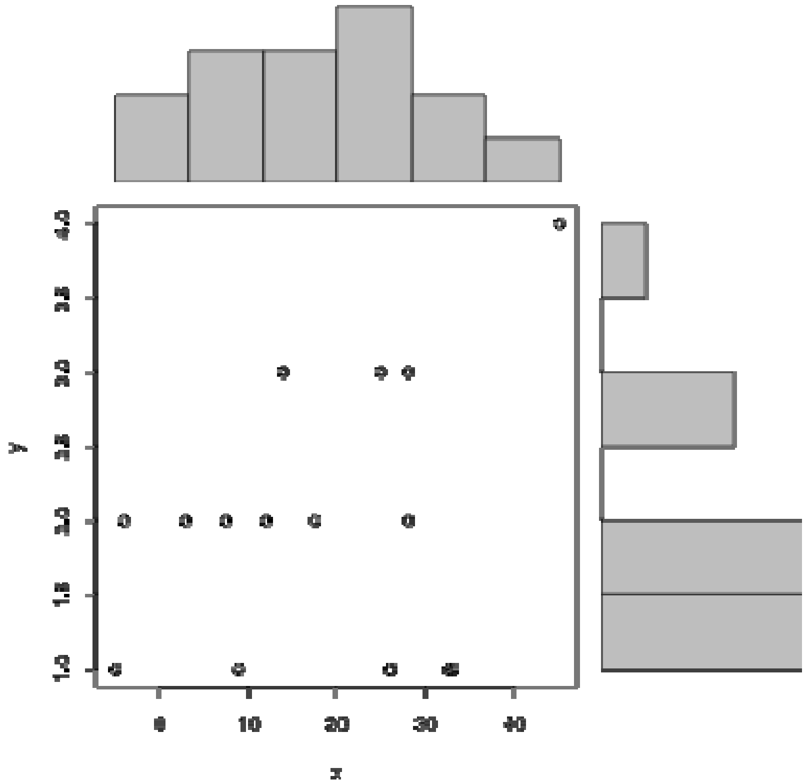
EFFICIENCY GAINS VS PROJECT SIZE

Pearson Product Moment Correlation - Ungrouped Data		
Statistic	Variable X	Variable Y
Mean	18.3666666666667	84
Biased Variance	198.448888888889	4414.93333333333
Biased Standard Deviation	14.0871888213685	66.4449646951019
Covariance	171.714285714286	
Correlation	**0.1712209070651 - Weak**	
Determination	0.0293165990161955	
T-Test	0.626598957589374	
p-value (2 sided)	0.541769648924106	
p-value (1 sided)	0.270884824462053	
Degrees of Freedom	13	
Number of Observations	15	



EFFICIENCY GAINS VS NUMBER OF FUNCTIONALITY SUBSETS USED

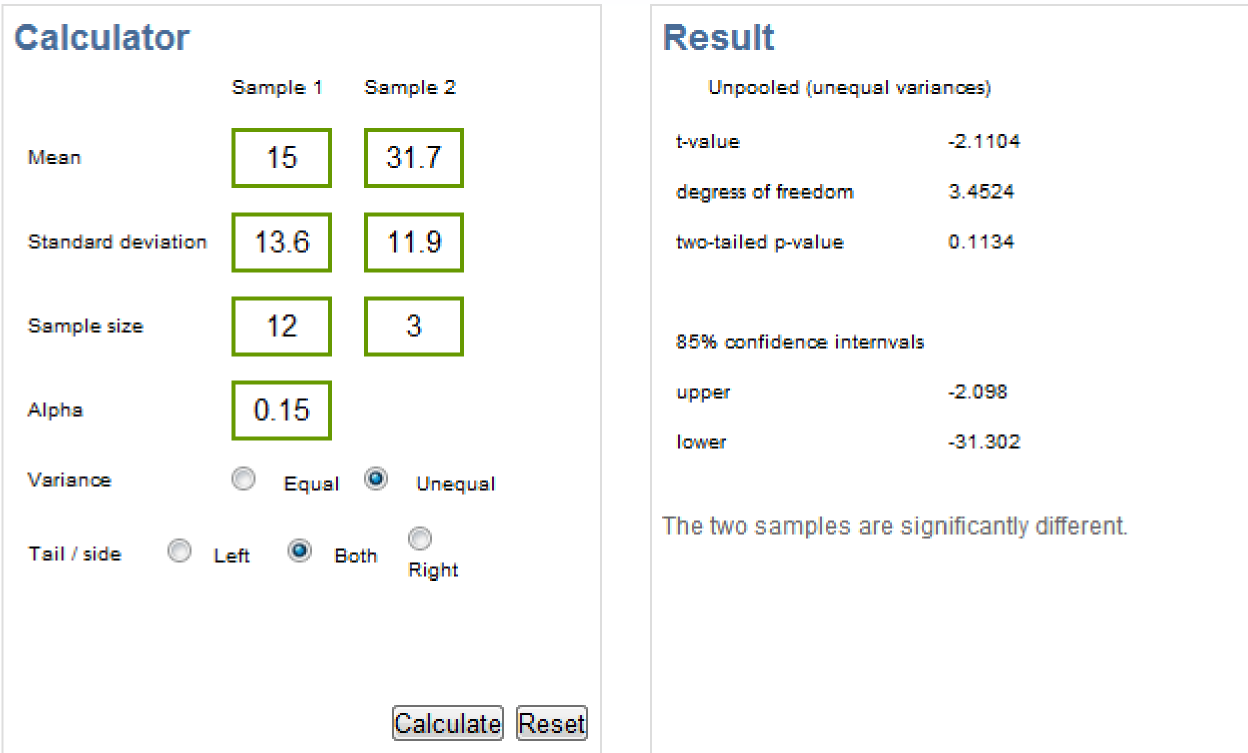
Pearson Product Moment Correlation - Ungrouped Data		
Statistic	Variable X	Variable Y
Mean	18.1	2
Biased Variance	197.24	0.8
Biased Standard Deviation	14.0442158912486	0.894427190999916
Covariance	4.39285714285714	
Correlation	0.32639339849019 - Moderate	
Determination	0.106532650577976	
T-Test	1.24501246400278	
p-value (2 sided)	0.235103217774565	
p-value (1 sided)	0.117551608887282	
Degrees of Freedom	13	
Number of Observations	15	



A.3 T-TESTS

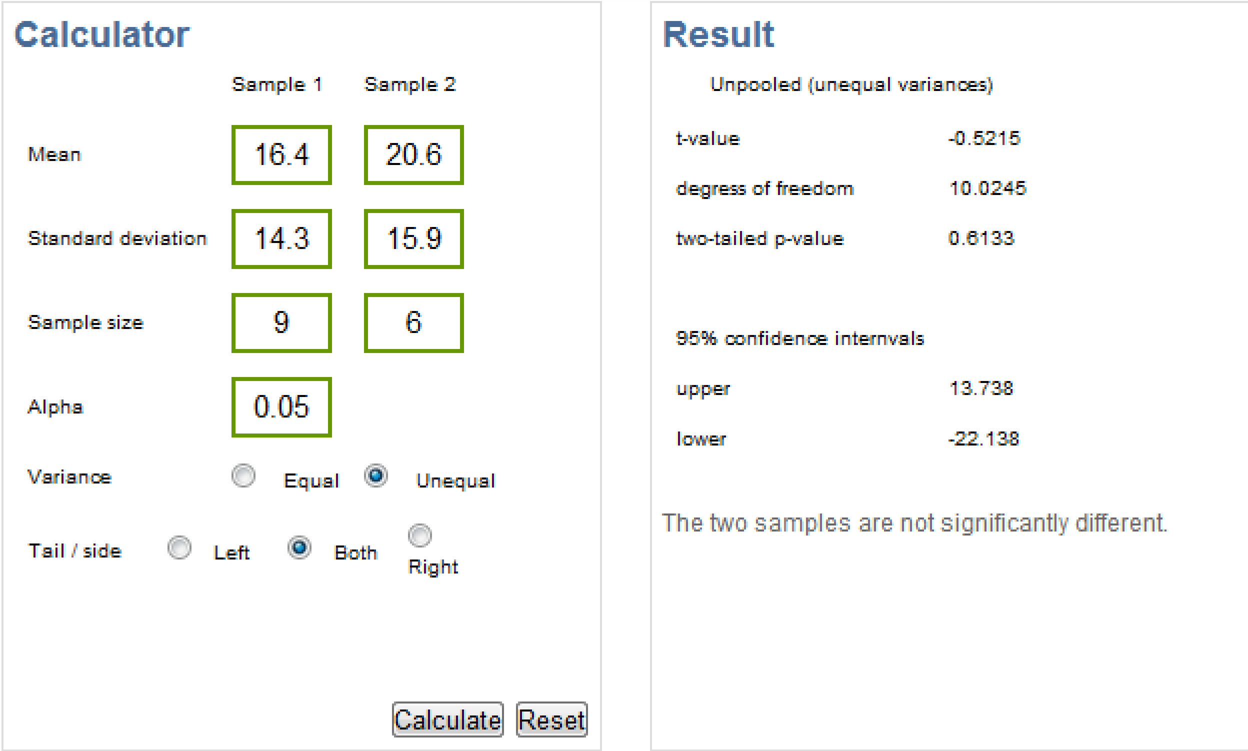
The interpretation of a significance test depends on the context and purposes. A difference at the 80% confidence interval may be regarded as significantly high in this case, where the environment is difficult to control and there is a large contribution from complicating factors.

COMPARISON OF EFFICIENCY GAINS OF VELA TRAINERS PROJECT TO REST OF SAMPLE



<u>Significantly different</u>

COMPARISON OF EFFICIENCY GAINS OF PROJECTS USING EQUIPMENT TRACKING VS THOSE NOT USING



<u>Not significantly different</u>

APPENDIX B - SUMMARIES OF PROJECT RESULTS

The following pages present summaries of the data collected by the surveys of 38 Skanska Vela users for each of the 15 projects

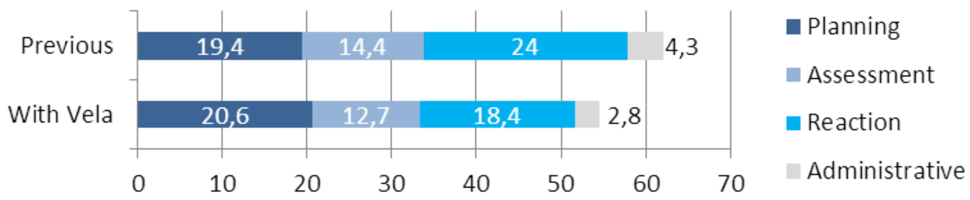
NCSU JAMES B. HUNT LIBRARY

Location: Raleigh, North Carolina
Contract Value: $90 Million
Delivery Method: CMAR
Contract Type: Guaranteed maximum price
Users surveyed: 5
Vela Tools used at time of survey:
Quality Issue tracking, Equipment Tracking

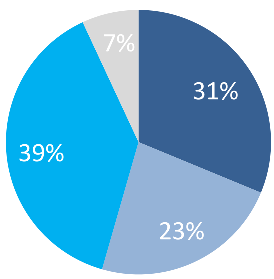
Average weekly distribution of management tasks before and after Vela use:

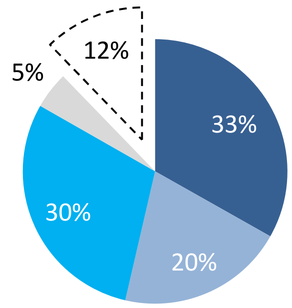
Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela % of total hours	Post Vela% of total hours	% Change
Planning	1	4,8	5,1	+0,3	8	9	+1
	2	1,4	1,1	-0,3	2	2	-
	3	1,6	1,6	-	3	3	-
	4	5,6	5,6	-	9	10	+1
	5	1,6	1,6	-	3	3	-
	6	1,6	1,6	-	3	3	-
	7	2,8	4,0	+1,2	5	7	+2
Subtotal		***19,4***	***20,6***	***+1,2***	***31***	***38***	***+7***
Assessment	8	9,4	8,8	-0,6	15	16	+1
	9	2,2	1,4	-0,8	4	3	-1
	10	2,8	2,5	-0,3	5	5	-
Subtotal		***14,4***	***12,7***	***-1,7***	***23***	***23***	***-***
Reaction	11	8,1	5,8	-2,3	13	11	-2
	12	7,3	6,1	-1,2	12	11	-1
	13	5,8	4,1	-1,7	9	8	-1
	14	2,8	*2,4*	-0,4	5	4	-1
Subtotal		***24,0***	***18,4***	***-5,6***	***39***	***34***	***+5***
Administrative	15	1,8	1,8	-	3	3	-
	16	2,5	1,0	-1,5	4	2	-2
	17	0,0	0,0	0	0	0	-
Subtotal		***4,3***	***2,8***	***-1,5***	***7***	***5***	***-2***
Total		**62,1**	**54,5**	**-7,6**	**100**	**100**	-

Average weekly hours per user:



Comparison of time distribution:

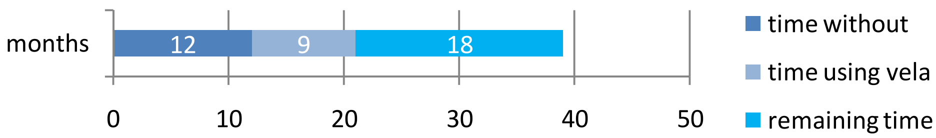




Previous Total: 62,1 hours

With Vela Total: 54,5 hours

Timeline of Vela use at time of survey:



Additional comments from surveys and interview with Vela Admnistrator Will Senner:

Contract terms on the project were open book, general conditions. All savings get returned to owner, although the implementation of Vela was entirely Initiated by Skanska, mainly to test an innovative technology and demonstrate to client that they strive for high quality, as this would result in winning more work through qualifications, reputation, and differentiation from other companies.

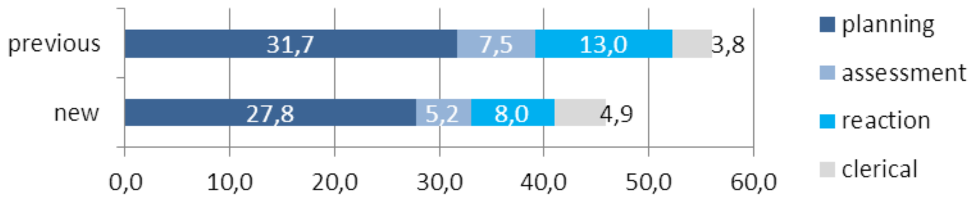
Some new, innovative document management techniques were introduced in this project which may have influenced efficiency gains, such as electronic mark-ups, Brava, Bluebeam, and Addenium which was used during bidding phase to subconctors. Vela and Addenium should have software integration. In future there may be option for integration on document side, but until then Vela should have improved document management solutions.

GEORGE C. YOUNG FEDERAL COURTHOUSE

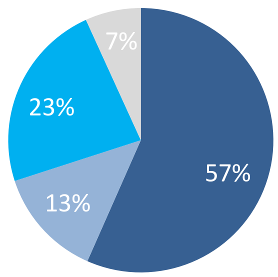
Location: Orlando Florida
Contract Value: $49 Million
Delivery Method: DBB with CM
Contract Type: Guaranteed maximum price
Users surveyed: 5
Vela functionality subsets used at time of survey:
Quality Issue tracking, Equipment Commisioning, Owner Handover
Average weekly distribution of management tasks before and after Vela use:

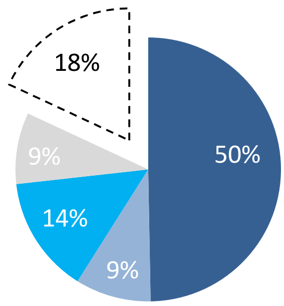
Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela % of total hours	Post Vela% of total hours	% Change
Planning	1	8	6,5	-1,5	14	14	-
	2	3	3	-	5	7	+2
	3	5,7	5,2	-0,5	10	11	+1
	4	8	6,3	-1,7	14	14	-
	5	1,5	1,5	-	3	3	-
	6	1,2	1,2	-	2	2	-
	7	4,3	4,3	-	8	9	+1
Subtotal		***31,7***	***27,8***	***-3,8***	***56***	***60***	***+4***
Assessment	8	5,3	3,7	-1,7	9	8	-1
	9	0,7	0,7	-	1	1	-
	10	1,5	0,8	-0,7	3	2	-
Subtotal		***7,5***	***5,2***	***2,3***	***13***	***11***	***-2***
Reaction	11	3,3	1,5	-1,7	6	3	-3
	12	3,3	2	-1,3	6	4	-2
	13	4,3	3,7	0,7	8	8	-
	14	2	*0,8*	-1,2	4	2	-2
Subtotal		***13***	***8***	***-5***	***23***	***17***	***-6***
Administrative	15	2,5	2,5	-	4	5	+1
	16	1,3	1,3	-	2	3	-2
	17	0	1,1	+1,1	0	2	+2
Subtotal		***4,9***	***1,1***	***-1,5***	***7***	***11***	***+4***
Total		**56,2**	**46,1**	**-10,1**	**100**	**100**	-

Average weekly hours per user:



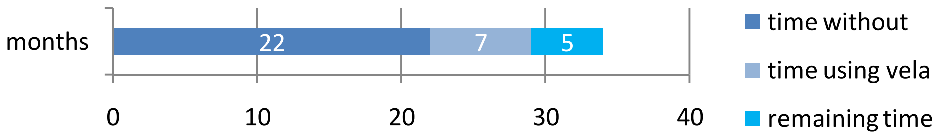
Comparison of time distribution:





Previous Total: 56,2 hours **With Vela** Total: 46,1 hours

Timeline of Vela use at time of survey:



Additional comments from surveys and interview with Vela Admnistrator Jennifer Tribble:

This is a 'shovel ready' project financed with stimulus funds. There were 6 Vela users in total, and it was observed that the product had more time-savings benefits for guys in field than for mostly office-based project managers. On major benefit which didn't necessarily save time, but which no-doubt improved quality was that subcontractors feet were 'held to the fire', by having a fully visible list of all their outstanding issues. As such issues are taken care of quicker, and it is much easier to track problem. There is a hope that there will be punch list reduction because quality is better. All savings are returned to client.

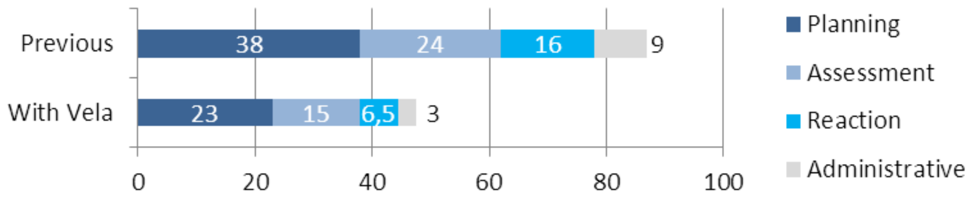
However, one problem is that subcontractors don't have access to administrative functions of Vela and cannot edit the full database. Vela was implemented too late to track equipment. Creating and maintaining the Vela database resulted in extra work and an extra time investment.

WESTIN HOTEL RENNOVATION

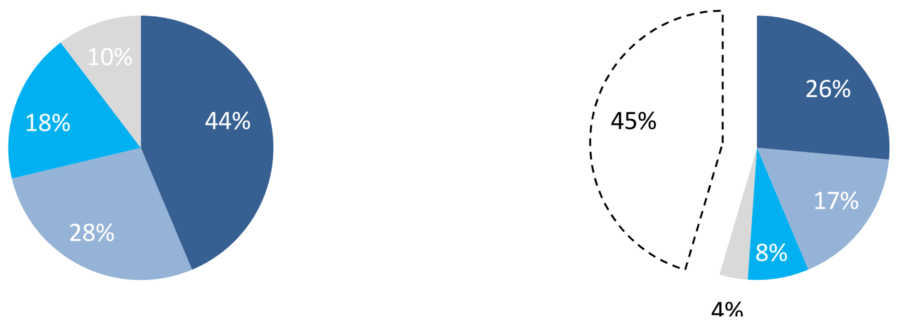
Location: Atlanta, Georgia
Contract Value: $32 Million
Delivery Method: IPD
Contract Type: Fixed Price
Users surveyed: 1
Vela functionality subsets used at time of survey:
Quality Issue tracking, Equipment tracking, Equipment commisioning, Owner Handover

Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela %	Post Vela%	% Change
Planning	1	10	6	-4	11	13	+2
	2	5	1	-4	6	2	-4
	3	5	2	-3	6	4	-2
	4	6	6	-	7	13	+6
	5	2	2	-	2	4	+2
	6	2	1	-1	2	2	-
	7	8	5	-3	9	11	+2
Subtotal		***38***	***23***	***-15***	***44***	***48***	***+4***
Assessment	8	10	6	-4	11	13	+2
	9	12	8	-4	14	17	+3
	10	2	1	-1	2	2	-
Subtotal		***24***	***15***	***-9***	***28***	***32***	***+4***
Reaction	11	10	4	-6	11	8	-3
	12	4	2	-2	5	4	-1
	13	2	0,5	-1,5	2	1	-1
	14	0	*0*	-	0	0	-
Subtotal		***16***	***6,5***	***-9,5***	***18***	***14***	***-4***
Administrative	15	9	0	-9	10	0	-10
	16	0	0	-	0	0	-
	17	0	3	+3	0	6	+6
Subtotal		***9***	***3***	***-6***	***10***	***6***	***-4***
Total		**87**	**47,5**	**-39,5**	**100**	**100**	-

Average weekly hours per user:



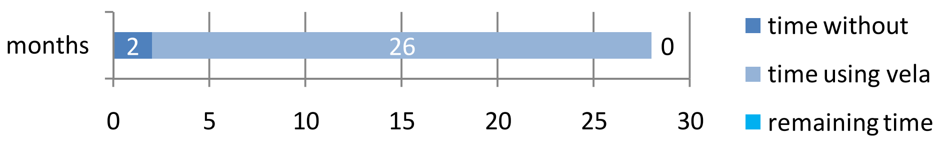
Comparison of time distribution:



Previous Total: 87,0 hours

With Vela Total: 47,5 hours

Timeline of Vela use at time of survey:



Additional comments from interview with Chip Gamble:

I am a major advocate of this software. Tracking work to complete lists, punch lists, etc. is a tremendous value in reminding subs and even my staff of their responsibilities. First phase of the project was a hotel renovation and we utilized punch lists and owner sign off (substantial completion form) per floor when completed. We utilized the first version of Vela and tablet computers. There was no available wireless throughout hotel. Second phase of the project was energy plant replacement, more drawings, and addition of QA/QC and 3rd party commissioning. This is when we implemented Vela mobile and the use of iPads. Both were beneficial. However, there are some issues with implementation and use:

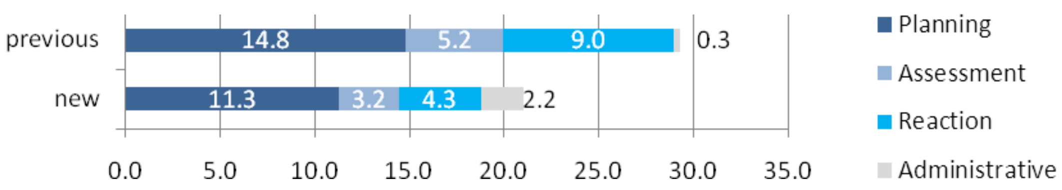
- *working to get more subs comfortable in using a computer and this software.*
- *hyperlinking attachments (rfi's) to drawings. We need to get this resolved.*
- *loaading drawings is cumbersome.*
- *Synching iPads through wireless is slow.*

CCHS WILMINGTON HOSPITAL EXPANSION

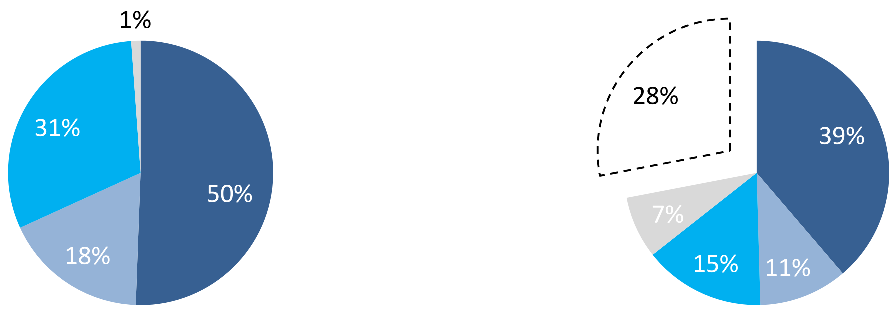
Location: Wilmington, Delaware
Contract Value: $182 Million
Delivery Method: DBB with CM
Contract Type: Guaranteed Maximum Price
Users surveyed: 3
Vela functionality subsets used at time of survey:
Quality Issue tracking, Equipment tracking

Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela %	Post Vela%	% Change
Planning	1	3,7	2,3	-1,4	12	11	-1
	2	1,7	1,2	-0,5	6	5	-1
	3	1,7	1,3	0,4	6	6	-
	4	2,8	2,3	-0,5	10	11	+1
	5	2,3	1,8	-0,5	8	9	+1
	6	0,8	0,8	-	3	4	+1
	7	1,8	1,5	-0,3	6	7	+1
Subtotal		***14,8***	***11,3***	***-3,5`***	***50***	***53***	***+3***
Assessment	8	4,2	2,7	-1,5	14	13	-1
	9	0,3	0,2	-0,1	1	1	-
	10	0,7	0,3	-0,4	2	2	-
Subtotal		***5,2***	***3,2***	***-2***	***17***	***15***	***-2***
Reaction	11	4,2	1,5	-2,7	14	7	-7
	12	2,2	1,2	-1	7	5	-2
	13	1,7	0,7	-1	6	3	-3
	14	1	1	-	3	5	+2
Subtotal		***9***	***4,2***	***-4,8***	***30***	***20***	***-10***
Administrative	15	0,3	0,3	-	1	2	+1
	16	0	0	-	0	0	-
	17	0	1,9	+1,9	0	9	+9
Subtotal		***0,3***	***2,2***	***+1,9***	***1***	***11***	***+10***
Total		**29,5**	**21,3**	**8,2**	**100**	**100**	-

Average weekly hours per user:



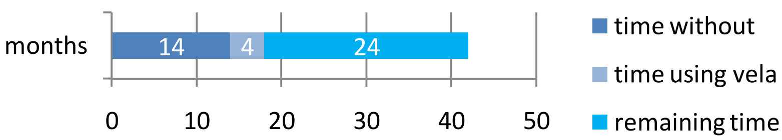
Comparison of time distribution:



Previous Total: 29,5 hours

With Vela Total: 21,3 hours

Timeline of Vela use at time of survey:



Additional comments from surveys and interview with Matt Pirolli:

Vela administrator Matt Pirolli has used Vela on about 12 projects. On this project it was mainly used to communicate on issues and track their history. Some subs were given admin rights. Vela was also used for tracking and installing door frames. Approximately 50 subcontractors were involved on the project, which will take 4 years to complete. Some older users are entrenched in set ways of working. The project is required by contract to have a 3rd party inspector, who is using Vela to track MEP equipment, but the BIM model is not sophisticated enough to link to issue tracking. Vela has the result of shorter working hours, and the ability to spend more time planning. Key features include:

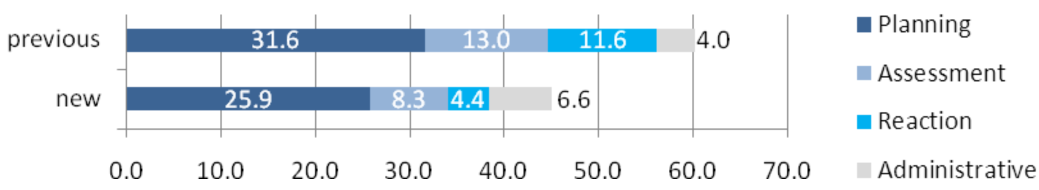
- *hyperlink rfis*
- *material tracking*
- *qa/qc*
- *installation checklist*
- *visual snapshots*
- *streamlines tasks*

GRU EAST OPERATIONS CENTER

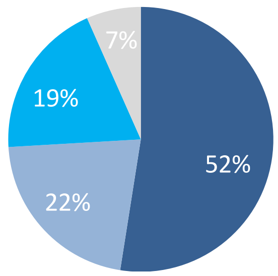
Location: Gainesville, Florida
Contract Value: $53 Million
Delivery Method: CMAR
Contract Type: Guaranteed Maximum Price
Users surveyed: 4
Vela functionality subsets used at time of survey:
Quality Issue tracking, Equipment comissioning, Owner Handover

Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela %	Post Vela%	% Change
Planning	1	10	5,3	-4,7	17	12	-5
	2	1,3	1,3	-	2	3	+1
	3	6,8	6,3	-0,5	11	14	+3
	4	7,3	7,3	-	12	16	+4
	5	2,8	2,5	-0,3	5	6	+1
	6	0,6	0,6	-	1	1	-
	7	3	2,8	-0,2	5	6	+1
		31,6	***25,9***	***-5,8***	***52***	***57***	***+5***
Assessment	8	9	5,8	-3,3	15	13	-2
	9	1	0,5	-0,5	2	1	-1
	10	3	2	-1	5	4	-1
Subtotal		***13***	***8,3***	***-4,7***	***22***	***18***	***-4***
Reaction	11	4,3	1,8	-2,5	7	4	-3
	12	1,5	0,4	-1,1	2	1	-1
	13	3	1,3	-1,7	5	3	-2
	14	2,9	1	-1,9	3	5	+2
Subtotal		***11,6***	***4,4***	***-7,3***	***19***	***10***	***-9***
Administrative	15	2	2	-	3	4	+1
	16	2	0	-2	3	0	-3
	17	0	4,6	+1,9	0	10	+9
Subtotal		***4***	***6,6***	***+2,6***	***7***	***14***	***+7***
Total		**60,3**	**45,1**	**15,2**	**100**	**100**	-

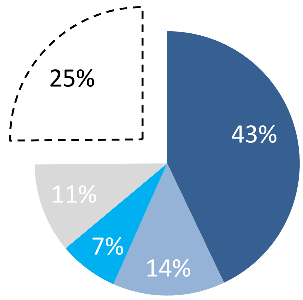
Average weekly hours per user:



Comparison of time distribution:

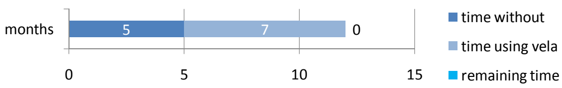


Previous Total: 60,3 hours



With Vela Total: 45,1 hours

Timeline of Vela use at time of survey:



Additional comments from surveys and interview with Frank Longo:

This is the operations center for the Gainesville Regional Utilities company, a 300,000 sq ft. complex with 3 nearly identical buildings. The similarity of the buildings let the team conduct their own experiment to see how much time using Vela for punchlisting could save. Building 1 was the benchmark, and took 240 hours to complete punch list activities without Vela. Using Vela, buildings 2 and 3 took 92 and 84 hours, respectively.

The project's commissioning agent – set up forms in Vela and estimated they saved over $30,000 in labor hours by using Vela, convincing the owner (GRU) to pay for the entire system - $15,000 for Vela software and iPads + 8,000 for barcode scanners, and printers for tracking and commissioning equipment.

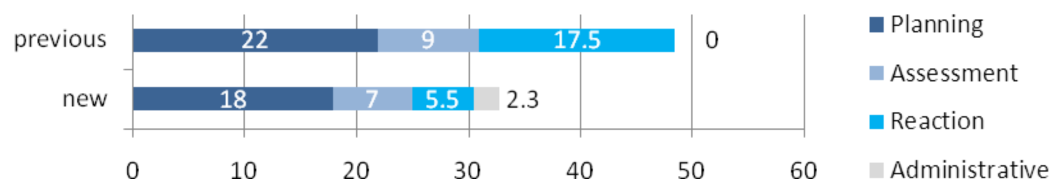
The Vela users were mostly young. The architect's confidence improved significantly upon seeing that Skanska had already logged up to 8,000 issues resulting in improved cooperation. The client is utility company so they are experienced in building maintenance and keeping track of complex systems business. For owner, handover, Skanska's team set up a data base so the owner could go into room, scan a room code, and bring up full list of equipment, as built info, etc.

BASSÄNGKAJEN

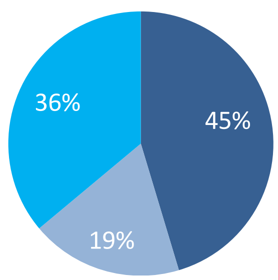
Location: Malmö, Sweden
Contract Value: $48 Million (340 million SEK)
Delivery Method: DBB with CM
Contract Type: Guaranteed Maximum Price
Users surveyed: 1
Vela functionality subsets used at time of survey:
Quality Issue tracking

Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela %	Post Vela%	% Change
Planning	1	2	1	-1	4	3	-1
	2	4	3,5	-0,5	8	11	+3
	3	2	1	-1	4	3	-1
	4	5	4	-1	10	12	+2
	5	2	2	-	4	6	+2
	6	2	1,5	-0,5	4	5	+1
	7	5	5	-	15	15	+5
Subtotal		***22***	***18***	***-4***	***45***	***55***	***+10***
Assessment	8	5	4	-1	10	12	+2
	9	3,5	2,5	-1	7	8	+1
	10	0,5	0,5	-	1	2	+1
Subtotal		***9***	***7***	***-2***	***18***	***21***	***+3***
Reaction	11	4	1	-3	8	3	-5
	12	1,5	0,5	-1	3	2	-1
	13	10	2	-8	21	6	-15
	14	2	2	-	4	6	+2
Subtotal		***17,5***	***5,5***	***-12***	***36***	***17***	***-19***
Administrative	15	0	0	-	0	0	-
	16	0	0	-	0	0	-
	17	0	2,3	+2,3	0	7	+7
Subtotal		***0***	***2,3***	***+2,3***	***0***	***7***	***+7***
Total		**48,7**	**33**	**15,7**	**100**	**100**	-

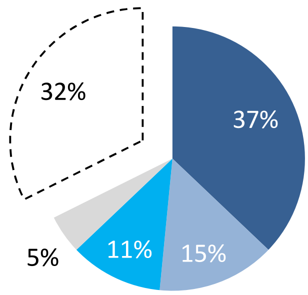
Average weekly hours per user:



Comparison of time distribution:

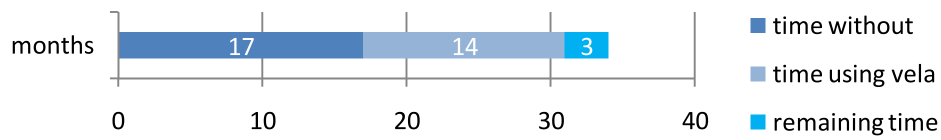


Previous Total: 48,7 hours



With Vela Total: 33,0 hours

Timeline of Vela use at time of survey:



Additional comments from surveys and interview with Johan Andersson:

Bassängkajen is an office property consisting of seven floors with garage in the basement and comprises a total of 16,200 square meters of leasable office space. The office building is one of Scandinavia's first with an energy pre-certification at the highest level, Platinum, according to the international environmental certification system LEED .

Vela was set up on the project by Matthew Pirolli (see CCHS hospital project)

Some subcontractors had iPads, printouts summarizing issues were handed to the ones without.

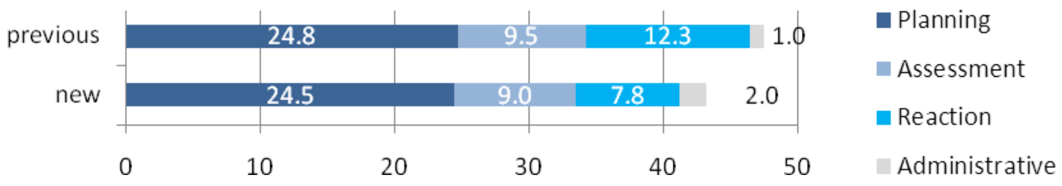
Vela is not being implemented on many projects in Sweden partly because company directors have no quantitative evidence of savings or benefits from using the software.

NOAA LABORATORIES AND OFFICES

Location: Rockville, Maryland
Contract Value: $55 Million
Delivery Method: DBB
Contract Type: Fixed Price
Users surveyed: 2
Vela functionality subsets used at time of survey:
Quality Issue tracking

Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela %	Post Vela%	% Change
Planning	1	8,5	8	-0,5	18	18	-
	2	2	3,3	+1,3	4	7	+3
	3	4,5	4,5	-	9	10	+1
	4	6,0	5,5	-0,5	13	13	-
	5	1,3	0,8	-0,5	3	2	-1
	6	0,5	0,5	-	1	1	-
	7	2,0	2,0	-	4	5	-
Subtotal		***24,8***	***24,5***	***-0,3***	***52***	***56***	***+4***
Assessment	8	6,0	6,0	-	13	14	+1
	9	2,0	2,0	-	4	5	+1
	10	1,5	1,0	-0,5	3	2	-1
Subtotal		***9,5***	***9,0***	***-0,5***	***20***	***21***	***+1***
Reaction	11	3,5	1,8	-1,8	7	4	-3
	12	3,5	1,8	-1,8	7	4	-3
	13	3,0	2,5	-0,5	6	6	-
	14	2,3	1,8	-0,5	5	4	-1
Subtotal		***12,3***	***7,8***	***4,5***	***26***	***18***	***-8***
Administrative	15	1,0	1,0	-	2	2	-
	16	0	0	-	0	0	-
	17	0	1,0	+1,0	0	2	+2
Subtotal		***1,0***	***2,0***	***+1,0***	***2***	***4***	***+2***
Total		**47,7**	**43,5**	**4,2**	**100**	**100**	-

Average weekly hours per user:

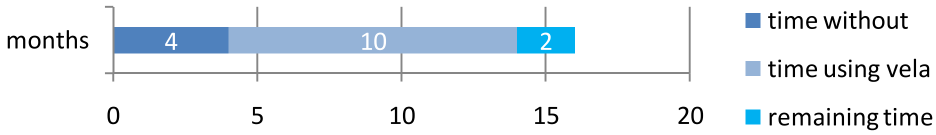


Comparison of time distribution:

Previous Total: 47,7 hours

With Vela Total: 43,5 hours

Timeline of Vela use at time of survey:



Additional comments from surveys:

It was hard on our project to implement Vela because it was introduced in the middle of the job. Implementation from project start-up would be helpful.
The ability to have a mobile plan set. Issue and check list generation are great.

Vela was a useful tool for Skanska to generate lists for the subcontractors. Larger subcontractors such as the mechanical and electrical subs who had a dedicated safety and/or quality control manager were more responsive to closing out issues with Vela.

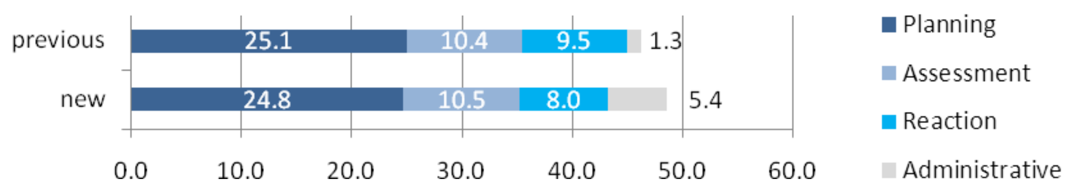
MEP subcontractors used Vela to review issues and track punch lists.

ST FRANCIS HOSPITAL RENNOVATION

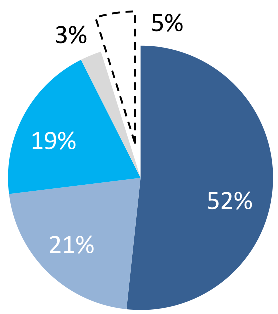
Location: Columbus, Georgia
Contract Value: $116Million
Delivery Method: DBB with CM
Contract Type: Guaranteed Maximum Price
Users surveyed: 4
Vela functionality subsets used at time of survey:
Quality Issue tracking

Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela %	Post Vela%	% Change
Planning	1	5,8	5,8	-	12	12	-
	2	3,5	3,5	-	8	7	-1
	3	3,0	3,0	-	6	6	-
	4	5,3	5,0	-0,3	11	10	-1
	5	2,9	2,9	-	6	6	-
	6	1,9	1,8	-0,1	4	4	-
	7	2,9	2,9	-	6	6	-
Subtotal		***25,1***	***24,8***	***-0,3***	***54***	***51***	***-3***
Assessment	8	7,5	7,8	+0,3	16	16	-
	9	1,8	1,8	-	4	4	-
	10	1,1	1,0	-0,1	2	2	-
Subtotal		***10,4***	***10,5***	***+0,2***	***22***	***22***	***-***
Reaction	11	2,0	1,9	-0,1	4	4	-
	12	2,0	1,0	-1,0	4	2	-2
	13	4,7	4,6	-0,1	10	9	-1
	14	0,8	0,5	-0,3	2	1	+2
Subtotal		***9,5***	***8,0***	***-1,5***	***20***	***16***	***-4***
Administrative	15	1,3	1,3	-	3	3	-
	16	0	0	-	0	0	-
	17	0	4,1	+4,1	0	8	+8
Subtotal		***1,3***	***5,4***	***+4,1***	***3***	***11***	***+8***
Total		**46,5**	**48,8**	**+2,3**	**100**	**100**	-

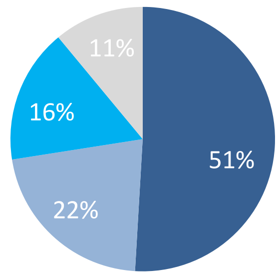
Average weekly hours per user:



Comparison of time distribution:

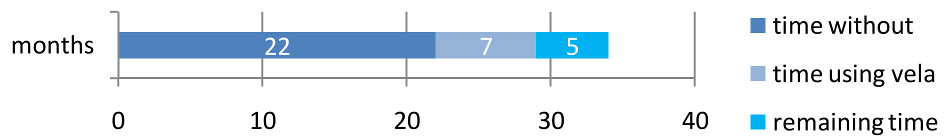


Previous Total: 46,5 hours



With Vela Total: 48,8 hours

Timeline of Vela use at time of survey:



Additional comments from surveys:

This is a four-story, 17,500 square meters clinical services building and a five-story, 15,700 square meters, medical office building. Skanska will also renovate the main hospital.

Subs are slowly getting on board with Vela and begin to positively respond.

Benefits:
1. Having evidence of QA/QC and safety of the project forever.
2. Ability to take photos, attach to issue, assign location and have an accurate record.
3. Ability to use cell phone to create an issue.

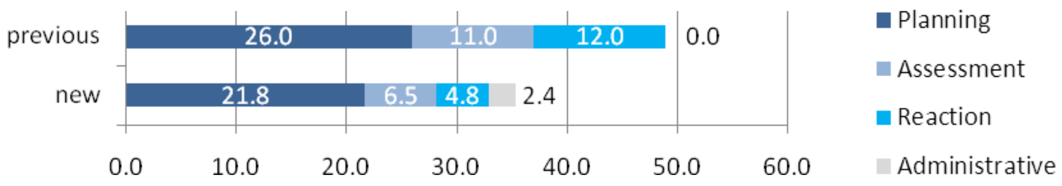
Problems
1. Difficult to open files (drawings, submittals) mark them up, and save them.
2. Hard able to upload drawing revisions easier and faster
3. Need to rename files before uploading to Vela
4. Hard able to hyperlink RFI's & submittals to drawings

UNIVERSITY OF DELAWARE CAMPUS HOUSING

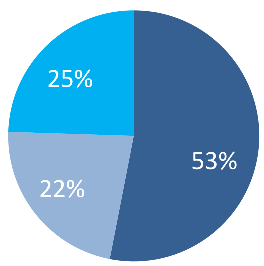
Location: Newark, Delaware
Contract Value: $72 Million
Delivery Method: DBB
Contract Type: Fixed price
Users surveyed: 2
Vela functionality subsets used at time of survey:
Quality issue tracking, equipment commissioning, equipment tracking

Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela %	Post Vela%	% Change
Planning	1	5,0	3,0	-2,0	10	8	-2
	2	3,0	3,0	-	6	8	+2
	3	5,0	5,0	-	10	14	+4
	4	5,0	3,8	-1,3	10	11	+1
	5	2,5	2,5	-	5	7	+2
	6	0,5	0,5	-	1	1	-
	7	5,0	4,0	-2	10	11	+1
Subtotal		***26,0***	***21,8***	***-4,3***	***53***	***61***	***+8***
Assessment	8	4,0	3,5	-0,5	8	10	+2
	9	1,0	1,0	-	2	3	+1
	10	6,0	2,0	-4,0	12	6	-6
Subtotal		***11,0***	***6,5***	***-4,5***	***22***	***18***	***-4***
Reaction	11	5,0	-1,8	-3,3	10	5	-5
	12	2,0	1,0	-1,0	4	3	-1
	13	2,0	1,0	-1,0	4	3	-1
	14	3,0	1,0	-2,0	6	3	-3
Subtotal		***12,0***	***4,8***	***7,3***	***24***	***13***	***-11***
Administrative	15	0	0	-	0	0	-
	16	0	0	-	0	0	-
	17	0	2,4	+4,1	0	7	+7
Subtotal		***0***	***2,4***	***+4,1***	***0***	***7***	***+7***
Total		**49,0**	**35,4**	**13,6**	**100**	**100**	-

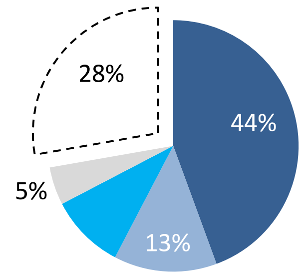
Average weekly hours per user:



Comparison of time distribution:

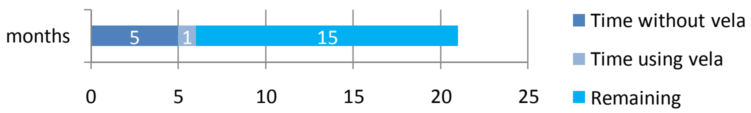


Previous Total: 49,0 hours



With Vela Total: 35,4 hours

Timeline of Vela use at time of survey:



Additional comments from surveys and interview with Vela administrator Lindsey Glasgow:

This is a 5 story dorm building. There are 4 Vela users, currently using it mainly to add issues, and fill out checklists, and look up drawings. The team is still in process of training subcontractors. client has access to system, so is involved. The team is also using iPunchlist and Prologue software.

It would be easier to drag and drop to upload, took long time to upload all contract drawings, iPad synch is slow

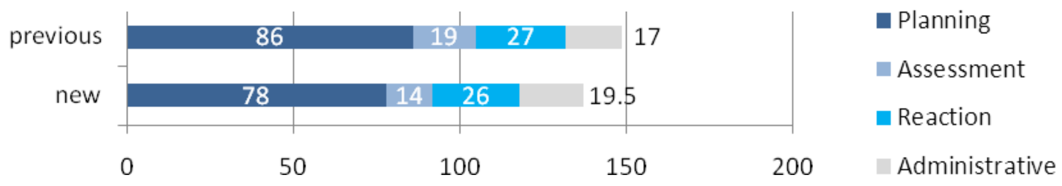
We are still in the early stages of implementing Vela, but so far it has been helpful to track issues for subcontractor's work. We receive reports from several different inspectors, so it's easy to keep track of all issues in Vela.

NOTRE DAME STAYER CENTER

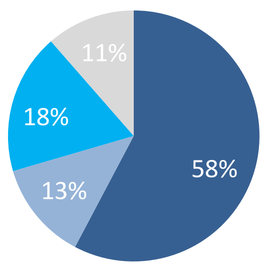
Location: Notre Dame, Indiana
Contract Value: $22 Million
Delivery Method: CMAR
Contract Type: Guaranteed maximum price
Users surveyed: 1
Vela functionality subsets used at time of survey:
Quality issue tracking, equipment tracking

Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela %	Post Vela%	% Change
Planning	1	15,0	13,0	-2,0	10	9	-1
	2	15,0	12,0	-3,0	10	9	-1
	3	15,0	14,0	-1,0	10	10	-
	4	15,0	15,0	-	10	11	+1
	5	4,0	2,0	-2,0	3	1	-2
	6	10,0	10,0	-	7	7	-
	7	12,0	12,0	-	8	9	+1
Subtotal		***86***	***78***	***-8***	***58***	***57***	***-1***
Assessment	8	10,0	7,0	-3,0	7	5	-2
	9	9,0	7,0	-2,0	6	5	-1
	10	0	0	-	0	0	-
Subtotal		***19,0***	***14,0***	***-5,0***	***13***	***10***	***-3***
Reaction	11	4,0	5,0	+1,0	3	4	+1
	12	7,0	7,0	-	5	5	-
	13	12,0	10,0	-2,0	8	7	-1
	14	4,0	4,0	-	3	3	-
Subtotal		***27***	***26***	***-1,0***	***18***	***19***	***+1***
Administrative	15	2	2	-	1	1	-
	16	15	15	-	10	11	-
	17	0	2,5	+2,5	0	2	+2
Subtotal		***17***	***19,5***	***+2,5***	***11***	***14***	***+3***
Total		**149,2**	**137,7**	**-11,5**	**100**	**100**	-

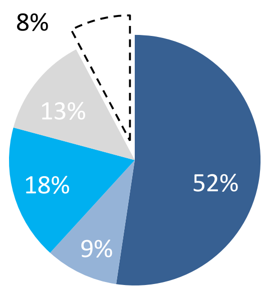
Average weekly hours per user:



Comparison of time distribution:

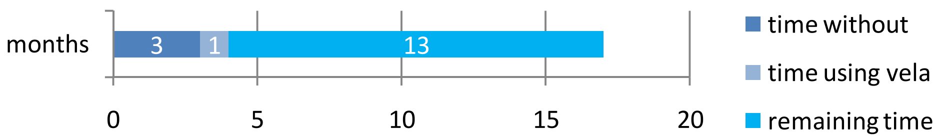


Previous Total: 49,0 hours



With Vela Total: 35,4 hours

Timeline of Vela use at time of survey:



Additional comments from surveys:

The Stayer center is a three-story, 54,000 square-foot structure featuring Notre Dame's traditional Collegiate Gothic brick-and-stone exterior.

Vela keeps issues organized and tracks history that would normally not be. Helps to organize the subs, so they can stay on task and see issues through until completion.

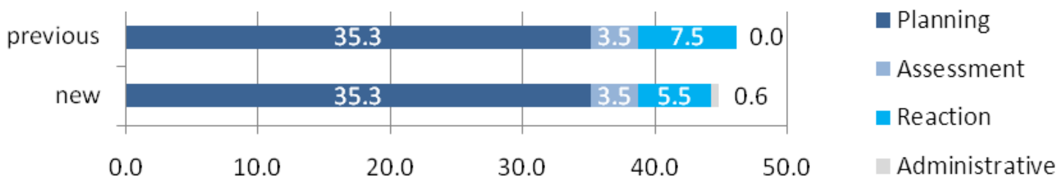
Would be nice for it to sync with Prologue on creating CE's for those issues and a way to link it to schedule activities. Also, we spend a lot of time hyperlinking files for electronic posting and we can't use them in VELA, defeats the purpose. Can't sync the documents from the teamsite so we are having to update mulitple sheets in multiple locations.

VT ACADEMIC & STUDENT AFFAIRS BUILDING

Location: Blacksburg, Virginia
Contract Value: $34 Million
Delivery Method: DBB with CM
Contract Type: Guaranteed maximum price
Users surveyed: 2
Vela functionality subsets used at time of survey:
Quality issue tracking, equipment commissioning

Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela %	Post Vela%	% Change
Planning	1	10,0	10,0	-	22	22	-
	2	7,5	7,5	-	16	17	+1
	3	5,0	5,0	-	11	11	-
	4	10,0	10,0	-	22	22	-
	5	1,0	1,0	-	2	2	-
	6	0,3	0,3	-	1	1	-
	7	1,5	1,5	-	3	3	-
Subtotal		***35,5***	***35,5***	***-***	***76***	***79***	***+3***
Assessment	8	1,5	1,5	-	3	3	-
	9	1,0	1,0	-	2	2	-
	10	1,0	1,0	-	2	2	-
Subtotal		***3,5***	***3,5***	***-***	***8***	***8***	***-***
Reaction	11	0,8	0,5	-0,3	2	1	-1
	12	0,8	0,5	-0,3	2	1	-1
	13	5,5	4,0	-1,5	12	9	-3
	14	0,5	0,5	-	1	1	-
Subtotal		***7,5***	***5,5***	***-2,0***	***16***	***12***	***-4***
Administrative	15	0	0	-	0	0	-
	16	0	0	-	0	0	-
	17	0	0,6	+0,6	0	1	+1
Subtotal		***0***	***0,6***	***+0,6***	***0***	***1***	***+1***
Total		**46,3**	**44,9**	**-1,4**	**100**	**100**	-

Average weekly hours per user:

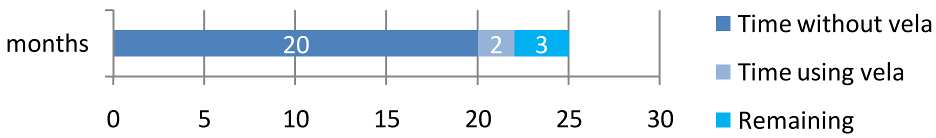


Comparison of time distribution:

Previous Total: 49,0 hours

With Vela Total: 35,4 hours

Timeline of Vela use at time of survey:



Additional comments from surveys and interview with Matt Kidwell:

The academic and student affairs building at Virginia tech includes a high-end dining hall facility with some classrooms. In total the structure has 77000 sq ft of interior space. General conditions savings go back to Skanska.

40-45 subcontractors are involve in the project, who use Vela at a variety of levels of competence. Mainly it is used for issue tracking. Reports summarizing issues are regularly printed out and given to subcontractors. Superintendents are then responsible for closing issues. A couple superintendants have iPads which gives them access to view iPad plans

Bar-coding is used to commission over 600 pieces of Kitchen equipment.

No architect involvement with Vela as they have a different issue tracking software.

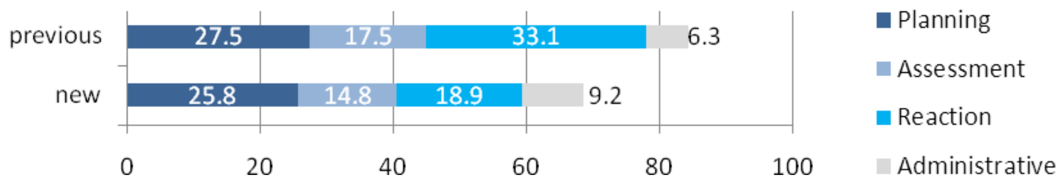
There is a Mobile electronic resource station on-site which allows all project team to access drawing, specifications and RFI's on a large common screen.

NEMOURS CHILDREN'S HOSPITAL

Location: Orlando, Florida
Contract Value: $250 Million
Delivery Method: DBB with CM
Contract Type: Guaranteed maximum price
Users surveyed: 3
Vela functionality subsets used at time of survey:
Quality issue tracking, equipment commissioning

Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela %	Post Vela%	% Change
Planning	1	6,3	5,8	-0,5	5	7	+2
	2	2,0	2,0	-	2	3	+1
	3	2,5	2,5	-	3	4	+1
	4	5,0	4,3	-0,7	6	6	-
	5	4,7	4,7	-	6	7	-
	6	3,3	3,3	-	4	5	+1
	7	3,7	3,2	-0,5	4	5	+1
Subtotal		***27,5***	***25,8***	***-1,7***	***33***	***38***	***+5***
Assessment	8	8,0	5,7	-2,3	9	8	-1
	9	6,0	4,3	-1,7	7	7	-
	10	5,8	4,3	-1,5	7	6	-1
Subtotal		***17,5***	***14,8***	***-2,7***	***21***	***22***	***+1***
Reaction	11	11,3	8,2	-3,1	13	12	-1
	12	6,0	3,7	-2,3	7	5	-2
	13	7,7	3,3	-4,3	9	5	-4
	14	8,2	3,7	-4,5	10	5	-5
Subtotal		***33,1***	***18,9***	***14,3***	***39***	***27***	***-12***
Administrative	15	5,0	5,0	-	6	7	+1
	16	1,3	1,3	-	2	2	-
	17	0	2,9	+2,9	0	4	+4
Subtotal		***6,3***	***9,2***	***+2,9***	***7***	***13***	***+5***
Total		**84,5**	**68,8**	**-15,8**	**100**	**100**	-

Average weekly hours per user:

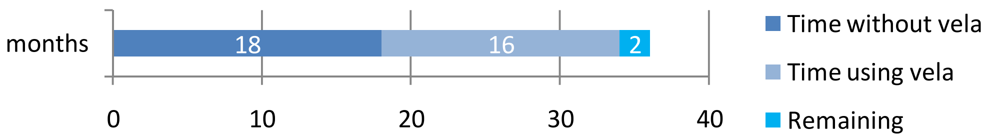


Comparison of time distribution:

Previous Total: 84,5 hours

With Vela Total: 68,8 hours

Timeline of Vela use at time of survey:



Additional comments from surveys:

600,000 sf., 95-bed hospital forms be part of a 60-acre, health campus.

All field reports issued from the architect were in Vela, however they were very slow to respond to us after the items were addressed .

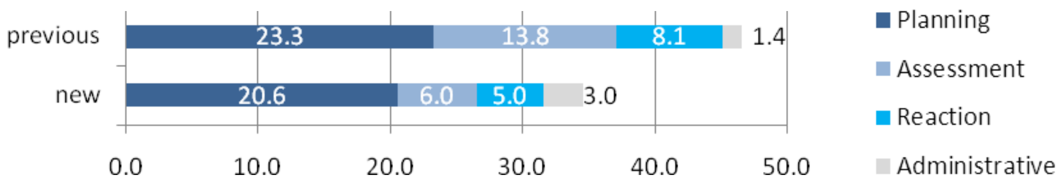
Some subcontractors were very engaged with the reports we sent them, others would take the paper printouts and slowly address them over time.

MERCK R&D LAB RENOVATION

Location: Kennilworth, New Jersey
Contract Value: $180 Million
Delivery Method: DBB
Contract Type: Fixed price
Users surveyed: 5
Vela functionality subsets used at time of survey:
Quality issue tracking, equipment commissioning, equipment tracking

Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela %	Post Vela%	% Change
Planning	1	4,5	4,0	-0,5	10	12	+2
	2	0,9	0,9	-	2	3	+1
	3	2,1	2,5	+0,4	5	7	+2
	4	6,9	5,5	-1,4	15	16	+1
	5	3,8	3,3	-0,5	8	10	+2
	6	2,4	1,7	-0,7	5	5	-
	7	2,7	2,7	-	6	8	+2
Subtotal		***23,3***	***20,6***	***-2,7***	***50***	***59***	***+9***
Assessment	8	6,8	3,0	-3,4	15	9	-6
	9	4,8	2,4	-2,4	10	7	-3
	10	2,2	0,6	-1,6	5	2	-3
Subtotal		***13,8***	***6,0***	***-7,8***	***30***	***17***	***-13***
Reaction	11	3,3	2,2	-1,1	7	6	-1
	12	2,7	1,7	-1,0	6	3	-3
	13	1,0	0,9	-0,1	2	3	+1
	14	1,1	0,8	-0,3	2	2	-
Subtotal		***8,1***	***5,0***	***-3,1***	***17***	***14***	***-3***
Administrative	15	0,7	0,7	-	2	2	-
	16	0,7	0,7	-	2	2	-
	17	0	1,6	+1,6	0	5	+5
Subtotal		***1,4***	***3,0***	***-1,6***	***3***	***9***	***+6***
Total		**46,6**	**34,6**	**-12,0**	**100**	**100**	-

Average weekly hours per user:

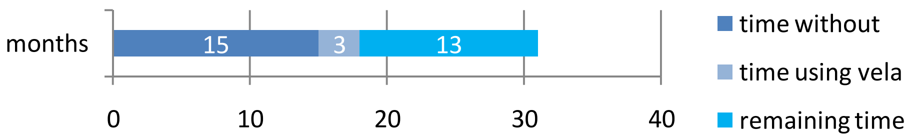


Comparison of time distribution:

Previous Total: 46,6 hours

With Vela Total: 34,6 hours

Timeline of Vela use at time of survey:



Additional comments from surveys and interview with Tracy Spataro:

Renovation of 250,000 sf of chemistry and biology laboratories and a 140,000 sf new building, more complex than most projects, involving around 70 subcontractors, with a very complicated set of MEP lines.

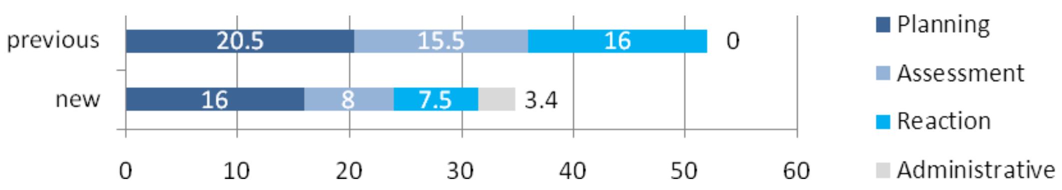
9 users are usingVela to track issues, quality checklists. Still in process of learning how to use Vela to its fullest.

PPL DATA CENTER

Location: Upper Macungie Township, Pennsylvania
Contract Value: $63 Million
Delivery Method: DBB
Contract Type: Fixed price
Users surveyed: 1
Vela functionality subsets used at time of survey:
Quality issue tracking

Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela %	Post Vela%	% Change
Planning	1	4,0	2,0	-2,0	8	6	-2
	2	2,0	2,0	-	4	6	+2
	3	2,0	2,0	-	4	6	+2
	4	6,0	4,0	-2,0	11	11	-
	5	2,5	2,5	-	5	7	+2
	6	0	0	-	0	0	-
	7	4	3,5	-0,5	8	10	+2
Subtotal		***20,5***	***16***	***-4,5***	***39***	***46***	***+7***
Assessment	8	12	6	-6	23	17	-6
	9	0	0	-	0	0	-
	10	3,5	2	-1,5	7	6	-1
Subtotal		***15,5***	***8,0***	***-7,5***	***30***	***23***	***-7***
Reaction	11	6,0	2,5	-3,5	11	7	-4
	12	2,0	1,0	-1,0	4	3	-1
	13	4,0	2,0	-2,0	8	6	-2
	14	4,0	2,0	-2,0	8	6	-2
Subtotal		***16***	***7,5***	***-8,5***	***31***	***21***	***-10***
Administrative	15	0	0	-	0	0	-
	16	0	0	-	0	0	-
	17	0	3,4	+3,4	0	10	+10
Subtotal		***0***	***3,4***	***-3,4***	***0***	***10***	***+10***
Total		**52,2**	**35,1**	**-17,1**	**100**	**100**	-

Average weekly hours per user:

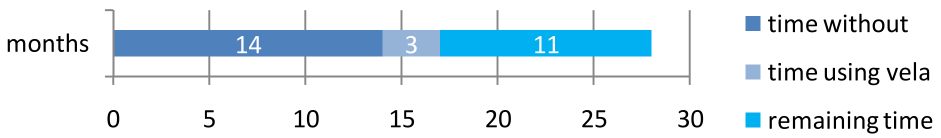


Comparison of time distribution:

Previous Total: 52,2 hours

With Vela Total: 35,1 hours

Timeline of Vela use at time of survey:



Additional comments from surveys and interview with Robert Penney:

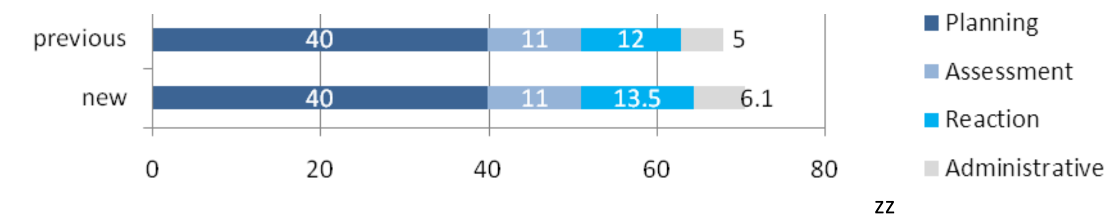
115,000 sf. data and operations center built according to high energy efficiency standards

Still in early phase of implementing Vela/construction activities. Using Vela mainly for QA/QC checklists while installing precast concrete structural elements.

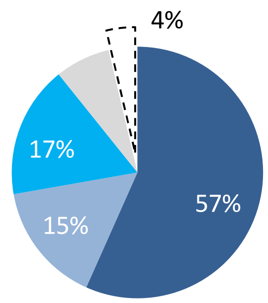
SOUTHERN CRESCENT TECHNICAL COLLEGE
Location: Griffin, Georgia
Contract Value: $15 Million
Delivery Method: DBB with CM
Contract Type: GMP
Users surveyed: 1
Vela functionality subsets used at time of survey:
Quality issue tracking, Equipment comissioning

Category	#	Pre-Vela Duration (Hrs/Week)	Post-Vela Duation (Hrs /Week)	Hour Change	Pre Vela %	Post Vela%	% Change
Planning	1	8,0	8,0	-	12	11	-1
	2	8,0	8,0	-	12	11	-1
	3	4,0	4,0	-	6	6	-
	4	8,0	8,0	-	12	11	-1
	5	4,0	4,0	-	6	6	-
	6	4,0	4,0	-	6	6	-
	7	4,0	4,0	-	6	6	-
Subtotal		***40***	***40***	***-***	***59***	***56***	***-3***
Assessment	8	5	5	-	7	7	-
	9	4	4	-	6	6	-
	10	2	2	-	3	3	-
Subtotal		***11***	***11***	***-***	***16***	***16***	***-***
Reaction	11	4	4	-	6	6	-
	12	2,0	3,5	+1,5	3	5	+2
	13	4,0	4,0	-	6	6	-
	14	2,0	2,0	-	3	3	-
Subtotal		***12***	***13,5***	***+1,5***	***18***	***19***	***+1***
Administrative	15	4	4	-	6	6	-
	16	1	1	-	1	1	-
	17	0	1,1	+1,1	0	2	+2
Subtotal		***5***	***+1,1***	***-3,4***	***7***	***9***	***+10***
Total		**68,2**	**70,8**	**+2,6**	**100**	**100**	-

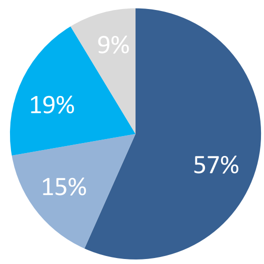
Average weekly hours per user:



Comparison of time distribution:

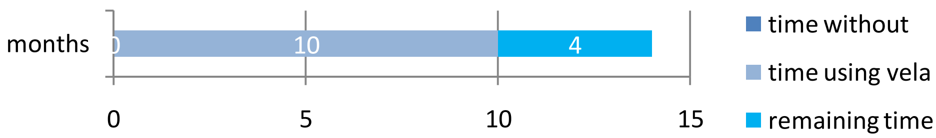


Previous Total: 68,2 hours



With Vela Total: 70,8 hours

Timeline of Vela use at time of survey:



Additional comments from surveys and interview with David Hansmann:

80,000 sf building with 12 classrooms, two biology labs and a chemistry lab, plus office suites.

The superintendent used Vela mostly to photograph and email pictures of issues. In his opinion, Vela does not seem cost effective to use for punch list.

Many subcontractors won't use Vela until it is a contract requirement that is communicated to them up front.

APPENDIX C – SURVEYS

The following message was sent via email to all project administrators, who then distributed the surveys which follow to the Vela users on their projects:

For surveys 1 and 2, could you please copy the blue text and send to Vela users according to the instructions. Survey 3 is only for you to fill out.

1. Skanska Vela user survey - *Forward the following message to all* ***Skanska construction management staff*** *who have used Vela on your project. I would also like you to fill out this first survey.*

I am a Construction Management Master's student at Delft University of Technology in the Netherlands. For my thesis project, I am measuring the ROI of Vela across multiple Skanska projects. I want to quantify the costs associated with implementing Vela, and the dollar value of time savings and/or quality improvements which can be attributed to using Vela on your project. I then want to determine what factors influence different performance results between projects.

Please could you fill out my survey regarding Vela. In it, you will be asked to rank the importance of various tools which Vela offers, estimate the weekly durations of your management tasks BEFORE and AFTER using Vela, and comment on use of Vela by other teams on your project. It can be accessed, filled out and submitted online by clicking this link: https://docs.google.com/spreadsheet/viewform?formkey=dEZMT0g2OEFzUV93TDZ2UFBibElxUHc6MA#gid=0 I expect this wont take more than 15 minutes your time, at the very most. The results will form a baseline to measure performance against, and hopefully an accurate picture of any time changes which have occured due to using Vela. Please submit the survey before Friday, May 25th.

The results of this survey will be published in an entirely anonymous way, and you do not need to fill out your names.

Thank you very much for helping me in my study. For any further information or questions, please contact me at moranmic@gmail.com.

Regards,

Michael Moran

2. Non-Skanska Vela user survey- *Forward this message to any other* ***non-Skanska project team member*** *(architect/engineer, subcontractor, client, inspector, etc) who you know has used Vela at some point during the job. You do not need to fill this out.*

I am a Construction Management Master's student at Delft University of Technology in the Netherlands. For my thesis project, I am measuring the benefits of Vela across multiple Skanska projects.

Please could you fill out my survey regarding Vela. It asks you to rank the importance of various tools which Vela offers. It can be accessed, filled out and submitted online by clicking this link:

https://docs.google.com/spreadsheet/viewform?formkey=dDdBXzNMOUVXUTdGVEZRTWdKMlQzTHc6MA#gid=0 I expect this wont take more than 10 minutes your time, at the very most. Please submit the survey before Friday, May 25th.

The results of this survey will be published in an entirely anonymous way, and you do not need to fill out your names.

Thank you very much for helping me in my study. For any further information or questions, please contact me at moranmic@gmail.com.

Regards,

Michael Moran

3. Vela Administrator survey - *This survey is* ***only for you****, and is about costs of Vela implementation, project-specific details, and reporting: https://docs.google.com/spreadsheet/viewform?formkey=dFZDN1FtaGJzdUhVMzNTUnozRXFETlE6MA#gid=0 This should take about 15 minutes to fill out at the most.*

CCHS Wilmington Hospital Expansion Project - Vela user survey

Please remember to fill in all required questions, denoted with an asterisk (*)

* Required

What is your job title? *

How many years of experience do you have in the construction sector? *

How many years of experience do you have with construction management software, including BIM? *

Which Vela tools did you use on this project? *

Tick any that apply

- Quality (Checklists and Issues)
- Safety (Checklists and Issues)
- General Issue Tracking
- Work List
- Punch List
- Equipment (Material) Tracking
- Equipment Commissioning
- Field BIM
- Owner Handover (combinations of quality check-outs, equipment and material tracking, commissioning and Field BIM)
- Other:

In your experience on previous projects, what is the average percentage of total project costs spent on rework? *

Rework is defined as: Activities in the field that have to be done more than once, or activities which remove work previously installed as part of the project regardless of source, where no change order has been issued and no change of scope has been identified by the owner.

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CCHS Wilmington Hospital Expansion Project - Vela user survey

* Required

Importance of Vela Features

Please Rank the below features of Vela on a scale from 1 - 5 :

1. Not at all important / Not applicable, 2. Not Very Important, 3. Somewhat Important, 4. Very Important, 5. Extremely Important

Access to construction documents in the field *
Viewing and annotating Plans/RFIs/Specs/Shop Drawings/Cut Sheets through use of tablet PC iPads and Mobiles, eliminating need to go back and forth to carry plans etc to and from job site.

1	2	3	4	5
○	○	○	●	○

Access to 'real time' information updated daily via 'synching' with Vela server *
Plans/RFIs/Specs/Shop Drawings/Cut Sheets

1	2	3	4	5
○	○	○	●	○

Automatically attach annotated pictures to QA/QC checklists as well as issues and punchlist *
Via Camera in Tablet PC as opposed to manually downloading pictures from a camera, printing and stapling to hard copy checklist

1	2	3	4	5
○	○	●	○	○

Automatically generate action items for subcontractors via punchlist and QA/QC checklists *
These 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	2	3	4	5
○	○	●	○	○

Filter punchlist items/issue by issue type, work area or responsible party for clear distribution to subcontractors *
As opposed to manual sorting in excel

1	2	3	4	5
○	○	○	●	○

Create electronic record and database of all QA/QC checklists *
As opposed to a file of hand written paper forms which require manual sorting and organization. Electronic paper trail can serve as audit trail reducing risk to owner and GC.

1	2	3	4	5
○	○	○	●	○

Create electronic pushpins to precisely locate an issue, punchlist item etc. on drawings *
Rather than having to verbally and physically explain and show specific location

1	2	3	4	5
○	○	●	○	○

Track quality issues and defects for specific materials *
Through bar-coding or RFID at the piece or unit level of detail

1	2	3	4	5
○	○	●	○	○

View a visual representation of supply chain information through linking material status to BIM *
Eg. seeing what pieces are manufactured, shipped, installed or damaged at any point in time

1	2	3	4	5
○	○	●	○	○

Differentiate firm from others in the industry through use of innovative project delivery techniques *

1	2	3	4	5
○	○	●	○	○

Create new RFI's on electronic plan sheets as questions or concerns arise in the field *
Eliminates need to return to office to generate RFI

1	2	3	4	5
○	○	●	○	○

Provide owner with electronic deliverables linked to BIM *
Eg. Manuals, warranties, commissioning info for equipment, etc., creating a single electronic information hub for future operations and maintenance staff

1	2	3	4	5
○	○	●	○	○

Other important features of Vela
Please elaborate on any other important features which you feel Vela provides in helping improve project delivery

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* Required

Distribution of Weekly Management Time

What's changed from before?

In this section, please estimate as accurately as possible the time (to the nearest half-hour) you spend on each task per average week.

Under PREVIOUS, estimate the hours you would have spent on each task per week before using Vela.

Under NEW, estimate the hours you actually spend on each task per week. In some cases this may be the same or more than the previous amount.

Planning

1. Coordinate with subcontractors for the next weeks' activities - Planning

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

2. Contact suppliers to verify quantities and delivery dates over next weeks - Planning

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

3. Determine what productivity for following week must be to stay on schedule - Planning

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

4. Review Plans/Specs/Shop Drawings/Submittals - Planning

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

5. CM Team Meeting - Planning

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

6. OAC Meeting - Planning

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

7. Plan for next week's construction/installation - Planning

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

Assessment

8. Go to field to monitor productivity/quality of installation/construction - Assessment

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

9. Quantify productivity of past weeks - Assessment

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

10. Walking with Owner/Commissioning Agent/Architect - Assessment

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

Reaction

11. Document/Photograph unresolved issues and their location and create appropriate notification - Reaction

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

12. Follow up statuses of last weeks' issues - Reaction

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

13. Email/Phone other trades about coordination issues/construction sequence - Reaction

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

14. Conduct Meetings with Sub and A/E on rolling punch list issues - Reaction

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

Clerical

15. Process Pay Applications - Clerical

PREVIOUS *
Hours per week:

0

NEW *
Hours per week:
0

16. Update information in the BIM to serve as electronic deliverable to Owner - Clerical

PREVIOUS *
Hours per week:
0

NEW *
Hours per week:
0

Travel from site to office

How long does it take on average to travel between the site and site office? *
Time in minutes
3

On average, how many times a day did you travel between site and office before using Vela? *
3

On average, how many times a day did you travel between site and office while using Vela? *
3

Other significant time consuming management tasks

Please describe any other typical weekly management tasks which consumed a significant amount of your time on this project
For each task, Include an estimate of previous and new hours per week, to the nearest half hour

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* Required

Project team involvement with Vela

Almost done! In this final section, please assess the extent to which other project team members were involved in using Vela.

Subcontractors' use of Vela *

	1	2	3	4	5	
No Involvement / Not applicable	◎	◎	◎	◎	◎	Very significant use

*
How effectively did subcontractors respond to issues created using Vela?

	1	2	3	4	5	
No Response / Not applicable	◎	◎	◎	◎	◎	Responded to all issues

*
Did subcontractors fill out QA/QC and Safety checklists?

Yes

Please comment on how subcontractors used Vela

Architect/Engineer's use of Vela *

	1	2	3	4	5	
No Involvement / Not applicable	◎	◎	◎	◎	◎	Very significant use

Please comment on how architect/engineer used Vela

Commissioning agent's use of Vela *

	1	2	3	4	5	
No Involvement / Not applicable	○	○	○	○	○	Very significant use

Please comment on how the commissioning agent used Vela

3rd party inspector's use of Vela *

	1	2	3	4	5	
No Involvement / Not applicable	○	○	○	○	○	Very significant use

Please comment on how 3rd party inspectors used Vela

Client/owner's involvement with Vela *

	1	2	3	4	5	
No Involvement / Not applicable	○	○	○	○	○	Very significant involvement

Please comment on how client/owner was involved with Vela

Inspector of Record (IOR) involvement with Vela *

	1	2	3	4	5	
No Involvement / Not applicable	○	○	○	○	○	Very significant involvement

Please comment on how IOR was involved with Vela

Other parties' involvement with Vela

Please record any additional use of Vela by any other parties

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* Required

What is your job title? *

How many years have you been involved in the construction industry? *

1

How many years have you used construction management software, including BIM? *

1

How many projects previous to the one in question have you used Vela on? *

0

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* Required

Project Details

What is the delivery method of your project? *

- Design-Bid-Build (DBB)
- DBB with Construction Management (DBB with CM)
- Design-Build (DB)
- Design-Build-Operate-Maintain (DBOM)
- Integrated Project Delivery (IPD)
- Other:

What is the contract type used on your project? *

- Guaranteed Maximum Price (GMP)
- Fixed Price
- Other:

What is the total contract value of your project? *

2

When did construction begin? *

Please enter in date format: eg. 12/01/10

2

When is your project currently expected to finish? *

Please enter in date format: eg. 12/01/10

2

When was Vela first implemented on your project? *

Please enter in date format: eg. 12/01/10

2

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* Required

Costs of Implementing Vela

What was the total cost in dollars of purchasing Vela? *
This includes software licensing, initial on-site training, and harware including tablets, iPads, wireless accessories, barcoding, etc.
2

How many hours did the initial set up of Vela take? *
This includes mass uploading of electronic documents, development of location hierarchy, development of folder hierarchy for contract documents, creating QA/QC checklists, setting up various trades within Vela, importing equipment and building components to be tracked, etc
2

Is there a designated document manager on your project? *
A document manager is responsible for uploading, editing and replacing plan sheets within Vela
Yes

On average, how many hours are spent each week generating handouts and deliverables in Vela? *
2

On average, how many hours are spent each week performing document control, including electronic RFI mark-ups, hyperlinking RFIs on electronic plan sheets? *
2

On average, how many hours are spent each week uploading new contract documents and plans? *
2

Is there a designated Vela trainer(s) on your project? *
A trainer is responsible for training new Vela users, including architects, engineers and subcontractors.
Yes

On average, how many hours are spent each week training new Vela users? *
2

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* Required

Reporting

On average, how many Vela work-to-complete lists do you generate a week? *

3

On average, how many Vela checklist results do you generate a week? *

These include quality, safety, or commissioning checklists

3

On average, how many Vela analytic reports do you generate a week? *

These can identify trends by comparing performance of teams and trades in quality, safety and other areas

3

If you generate analytic reports, who do you send them to?

Check any that apply

- [x] Skanska staff within project
- [ ] Skanska staff on other projects (cross-project analytic reports)
- [ ] Subcontractors
- [ ] Owner
- [ ] Architect/Engineer
- [ ] Other:

Did your project team use the results of Vela analytic reports from WITHIN YOUR PROJECT to drive quality management programs and target common problem areas, subcontractors or root causes? *

Check any that apply

Yes

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Additional Comments

Please comment on any issues which you have encountered in implementing Vela:

Please comment on any benefits of Vela you feel are particularily important:

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NOTES