UTILIZATION OF INFORMATION AND COMMUNICATIONS TECHNOLOGY (ICT) TO IMPROVE WORKFACE EFFICIENCY

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Abstract

Improving the efficiency of personnel at the workface is a key objective for executing construction, maintenance, quality, engineering and human performance activities. Schedule and cost overruns have a significant impact on the bottom line and on future business – efficiency in execution of tasks is paramount to success. Leveraging information and communications technology (ICT) in construction, maintenance and operation environments can create a mobile workforce where personnel efficiency is improved, significant gains are made on schedule and cost, and the overall quality of work is raised. This paper will discuss the impact of mobile technology specifically on workface efficiency and productivity.

1. Introduction

What is ICT?

ICT encompasses any hardware or software which transmits, receives, captures, stores or manipulates information electronically. This includes a wide breadth of software and hardware, from word and spreadsheet applications to cell phones and personal digital assistants (PDAs).

Statistics Canada describes ICT as follows: "ICT includes technologies such as desktop and laptop computers, software, peripherals and connections to the Internet that are intended to fulfill information processing and communications functions" [1].

How is ICT used?

With drastic improvements in cellular networks, wireless networks and mobile technology in recent years, the work force has undergone an exponential growth in the use of ICT, initially for phone capabilities and more recently for access to email and internet. This has resulted in a constantly 'connected' environment where personnel can communicate rapidly and effectively both internally and externally, with clients. Table 1 illustrates the trend in growth of ICT access and usage, using a data subset of Group of Seven (G7) countries:

	Fixed telephone lines per 100 inhab.		Mobile cellular subscriptions per 100 inhab.		International Internet Bandwidth per Internet user (bit / s)		Proportion of households with computer		Proportion of households with internet	
	2002	2007	2002	2007	2002	2007	2002	2007	2002	2007
Canada	65.9	55.5	37.9	61.7	4'628	22'250	64.0	79.1	54.5	72.1
France	57.1	56.5	64.6	89.8	11'076	46'086	36.6	62.0	23.0	49.0
Germany	65.1	65.1	71.7	117.6	6'448	35'487	61.0	79.0	46.0	71.0
Italy	46.9	49.0	93.6	153.1	4'173	27'339	39.9	53.0	34.0	43.0
Japan	47.7	40.0	63.6	83.9	511	5'415	71.7	85.0	48.8	62.1
United Kingdom	58.8	55.4	83.3	118.5	9'662	55'281	57.9	75.0	40.0	67.0
United States	65.3	53.4	48.9	83.5	2'208	15'341	59.0	70.2	52.0	61.7

Table 1: Access Indicators [2]

Table 1 indicates a clear plateau in the use of fixed telephone lines and a major trend upward in the use of mobile devices, internet and personal computers (PCs).

Beyond the growth in mobile device use within the G7 economies shown in Table 1, most industry sectors have integrated computers systems and software applications into the way they do business, either for basic desktop computing, email and word processing, or for more advanced functions such as computer-aided design, modeling and analysis. While the level of integration and depth of use is still unstudied in some industry sectors, the available evidence clearly demonstrates that the use of ICT is trending upward and will continue to do so.

How can ICT help in construction, maintenance and operations?

By adopting an ICT strategy organizations can improve communication, systems interfaces and exchange of information on projects. These are all critical factors to successfully delivering projects on time and on budget. This paper will discuss how implementing ICT can improve the efficiency of construction, maintenance and operations. A pilot project executed in the Canadian nuclear industry will be used as the basis for examining the application of ICT at the workface and the resulting impact on efficiency.

This paper will address the following topics:

a. The evolution of ICT and its impact on productivity and efficiency
b. ICT and the construction industry
c. Implementing ICT at the workface to improve efficiency

2. Evolution of ICT and its Impact on Productivity

2.1 The ICT Industry – Growth from 1995 to 2005

In the mid-1990s, the price of technology declined significantly due to advances in the silicon chip manufacturing process and a steep reduction in the product life cycle for manufacturing semiconductors. The decline resulted in the commoditization in price of PCs, making computer

technology accessible to the mass market. The commoditization of the PC was coupled with the maturation of Graphical User Interfaces (GUIs), which made navigating complex operating systems accessible to the layperson. Computer systems were no longer the realm of only the highly technical users.

This period also saw the early adoption of the internet as a communication tool and information system. By the 2000s, high-speed connections through cable and DSL modems had become commonplace and email had become a standard method of communication. As the speed of networks steadily increased, so did access to the internet and the sophistication of web-based applications. Websites that used to be static and informational became intuitive and interactive for the user, allowing new ways to collaborate and share information across systems.

2.2 The ICT Industry – 2005 to Present

The last few years have seen advancements in the speed and capacity of broadband wireless networks in both the home and the office. Accessibility to the internet has become less of an issue, even in remote locations - the development of mobile 'internet sticks' for laptops now allows users to access the internet remotely, at high-speed rates.

The latter part of the decade has also seen incredible growth in the storage capacity of electronic devices – in 2000, typical hard drive capacity in a PC was between 10-20 GigaBytes (GBs). In 2010, hard drives with 1 TeraByte (1000 GB) capacity are readily available from retailers at affordable prices. High volume data storage and secure encryption are no longer issues and we are now seeing the move toward 'cloud' computing, where data is stored in centralized server banks which are accessed through the internet.

2.3 Impact of ICT on Productivity

In light of these developments, one is left wondering whether the advancements in ICT and the adoption of ICT as organizational strategy have actually had an impact on efficiency and productivity.

Jorgenson, Ho and Stiroh [3] studied the economic growth period in America from 1995 to 2005. Their study classified industries into 'ICT-Producing', 'ICT-Using' and 'Non-ICT Using' sectors for the purposes of comparing the impact of each sector on economic growth. Their results show ICT-Producing and ICT-Using sectors have been a major contributor to economic growth in the US since the emergence of ICT in the mid-1990s, despite a blip corresponding to the dot-com crash in the early 2000s. At the time of Jorgenson *et al.*'s analysis, ICT-using and ICT-producing industries accounted for only 30% of the US gross domestic product, but contributed half of the acceleration in economic growth. This indicates that ICT has indeed had an impact on productivity, as use has expanded and user capability has increased.

3. ICT and the Construction Industry

Despite the major advancements in ICT and the potential impact on productivity, some industry sectors have not been quick to embrace ICT as a strategy. In their research, Jorgenson *et al.* [3] identified the construction industry as one of the 'non-ICT using' sectors. While ICT use in the construction industry has increased in recent years, there has been no widespread adoption of ICT as a strategy. Moreover, if and when these technologies *are* adopted, they are often done so independently of one another and have not been successfully integrated to work together in the construction environment [4].

Why has the construction industry been slow to adopt ICT? There is no one answer to this question, but rather a mix of factors that have contributed both at a management level (initial adoption) and an end-user level (implementation). While those factors can be overcome, exploring that topic is outside the scope of this paper. It is important to recognize, however, that relative to other industries, the construction industry has been slow to move toward ICT.

3.1 Study on Advancing Competitiveness and Efficiency in the US Construction Industry

In 2008, the National Institute for Standards and Technology (NIST) requested that the National Research Council (NRC) form a committee of experts to investigate ways of improving the competitiveness and efficiency of the American construction industry, and to provide recommendations to the industry. Through a series of workshops and input from leading industry personnel, the NRC identified five key opportunities for breakthrough improvements. The NRC's summary report sets out those opportunities as follows.

> ***1. Widespread deployment and use of interoperable technology applications, also called Building Information Modeling (BIM).***
>
> Interoperability is the ability to manage and communicate electronic data among owners, clients, contractors, and suppliers, and across a project's design, engineering, operations, project management, construction, financial, and legal units. Interoperability is made possible by a range of information technology tools and applications including computer-aided design and drafting (CADD), three- and four-dimensional visualization and modeling programs, laser scanning, cost-estimating and scheduling tools, and materials tracking.
>
> Effective use of interoperable technologies requires integrated, collaborative processes and effective planning up front and thus can help overcome obstacles to efficiency created by process fragmentation. Interoperable technologies can also help to improve the quality and speed of project-related decision making; integrate processes; manage supply chains; sequence work flow; improve data accuracy and reduce the time spent on data entry; reduce

design and engineering conflicts and the subsequent need for rework; improve the life-cycle management of buildings and infrastructure; and provide the data required to measure performance. Barriers to the widespread deployment of interoperable technologies include legal issues, data-storage capacities, and the need for "intelligent" search applications to sort quickly through thousands of data elements and make real-time information available for on-site decision making.

2. *Improved job-site efficiency through more effective interfacing of people, processes, materials, equipment, and information.*

The job site for a large construction project is a dynamic place, involving numerous contractors, subcontractors, tradespeople, and laborers, all of whom require equipment, materials, and supplies to complete their tasks. Managing these activities and demands to achieve the maximum efficiency from the available resources is difficult and typically not done well. Time, money, and resources are wasted when projects are poorly managed, causing workers to have to wait around for tools and work crews' schedules to conflict; when work crews are not on-site at the appropriate time; or when supplies and equipment are stored haphazardly, requiring that they be moved multiple times.

Greater use of automated equipment (e.g., for excavation and earthmoving operations, concrete placement, pipe installation) and information technologies (e.g., radio-frequency identification tags for tracking materials, personal digital assistants for capturing field data), process improvements, and the provision of real-time information for improved management at the job site could significantly cut waste, improve job-site safety, and improve the quality of projects. A primary barrier to more effective use of such technologies is the segmentation and sequencing of planning, design, engineering, and construction processes. Improved job-site efficiency also requires a skilled labor force with communication, collaboration, and management skills as well as technical proficiencies.

3. Greater use of prefabrication, preassembly, modularization, and off-site fabrication techniques and processes.

Prefabrication, preassembly, modularization, and off-site fabrication involve the fabrication or assembly of systems and components at off-site locations and manufacturing plants. Once completed, the systems or components are shipped to a construction job site for installation at the appropriate time. These

techniques offer the promise (if used appropriately) of lower project costs, shorter schedules, improved quality, and more efficient use of labor and materials. Various obstacles stand in the way of the widespread use of such technologies, including building codes that hinder innovation as well as conventional design and construction processes and practices.

4. Innovative, widespread use of demonstration installations.

Demonstration installations are research and development tools that can take a variety of forms: field testing on a job site; seminars, training, and conferences; and scientific laboratories with sophisticated equipment and standardized testing and reporting protocols. Greater and more collaborative use of demonstration installations can be used to test and verify the effectiveness of new processes, technologies, and materials and their readiness to be deployed throughout the construction industry. By allowing determinations to be made about whether innovative approaches are mature enough for general use, demonstration installations can help to mitigate innovation-related risks to owners, contractors, and subcontractors.

5. Effective performance measurement to drive efficiency and support innovation.

Performance measures are enablers of innovation and of corrective actions throughout a project's life cycle. They can help companies and organizations understand how processes or practices led to success or failure, improvements or inefficiencies, and how to use that knowledge to improve products, processes, and the outcomes of active projects. The nature of construction projects and the industry itself calls for lagging, current, and leading performance indicators at the industry, project, and task levels, respectively [5].

3.2 Implications of the NRC Study

The NRC committee identified the need for each of the five key opportunities to work in tandem to maximize overall improvement in efficiency and productivity. The lynchpin to being able to realise each of these opportunities is the effective use of an ICT strategy to improve the communication and exchange of information within a business. Looking at each element again from the perspective of ICT leads to the following insights:

Widespread deployment and use of interoperable technology applications (BIM)

This opportunity identifies implementing software applications to improve capturing, organizing and communicating information – this is the very objective of ICT.

Improved job-site efficiency through more effective interfacing of people, processes, materials, equipment and information

Like the first this opportunity identifies the application of technology to improve the organization and communication of information through a focused integration of ICT systems.

Greater use of prefabrication, preassembly, modularization and off-site fabrication techniques and processes

To maximize the benefits of these techniques, ICT must be used to coordinate the efforts of a number of contractors, sub-contractors and functional roles.

Innovative and widespread use of demonstration installations

Using ICT, information gained through demonstration installations can be fed back into the overall knowledge management system and embedded in the production environment.

Effective performance measurement to drive efficiency and support innovation

Data that has been tracked electronically can be fed back into trending and analysis systems to drive continual improvement across the job-site.

4. Implementing ICT to Improve Workface Efficiency

The discussion of the NRC study in section 3.0 focused at a macro level for the construction industry. The purpose of this section is to explore the specific implementation of one piece of ICT – mobile devices – to improve workface efficiency.

4.1 How can ICT be Used at the Workface?

ICT, and particularly mobile technology applied on a job site, can supplement and enhance existing processes that are traditionally paper-based. The objective is to use mobile technology in the field to capture information once and transmit this information back to existing systems without transcribing the work from paper to an electronic format. The use of mobile technology improves the speed of executing tasks and the likelihood that information is captured and captured correctly, and reduces errors that can result from moving data from system to system. This approach also improves the overall flow of information through the organization, improves the documentation of completed work and strengthens the interfaces between the field, the office and the project management systems currently in place.

Implementing an ICT system should not require an overhaul of existing processes; it should support and enhance the execution of existing processes. Further, it should provide a new stream of trending data, which gives the organization real insight into performance and identifies opportunities for continual improvement.

4.2 ICT at the Workface – A Case Study in the Canadian Nuclear Industry

A 2-year pilot project was undertaken with a general contractor in the nuclear industry. Mobile technology was integrated into core components of the contractor's project management and quality operations. The following areas were enhanced using mobile technology.

Daily project progress tracking on metrics defined for each trade crew

The contractor defined key metrics and milestone targets for pipe fitters, electricians and millwrights during the project planning phase. The foreman on each project was given a mobile device with a project progress form, which was completed daily at the workface along with the hours worked by each crew member. At the end of the day, each foreman would upload the completed forms to the central system, which would then automatically generate PDF documentation of the work completed for the contractor's records and drive updates to the progress tracking reports.

The contractor used this information to monitor each active project with respect to schedule and cost. Field delays were captured electronically and transmitted into the system for trend analysis and documentation of issues. The information was made available to the facility owner and contractor sponsor through an online reporting interface.

Quality documentation and objective evidence of program compliance

The contractor also used mobile technology to supplement its quality program. Forms needed to demonstrate program and regulatory compliance were built electronically and embedded at the workface in the hands of quality personnel. Procedures were built into the forms and processes were gated at each step to ensure work was executed in the correct sequence. Required sign-offs were captured directly on the mobile device and included in the documentation produced at the end of each shift for objective evidence of program compliance. The types of forms built electronically included receiving inspections, visual weld inspections, non-conformance reports and vendor surveillance forms.

Ad-hoc human performance and safety documentation

Forms were embedded on each mobile device to capture *ad hoc* information in the field (unplanned activities) such as human performance tracking, observation and coaching, and safety observations. These forms were implemented in a way to provide an 'unlimited' number of forms in the field for the user; once a form was completed a new blank one was available and ready to be completed. This allowed data to be observed and captured in the field as it occurred,

without the need to go back to the office to print off and complete a form by hand. The *ad hoc* information captured was used to trend results and build continual improvements into processes and field operations.

Online reporting for trend analysis to identify bottlenecks in project execution

The information captured at the workface was transmitted into a centralized electronic database at the end of each shift. This database automatically updated a series of online reports which were available to the management team and the facility owner. All stakeholders had securely-controlled access to the information and documentation occurring on each job, at any time.

4.3 Findings From Pilot Project

As a result of a post-implementation study of the pilot project conducted by the authors of this paper, the following areas have been identified as major contributors to improving overall crew efficiency at the workface.

A. Improve crew by maximizing foreman time in the field

By implementing mobile technology, the foreman of each crew can stay at the workface for longer periods of time throughout the day, applying their skills and expertise to supervise and direct the crew. By capturing information electronically during the shift at the workface, the foreman does not need to leave the field to complete tasks or transcribe information back at the office into another system. When the foreman synchronizes the mobile device, the information captured electronically will be transmitted to the database and interfaced into other systems.

B. Improve job-site efficiency through more effective interfacing of people, processes, materials, equipment and information [5]

Integrated mobile technology enhances the interfaces between people and process by streamlining the flow of information from project management, scheduling, assessing, materials tracking and performance monitoring systems to the workface. Systems are automatically synchronized throughout the shift (in wireless environments) or at the end of the shift.

C. Improve accuracy of work documentation by capturing information at the point of occurrence

Mobile technology allows forms to be created and completed where the work is occurring. By capturing the work electronically at the point of occurrence, the work only needs to be recorded once. The data can be passed from the mobile device to any other existing system and trigger updates accordingly. This process eliminates the need for transcription in the office of what happened in the field – the work is only documented once. Documentation can be gathered electronically, through intelligent forms, bar code readers, RFID, digital cameras or other handheld technology by performer, peer reviewer or QCI at the workface [6].

D. Real-time transfer of information from the field to existing schedule and cost systems

In wireless environments, completed forms can be transferred back to centralized systems as soon as the work is completed, without the need for personnel to move from the field to the office and back. This allows the project management team to remain constantly up to date on what is occurring in the field and react accordingly.

E. Reduce re-work and improve overall quality of work by embedding continuous in-hand procedures and reference documentation at the workface

Procedures are built directly into forms and embedded in hand where the work is occurring. Procedural documentation, drawings and sketches can be quickly referenced in the field. The capacity of mobile devices has advanced to the point where the amount of information to be stored is not a limiting factor. It is important not only to have the procedural documentation in hand when and where the work is occurring, but also to have the *right* information in hand. The information is filtered to show only what is relevant to the work that is being executed. The user does not see unnecessary procedures and forms.

F. Electronic documentation captured in the field eliminates need for transcription and allows turnover packages to be built immediately

Documentation of completed activities for program compliance is only recorded once in the field, which produces electronic documentation in PDF form as an output. There is no need for the user to re-write work that was captured electronically – it is automatically produced in the necessary format.

By producing the documentation electronically immediately as the tasks are completed, the project team can ensure all the necessary paperwork and records of compliance are being captured and stored as the job is being executed. If there is anything missing at the end of a shift, the team can react and capture that information. This improves the overall efficiency of the project team and ensures the job can be completely turned over at work completion.

G. Cross-functional integration of supply chain into construction, maintenance and operational activities

By capturing and receiving information electronically at the point of occurrence, better material tracking controls can be implemented. Supply chain can be triggered to material supply issues, before they escalate to significant delays. Reducing delays due to access and availability of materials and tools can have a significant impact on the delivery of projects.

H. Tracking and trending of field delays to identify and eliminate bottlenecks in process:

Using a field delay form, common issues for delays in executing work on a shift-by-shift basis are tracked, along with the length of the delay experienced. As the results of the delays are gathered and trended, the management team can analyze where the process is breaking down and make adjustments to either provide more resources or improve the overall approach.

I. Enforce regulatory compliance by driving ownership of the quality process to the workface

By building best practices, procedural documentation and gated processes into each form executed in the field, ambiguity can be eliminated and quality compliance can be driven directly to the workface. This information can be screened for acceptability through automated processes or remote reviewers, significantly reducing the amount of time and effort spent on quality control checks. This same information can be used to provide true status reporting on accepted work [6].

J. Accurate capture of metrics on daily job site performance and trend analysis to determine opportunities for improvement

As information is received from the field on a shift-by-shift basis, reports are updated to provide performance data on each crew across each job. This real-time capture of information gives management insight into exactly what is happening each day and where the problems lie. By improving the overall communication and information flow, action can be taken on issues before they escalate.

5. Conclusion

Significant opportunities exist to implement ICT in the construction industry to improve organizational efficiency and productivity. Integrating mobile technology at the workface can impact daily crew efficiency by reducing the time to execute tasks and reducing re-work through improved quality, and can drive process improvement through trending analysis. If each crew can improve daily wrench time by thirty minutes, significant gains on schedule can be achieved – improving overall profitability and time to deliver. The main organizational areas identified which can generate improvements in efficiency from the use of ICT are:

- Construction Project Management
- Quality
- Maintenance
- Engineering
- Human Performance and Safety

While the efficiencies gained from implementing ICT at the workface have been described in detail in this paper, organizations must adopt ICT implementation as a greater overall strategy to maximize results and sustain a competitive advantage. This includes integrating workface solutions into existing software systems, using online collaboration tools, and leveraging online reporting and analysis tools for performance tracking and trend analysis.

There are clear challenges involved in implementing ICT from both an integration and an adoption perspective. Through management commitment and support, significant return on investment can be delivered.

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