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Mobile communications for on-site collaboration

The construction industry's drive towards using information and communications technology to enhance collaborative working seems to have left site staff behind. This paper examines the information needs of site staff and shows there are several technology solutions currently available to support them. Based on a recent site trial, it also shows that, contrary to general perceptions, site staff are more than ready to adopt modern technology and should be included in all future strategies for collaboration systems.

Currently there is much discussion about web-based collaboration systems solving the construction industry's fragmentation problems. However, these systems are not yet in common use in the field, for example by foremen and site engineers. The flow of electronic information comes to an abrupt halt when it reaches the construction site, only reaching selected personnel in the site office. Many of the efficiency and knowledge-based benefits of collaboration tools are thus lost. The extension of these tools to include site information needs will be an essential factor in eliminating these problems.

The information difficulties faced by site-based construction personnel have been described and documented in several studies over the past decade.^{1,2} In its broadest sense information can be defined as the data and messages that are transmitted between people within a communications network.³ The ability to convert data quickly into information, while at the

same time reducing the drudgery associated with many of the administrative tasks, improves both staff efficiency and work interest.⁴

It has been suggested that the cost of construction can be reduced by 25% through the efficient transfer of information.^{5,6} Many people have argued that construction products are one-off with each project being unique; however, the same procedures and processes are adopted time and again.⁷ By enhancing information flow between the different site processes and teams, it is easier to monitor, control and assess the project progress and hence integrate the on-site process.⁸ If information retrieval can be enhanced there are significant savings to be made. For example, BP Exploration estimated that reducing the time needed to locate and acquire information would increase efficiency and result in annual savings of between US\$10 million and US\$20 million.⁹



Understanding the information needs of site staff

There have been many attempts to categorise and identify construction information. Researchers have filtered site information to a greater or lesser extent, from a high-level division into technical, commercial, management and control¹⁰ to a more detailed level where different types of documentation are classified, for example technical queries, dayworks, requisitions, method statements and so on.¹ Tenah² conducted his research from a slightly different angle, looking at the information needs of specific construction personnel. His study found a wide array of functions within construction organisations, and that information needs are inextricably linked to the management responsibilities of each member of the project team. Table 1 shows an example of the foreman's functions and information needs.

The data on Fig. 1¹¹ indicates that 65% of contractor rework is attributed to insufficient, inappropriate or conflicting information. Site issues need to be resolved quickly and efficiently to avoid cost overruns and this often requires collaboration between on-and-off-site personnel.¹² However, most site information is currently stored on paper, which is difficult to access and requires large storage space. A computerised information system can store vast amounts of data efficiently, and information can be located and viewed quickly through computerised searching and display.¹³

However, we should not be aiming for a paperless office/site, merely a less-paper office/site utilising information technology when and where it brings demonstrable benefits. The evidence is conclusive in that office automation has failed to yield the forecast utopia of the 'paperless office'. In fact, almost the exact opposite has happened: desks are now littered with computer printouts. People are comfortable with the 'feel' of paper.¹⁴ Further research into the current production rates of paper-based, electronically created information would be of value.

Construction project managers typically spend 70% of their time dealing (generating, managing, sending, collecting and analysing) with data.¹⁵ Tenah² concluded

that personnel who have good access to timely accurate information will

- reduce or maintain project durations
- make better use of resources
- increase labour and equipment productivity
- decrease cost.

In order to determine where information technology can be used in the delivery and capture of information on site to enhance collaboration with the project team, the current site information needs and flows must be understood.

Benefits of electronic data in construction

Due to its very nature the construction industry requires its personnel to be mobile in order to complete the realisation of the project. To carry out their job function, communication with others is essential and quality, quantity and timing of information can either hinder or facilitate successful results.¹⁶

The benefits of implementing electronic data capture systems in construction have been well-documented.¹⁷⁻²⁴ The benefits can be broadly categorised as follows

- improving efficiency of data capture.
- improving access to data
- reducing errors and improving data integrity.

Taking each of these benefits in turn; data capture is made more efficient by capturing the data at source, that is electronically while it is being generated on the site,²⁵ eliminating the task of entering data from the paper form into a computer.

Access to data is improved by virtue of it being in an electronic format. Information can be searched, manipulated and electronically transferred into other applications for use by the project team.¹⁷ Quality and integrity of data is improved since fewer mistakes are made in recording and mistakes made during the transcription process are eliminated.¹⁸

De La Garza and Howitt¹⁶ examined

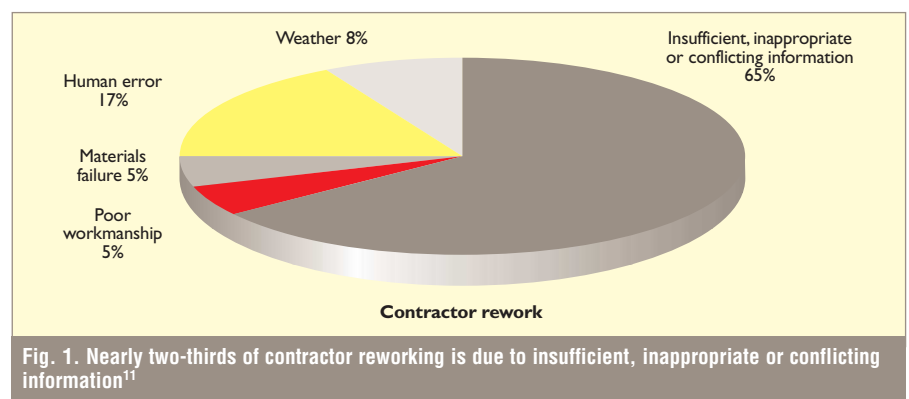


Table 1. A site foreman's functions and information needs²

Primary functions

- Organises and coordinates employees engaged in a specific craft or function on a construction projects
- Reads and interprets drawings, blueprints and specifications
- Allocates, assigns and inspects work
- Administers union agreements and safety enforcement; hires and trains employees

Primary information needs

- Blueprints, specifications and other contract documents
- Local union activities, safety regulations and laws, labour agreements, quality control and testing regulations
- Shop drawings and sample control, procurement status, bar charts by system or area, production schedules and field performance reports

the use of wireless communication and computing on construction sites, giving particular consideration to the trade-off between the value of transmitting the information wirelessly on demand against the cost of transmitting it. The costs of investing in wireless technology are

- purchase of hardware and software
- maintenance and upgrading of hardware
- upgrading and licensing of software
- fees of wireless service providers
- salaries of technical support staff
- training of users
- fees to a specialised wireless consultant
- integration with existing systems.

The value of having immediate access to information on site is more difficult to quantify.

- Information can be immediately fed into a collaboration tool for use by the project team, potentially providing an extra day to work on the data.
- Site personnel would not have to halt operations in order to go back to the site office to obtain the most up-to-date information potentially saving many wasted man-hours, equipment downtime and lost productivity.
- Site personnel would always have access to the most up-to-date information, eliminating rework due to insufficient, inappropriate or conflicting information.

However, many of the benefits of collaboration tools that are being realised by the rest of the project team will be equally applicable to the site-based team

- provides a single communication medium
- provides 24/7 access to up-to-date information
- reduces response times
- increases ownership and accountability
- improves record-keeping and documentation
- reduces disputes and litigation.

Taking these costs, values and benefits into consideration, extending the collaboration tool out to the field seems an obvi-

ous progression, but providing information technology in the harsh site environment has until now required proprietary solutions. However, with the increasing availability of mobile rugged devices and construction-targeted software solutions this should no longer hinder the creation of total-project-team-encompassing collaboration tools.

Requirements for site-based information hardware

The construction site is a tough environment with sunlight, rain, mud and heavy handling to contend with. Manufacturers are well aware of these constraints and are providing hardware to match up to them. There are various levels of ruggedness available. A truly rugged device should have an International Protection Code rating for dust and waterproofing, and also protection from falls of at least 1 m.

One of the biggest factors that will influence the choice between rugged or non-rugged is cost, with rugged devices currently costing at least 50% more than their non-rugged counterparts. However, the consequences of damaging a device in the field and losing both time and data could cost more in the long term.

If non-rugged devices are chosen then there are suitable rugged cases to be found, but this then relies on the personnel to use the cases provided. However, be aware that some cases call themselves rugged but provide little protection.

Mobile computing hardware comes in many shapes and sizes. There are personal digital assistants, pen tablets, hand-helds and even personal digital assistants combined with mobile phones. Examples of these devices are shown in Fig. 2.

Previous studies²⁵ of the use of mobile information technology devices on construction sites have shown that users require the devices to satisfy the following criteria

- able to be dropped from about 1 m onto a hard surface
- able to be used in the rain
- screen visible in bright sunlight and near darkness
- large buttons, if applicable
- able to be carried in one hand
- battery life of at least 8 h.

When deciding on which hand-held device to use the following features should be considered.

- *Portability.* Is a device that fits in your pocket or in a rucksack more suitable (remember site workers tend not to wear jackets in the summer.)
- *Display.* Colour displays are more pleasant to use, but monochrome screens consume much less power.
- *Batteries.* Built-in rechargeables can save money, but standard alkaline batteries can be purchased anywhere—an 8 h battery life is desirable.
- *Expansion.* Important to retain flexibility—accessories include digital camera, bar-code reader, global positioning system, extra memory and wireless connectivity
- *Rugged.* Do site staff require a rugged device in order to ensure a longer life-span-for the equipment?

One of the most important features is screen visibility: after all, if the screen cannot be read then the device is of little use. It is essential that site personnel are



Fig. 2. Examples of hand-held mobile computing hardware which could be made available to site staff

able to use the device both outside in bright sunlight and in near darkness. A thin-film transistor screen provides higher contrast and therefore appears brighter and easier to see. The recommended screen type for outdoor hand-held devices is a reflective thin-film transistor with a front light. Devices with wireless connectivity provide further benefits, and as technologies and site applications develop, progression to instant data availability and feedback capabilities will be desirable.

Understanding site software needs

Software applications for use on a construction site can be split into the following categories

- computer-aided design applications
- collaboration software
- data capture
- project management
- discipline-specific applications.

Many of the benefits of these applications could be enhanced by integrating the solutions with the project collaboration tool.

The following factors should be considered in order to choose the most suitable application.

- What information do staff need/record in the field?



Fig. 3. Arup has developed a hand-held software package to perform site-safety audits

- Can existing information technology applications be extended to be used in the field?
- Do staff need real-time access to information, or can they simply synchronise it when they are back in the office?
- Will the palm or pocket PC operating system be used?
- What training will be required?
- What support will be available to staff?

Collaboration software suppliers are beginning to extend key collaboration features to mobile users in the field either through their mobile phones or other hand-held devices. These applications allow, for example, site managers to view build programmes by plot or site and to see their daily, weekly or monthly tasks. Tasks such as call-offs, delivery confirmations and work orders can be performed while walking around site. Call-offs are relayed immediately to suppliers and subcontractors who respond with a confirmed delivery time. Similarly, when deliveries arrive on site, an electronic delivery note is issued, indicating a complete or partial order fulfilment.

Computer-aided design is now used on almost all construction projects to produce drawings for use in the field. However, although the drawings are produced electronically, they are printed out for use. This eliminates many of the advantages of electronic production, and reduces the opportunities for effective feedback from the field.

Data capture on site can be used to perform site-safety audits (Fig. 3), snagging, quality inspections, resource management and so on. Using a mobile device and the appropriate software, almost any process that is currently performed using a clipboard and pen can be replaced.

The project management area overlaps with some of the features that collaboration tools offer. However, there are also software applications available that add project and programme management capabilities. A US consultant working on the US\$440 million (£310 million) expansion of Houston's George Bush Intercontinental Airport used Primavera Systems' 'Expedition Mobile' software to provide the necessary interface between

the different electronic document types used on the project.

Mobile applications are designed to help all members of the team keep project information fresh, with activity progress continually updated. Using personal digital assistants, site staff can monitor the status of tasks, issue change orders or create a priority list on site without having to go back to their desks. With the ability to update project information anywhere, contractors and subcontractors can easily communicate progress and problems.²⁶

Infrastructure considerations for site communications

For many years the walkie-talkie has been synonymous with the construction industry;¹⁶ however, with the advent of mobile phones and wireless data communications there are now many more options available

- mobile phone
- wireless local area network
- private mobile radio
- terrestrial trunked radio
- low earth orbit and geostationary satellites.

Each of these will provide the technology to eliminate the time wasted on site simply travelling to and from the site office to retrieve information. The following factors need to be taken into account when implementing a solution in order to determine the most suitable technology

- mobile telecommunications and/or access to data
- number of staff on site
- permanent or mobile site office
- site area (dimensions)
- availability of direct line of sight
- importance of certainty of cost
- coverage available from a national provider
- suitable (robust etc.) devices available for the required usage.

To enable data transfer to the operatives in the field, wireless local area network or mobile telephony solutions should be considered.

Two-day trial reveals willingness to adopt new tools

The technology to extend collaboration solutions out to personnel in the field is available, but there is a preconception that site personnel are not information technology (IT) literate and therefore will not be able, or willing, to take full advantage of the benefits that collaboration tools bring the 'upstream' project team.

At the beginning of March 2002, a two-day event, to raise awareness of mobile technology and its potential uses in construction, was held at the headquarters of the M6 toll road project. The contractor consortium CAMBBA (Carillion, Alfred McAlpine, Balfour Beatty and Amec) hosted the event on site. The event consisted of two parallel activities: a series of presentations and demonstrations were open to all site personnel throughout the two days while a series of usability trials were carried out on four hand-held devices with 17 construction worker volunteers (Fig. 4).

On a construction site there are several different roles that involve different skills and hence different types of people. They each have different levels of IT literacy, and differing perceptions of the applicability of IT use in the field.

To understand whether different devices would suit the different people and tasks, representatives from each of the user groups identified below performed the usability tests

- agent
- section engineer
- site engineer
- works manager/foreman
- health and safety/environmental adviser.

Following a desk-based study of current devices on the market it was decided to trial the following

- Itronix FEX21—Indoor Screen
- Sagem WA3050
- Symbol PPT8100
- Casio IT 700.

These provided a range of different sizes, functionality, ruggedness and screen types. The Itronix device acted as a demonstration of the use of an indoor

specification screen outdoors.

Each participant performed the following construction-based tasks using different applications on each of the four devices in a random order.

- Find out the width of room 1 on a house plan and annotate with the correct dimension (application: PocketCAD).
- Find out how thick the backfill layers should be in the reinforced earth wall from a method statement (application: eReader).
- Enter the details of a concrete pour into a site diary (application: Outlook).
- Complete a quality inspection on a catchpit using the inspection test sheet form (application: PocketPC Creations).

The participants were also asked to assess the portability, screen clarity, appearance, ease of data entry and input keys on each device. To gain realistic results, the participants were tested while in their everyday situation

- the trials took place outside
- all participants wore helmet, coat and boots
- the weather was cold and sunny with showers
- all participants were standing.

Taking into consideration age, job type and previous IT experience, the usability trials set out to discover if construction workers would be happy to use a hand-held device for their work and which device they preferred.

The results were very encouraging, with fifteen (88%) of the participants confirming that they would be happy to use one of these devices for their work. There was no significant variation across age, job type or IT experience, and interestingly contrary to commonly held beliefs the foremen and works managers were most enthusiastic. Typical comments were 'superb', 'very powerful', 'definitely see an advantage'. However, these comments were tempered by the barriers of cost and training, and many participants reiterated the need for proof that the devices would be cost-effective,

and that usable, useful applications would be the key differentiator.

A total of 82% of the participants had never used a hand-held device and two (129%) had never even used a computer before. Nevertheless, considering that there was only a 10 min training session prior to the trials, the participants were able to complete 79% of the tasks.

When asked how the devices could be improved for use by the construction industry, many of the participants recommended that the devices should be more rugged—dust-, water- and shockproof. They particularly thought that the screen should have some form of cover. However, this conflicts with the result that eight (47%) of the participants preferred the Sagem WA3050 that was the only non-rugged device. Perhaps this indicates that manufacturers should be aiming to cut down the size and weight their of rugged devices if possible.

Other interesting results of the trials were

- 14 (82%) preferred a colour screen
- 12 (71%) thought that combining the device with a mobile phone is a good idea



Fig. 4. One of the 17 site staff on the M6 toll road project to evaluate four different types of hand-held mobile computing devices

- screen size was not thought to make much difference: clarity was more important.

Limitations of existing information technology

The following barriers were identified by the participants during the trials.

- Many found the stylus too small to handle with larger hands and potentially having to wear gloves too.
- You may become too reliant on the device, such that if it were to break down you would have to go back to pen and paper and the necessary protocols would no longer be available.
- If the device broke down you could lose all of the work that had been carried out since the last synchronisation. This could however be overcome by saving the data onto a removable disk from which the data could then be retrieved and if necessary uploaded onto a new device.
- It was thought that the screen size available was impractical for viewing drawings, and many would prefer to

stick to A2 paper copies to carry out drawing-based tasks.

- Manual data input using either the stylus or the pop-up keyboard was found to be time-consuming. This indicates that manual input should be minimised through the use of drop-down menus and pre-written text.
- It was thought that the costs involved in purchasing a device would outweigh the benefits gained. At approximately £1200 for a rugged device many participants thought that management would have to be convinced that purchasing these devices was worthwhile. But potentially these devices could replace the provision of desktop computers to some operatives. This would provide savings both in terms of the equipment and also the security provisions that are made.
- Attitudes towards the devices and information technology in general could be a barrier; one participant commented: 'Ought not to underestimate people, could just pick up a telephone instead'.
- Battery life should be considered. With staff working a 10–12 h day in the summer the inconvenience of running out of batteries when out on site could create reluctance to rely on the device.
- The devices were perceived by some participants as a gimmick or a toy, and it was thought that they should only be used when appropriate rather than as standard.

Perceived benefits of using information technology

Although the barriers given above were identified there was a general level of enthusiasm for the future use of similar devices on a construction site. This is illustrated by the benefits that the participants identified during the trials.

- The information is less subjected to the elements, unlike paper, which can get wet and blows around in the wind.
- The information is easy to carry, rather than having a lot of paperwork 'filed' in the back seat of the pick-up truck.
- The tedious task of typing up notes when you are back at the office is

eliminated by collecting data electronically in the field and then synchronising it back to the site data network.

- It could provide a useful reference tool so that you do not have to remember or predict what information you will need to view/record in the field.
- It could enable engineers to spend more time actually out on site.
- Data collected in the field will be more structured and consistent.

There are also further benefits for the project team as a whole that result from having instant access to well-structured data.

- Information collected in the field can be immediately passed on to other members of the project team.
- Data can be imported into, and manipulated using, other software packages.
- Data can be easily searched in the future both for auditing purposes and for future knowledge management applications.

The next step

This paper has illustrated that many of the perceived barriers to the uptake of hand-held devices in construction are either non-existent or can be easily overcome. However, there are currently very few construction teams realising the full potential of their use.

In the future mobile technology will enable collaboration on several different levels (Fig. 5) extending the use of extranet-based collaboration tools into the field.

- *Site to site.* Information can be rapidly exchanged by personnel out on site, often in conditions where more traditional methods of exchange are not viable. For example speaking above the noise of an active piling rig or attempting to pass paper-based information will often entail interrupting the activity in progress.
- *Site to site office.* Site-based personnel will no longer need to return to the site office in order to obtain further information that they require or that they have been requested to provide. Time-savings in this case could be in the order of several

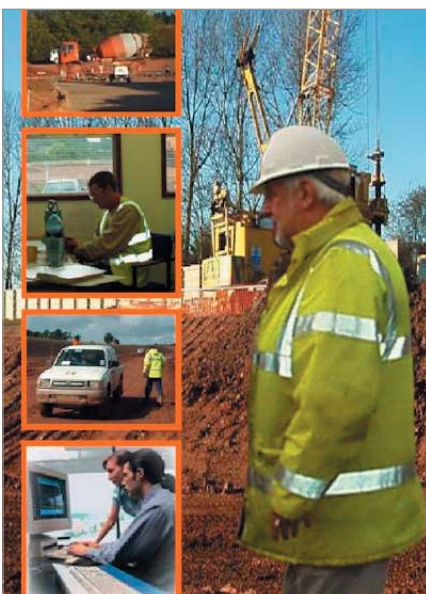


Fig. 5. Mobile technology could enable collaboration on several different levels, extending the use of extranet-based collaboration tools into the field

hours per person each day.

- *Site to project team.* The office-based project team are able to communicate directly with personnel on site, often allowing the immediate resolution of construction difficulties. This collaboration can also take place in reverse, allowing site-based personnel to provide immediate feedback to the project team and resulting in more efficient and appropriate solutions.

Besides the information-based benefits there will be an additional benefit that has the potential to outweigh these. Through

access to collaboration systems site personnel will begin to feel less isolated from the project team, which will result in greater cooperation, mutual understanding, enhanced team relations and consequently better quality projects.

Conclusions

There are many different mobile devices and software solutions to choose from to extend collaboration tools for use by site-based personnel. Contrary to common perception site-based staff are ready and willing to use these devices to com-

municate with the wider team.

The information needs of site-based staff will differ from those of the rest of the project team, not only due to their particular role but also the physical and technical constraints of receiving and sending information from site. Collaboration tool providers must take this into account. It is imperative that the introduction of information technology solutions for field-based staff does not produce yet more incompatible applications in the construction industry but that they integrate with existing project-wide collaboration solutions in order to reap the benefits they provide.

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