Web-Based Synchronous Communication in Construction: Breaking Out of the Zero-Sum Game

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Abstract

The introduction of rugged wireless communication technologies for long and short haul applications allows that electronic data from mobile equipment, tools, video cameras, and entire sensory platforms to be shared by everybody or every system that is allowed to access the wireless site network. No longer is information sharing limited to Memos, radio/phone or weekly trailer meetings. A critical component of such a network is telemetry that collects and distributes electronic data automatically allowing us to move from a mostly qualitative to a quantitative management approach. In order to reap the offered benefits, construction has to abandon the zero-sum game mentality that leaves no room for collaboration. Sharing information with everybody is foreign to a contractor who has to make a profit in a "low-bid" environment. Here, a contractor has to find mistakes that he "must" exploit to stay profitable. This paper will address the promises of abandoning this paradigm in housing construction.

Keywords: wireless-communication, information sharing, information technologies, GIS, RFID, production waste reduction, value adding, value sharing, quantitative management, telemetry, spatial integration, as-builts, accident prevention

Introduction

Housing construction experienced several decades of stagnant productivity, high accident rate, large amount of production waste, as well as consistently poor quality. Two main issues have been found to contribute to the problem: 1) Low-bid leading to confrontational working relationships, and 2) lack of effective communication across the project team. The following will highlight some representative examples in an introductory fashion.

Underground Utilities that Kill and Destroy

On September 12, 2002, a public works crew in Hornell, NY struck a 2-inch gas line while repairing a fire hydrant. One witness told news media that the gas company had put yellow paint marks on the ground to indicate the line's location, but the marks were about five feet from where the line was hit. On November 11, 2002, in Exeter NH, a construction crew damaged a gas line with a backhoe. The backhoe bucket had caught a 2-inch gas line that was known to be there. However the crew thought it was much deeper. Firefighters had to evacuate a nearby hospital building while police closed off streets while the break was repaired. Utility companies, locator services, and contractors are searching for new locating equipment, methods, and ways to overcome unreliable utility locates. But they face huge obstacles. For instance, the conduits for these utilities range from steel, cast iron and ductile iron pipes to clay, polyethylene, polyvinyl

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chloride, and fiberglass reinforced plastic pipes. Cables may be copper or fiber optic. The conduits have different shapes, compositions, densities, and diameters, and their depths range from 0 to 10 meters. Some lines (usually local telephone, electric and gas lines) may be stacked vertically in a common trench. Multiple lines may be grouped in a single conduit or duct.

The reason for having to locate pipes before digging is that there are poor records with inaccurate utility positions. Some live (e.g., operating) services do not even appear on the utility plans. Valid as-built information about the location of all buried facilities in absolute coordinates is essential in avoiding hitting them during digging or drilling. The establishment of such data would most effectively start during utility construction. In fact, the Best Practices report by the Common Ground Alliance (US DOT, 2003) suggests that: "Contractors installing underground facilities notify the facility owner/operator if the actual placement is different from expected placement. …" The Alliance adds that the keeping and updating of the data is best done by the utility owners.

Stagnant Productivity Linked to Poor Communication

Productivity is centrally important to the economic health of the United States' economy. Over 10 million people are employed in the construction industry. Therefore, productivity changes within it have direct effects on the national productivity and economic well being of the United States (Allmon et al. 2000). Teichholz (2000) concluded that the construction industry has suffered from low performance for more than three decades. He adds that since 1964, the labor productivity as not changed. Dainty (et al., 2001) reported that the result of an extensive survey showed that the poor quality of information was considered one of the main barriers to increase poor performance in construction. Poor management and lack of formal training in construction are also regarded major causes of low productivity.

A Raising Amount of Production Waste

The ever-increasing amount of waste generated by construction has become a growing concern as cost for landfills is increasing. Construction waste now accounts for 23% of America's municipal solid-waste stream. In home building, lumber, drywall, masonry, and tile are responsible for over half of construction waste (Gavilan and Bernold 1994). Waste can be accumulated from unskilled workers, human error, improper material handling, and material packaging. According to Gavilan and Bernold (1994), sources of waste seem to be closely linked to the traditional sources of low productivity. Trying to find ways to reduce construction waste can be viewed as an effort to increase construction productivity and safety.

Lowest-Bid and the Zero-Sum Game

To "win the bid" general contractors (GCs) need to minimize cost by getting the "lowest" offers from their subcontractors and suppliers. During the actual construction of a "low-bid" project, each participant will hold his/her information about the processes that associate with their true cost and profit close to "their chest." Locked by their bid, additional money can only be made using the zero-sum approach, either you win and I loose or I win and you loose. The participants see each other like a black box. The only information they are willing to share is the price tag and the only way to make additional profit is to "WIN" the game. If we can't change the zero-sum strategy of contractors are forced to apply, some of the key benefits of a SWS will never materialize.

Poor Work Quality

The success of a construction company is often measured in terms of finishing on schedule and under budget. This type of measurement overlooks the important considerations of quality. Already seen in 1981, quality was sacrificed for an increase in productivity or a decrease in direct costs (Helander, 1981). Even though the short-term goal for the contractor is to meet contract requirements, a contractor's quality performance has long-term implications. Since productivity is directly related to the quality of the contractor's work, the construction industry is realizing that quality must adopt a more important role and become a part of the construction company's culture (Mincks and Johnston 1998). Quality in masonry can be shown through a final product of unsurpassed durability and beauty.

Need for New Management Paradigm

The Zero-Sum-Game of Today

The prisoners' dilemma is a well-known example of non-zero-sum-game that has been formulated in the field of game theory since 1950s. The prisoner's dilemma is the story of two criminals who have been arrested for a crime and are being interrogated in separate cells. Each has no way to communicate with the other. The case against them is weak and the police have no strong evidence unless one of them confesses. They both receive the same three messages: 1) If you both confess, you will both get four years in prison, 2) if neither of you confesses, the police still be able to pin part of the crime on you, and you'll both get two years, and 3) if one of you confesses but the other doesn't, the confessor will make a deal with the police and will go free while the other one goes to jail for six years. The Fig. 1 illustrates the structure of payoffs.

		Prisoner A			
		Confess		*Silent*	
Prisoner B	*Confess*	4	4	6	0
	Silent	0	6	2	2

Figure 1. Payoff matrix of the prisoners' dilemma

In the presented situation, both prisoners see no good solution for their problem without knowing the other's decision. The best they can do is to confess and get four years in prison. However, if they can communicate and cooperate, they could choose to remain silent and get two years in prison. A contractor locked into the "lowest-bid" must feel similarly when he detects a mistake in the drawings early on. If he warns about the mistake, it will be fixed proactively. If he stays silent, it will lead to a change order that promises a higher profit. Why should he "confess"?

A Non-Zero-Sum Strategy for Tomorrow

Most often, as in the case of the rebar bundling, savings are only possible if one party "invests" in form of additional work. In case of a supplier-contractor relationship, it would be the suppliers who has to invest and the contractor would be gaining the benefit. To make this collaboration attractive to a supplier the contractor has to be willing to share the overall savings or gain that are only achievable with the "help" of the supplier. If we assume that the two partners decide to cooperate and to split the overall gain equally, the supplier will first be reimbursed his $10 extra "investment" and receive an additional $5 from the "coalition fund". Thus the suppliers actual cost will be reduced from $50 in the competitive mode to $45. The contractor, on the other hand, will end up with a cost of $85 vs. $100. The payoff matrix of the coalition is shown in Fig. 2.

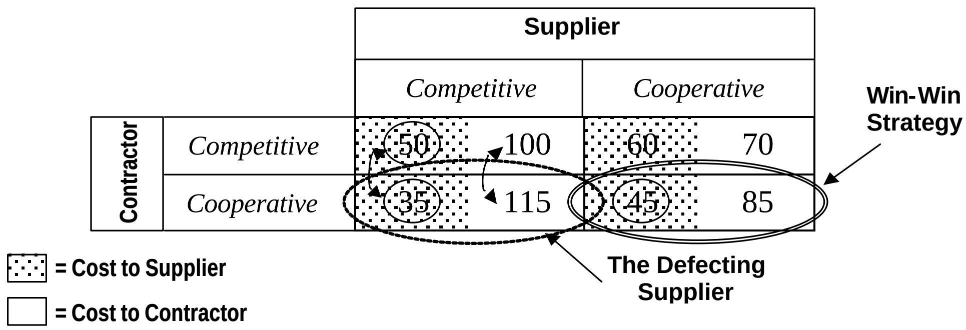


Figure 2. Payoff matrix of strategies

According to the payoff matrix, both contractor and supplier can gain the benefit only if: a) they both share information, b) agree to share the overall gain, and c) remain in a cooperative mode. The effect of a "defecting" supplier who switches from a cooperative win-win mode to a win-loose mode is clearly seen. He may find a way to break his promise and ship the rebar the "cheaper" way costing him only $ 50 but still get the $ 15 differential ($10 for extra cost and $5 value sharing) from the contractor. As shown in Fig. 4, the supplier's cost are now down to $ 35 while the contractor is stuck with the old method of placing rebar, costing him $ 110, including the $ 15 that he already paid the supplier. It is prudent to assume that the contractor will not continue the coalition, which will bring him back to the original competitive-competitive low bid strategy which costs him only $ 100. While this example is simplified, it demonstrates how a defection causes both of them to fall back to competitive mode and thus loosing the opportunity to share in an $20 value gained through collaboration which is critical for the effective use of a shared website.

The Integrated Wireless Site Network (IWS)

The main objective of a IWS is to provide an electronic hub that allows the real-time sharing of information between collaborating entities. It consists of a computer with broadband Internet access as a hub and a set of peripherals such as PDA, wireless communication system, video cameras, ruggedized electronic sensors of all types, etc. Cameras can be wireless providing more flexibility. Digital pictures from video or cameras can be kept on the website as a project history. The information maintained in the system can be visual and media rich. One such basic system has been demonstrated at the residential building construction site in Raleigh, North

Carolina. Contractors were so impressed that they asked for additional linkages which led to the more extensive IWS design, shown in Fig. 2, which includes a list of linked transmitters, receivers, temperature/humidity sensors inside the building, data entry ports, and electronic access portals. It is also indicated that on-site data communication using wireless technology will allow equipment to communicate with each other.

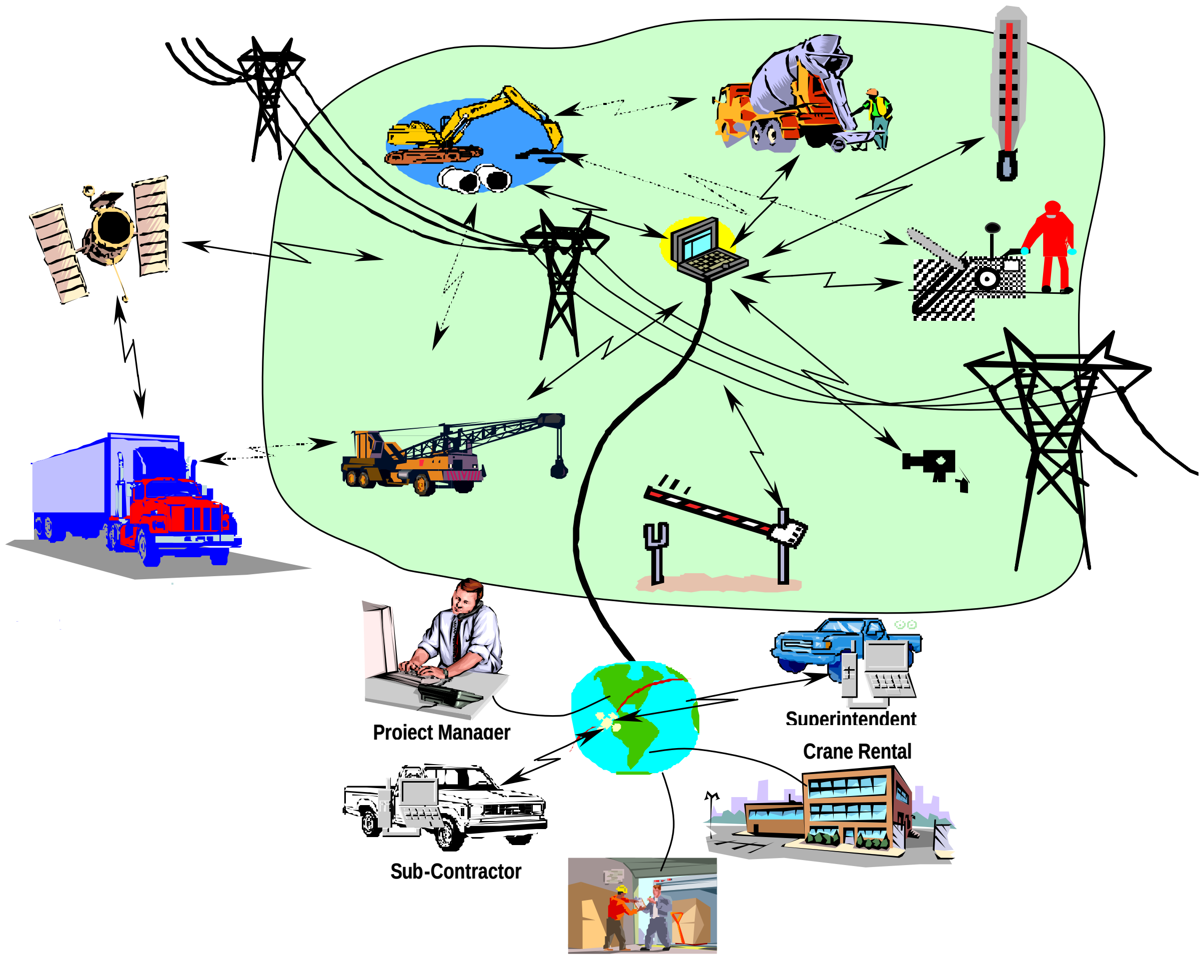


Figure 3. Structure of the Integrated Wireless Site network

As indicated in Fig. 3 the wireless site is connected to the internet via a hardwire. Since the site network transmits and receives data, synchronous communication between a internet user and any system with an IP address is enabled. Thus, a crane on site can send messages automatically to the rental company about its status, etc. The field of automatic communication between systems is referred to as telemetry.

Telemetric Machine-to-Machine Communication

In broad terms, telemetry is the science and technology of collecting, communicating, and receiving electronic data. Encyclopædia Britannica (2003) defines telemetry as the: "highly automated communications process by which measurements are made and other data collected at remote or inaccessible points and transmitted to receiving equipment for monitoring, display, …" Telemetry is extremely well suited to serve as a second tier enabling technology if "married" with other technologies, including GIS or portable location devices that have given rise to exciting new types of information utilities. For example, personnel in the field, away from their office desks, are now using wireless devices to retrieve information that is in any way relevant to their current location. Signaling an even larger boost to location measurement was a mandate of the United States Federal Communications Commission (FCC) that the geographic position of all cellular phone devices must be detected so that emergency services can be dispatched to the caller's location. It is estimated that more than 100,000 calls per day to 911 come from wireless phones. Most of these wireless calls are from highways where it is difficult for callers to identify their precise location.

Very exciting, albeit still in its infancy, is machine-to-machine communication. Bypassing any delay causing interferences, one unit automatically notifies another about its location and state. Machines that are considered as potential candidates for building telemetric nets include cranes, loaders, trucks, and power lines crossing the construction site. Thus, power lines that warn and possibly disable encroaching cranes may become a common accident prevention technology in the future.

Automatic Resource Tracking

Since equipment, material and labor are key resources on a building site, tracking their whereabouts is essential. The RFID (Radio Frequency IDentification) tag technology has successfully been used in the retail and service industries. For example, Wal-Mart and FedEx have implemented RFID tags to improve their supply-chain and logistics management. By using RFID tags, IWS will be able to track and identify materials, equipment, tools, and other resources automatically off- or on-site.

Visual Information from the Wireless Site

Visual information, especially video and photo images, has proven to be an effective tool for communication in engineering. Wireless video feeds and digital still photos provide the opportunity for project participants to monitor progress, inspect compliance or quality, solve problems, etc. while residing off-site. The following discusses two examples of situations where the IWS equipped with video is able to reduce wasteful non-value adding activities or create new value for a very small price.

Visual Inspection

Most inspections required during construction are visual. As can be observed many times on building sites, the scheduling of an inspection is more or less a trial-and-error operation. Very often, crews have to idle or have to kept busy doing other thing because the inspector has not shown up. Fig. 4 presents examples of video images that could be sent to an inspector live or could be time-stamped to verify compliance. Similarly, IWS would allow safety inspectors to do their visual inspection remotely.

Visual As-Builts

It is self-evident that a visual image stored electronically could be used for multiple purposes (free of charge). Fig. 4 highlights a second set of examples that demonstrate how the time-

a) Foundation after concrete pour b) Roof structure and HVAC in place c) Electric and plumbing system

Figure 4. IWS images for remote inspection

stamped images captured during construction could be used to create a visual as-built for the entire building. Spatial data about the location of a new water pipe can be shown relative to above surface markers (e.g., steps). Alternatively, digital pictures allow the new homeowner to see through the walls.

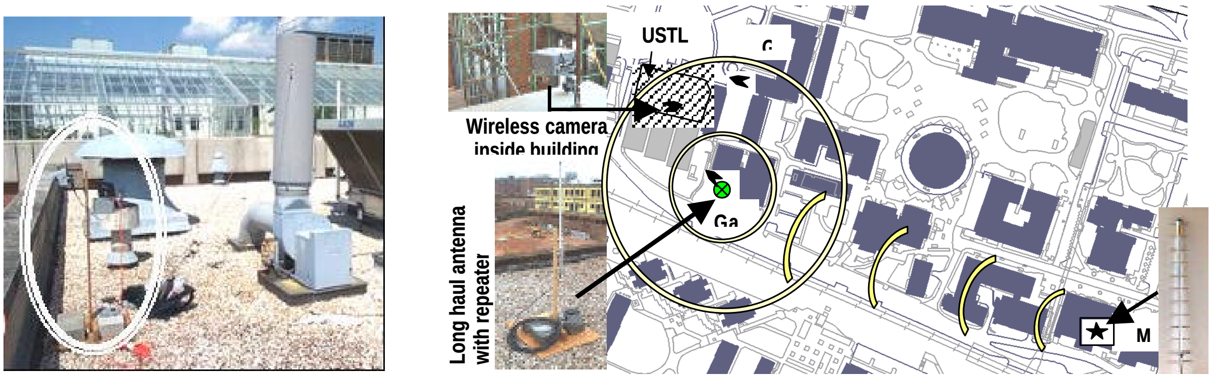
a) Material storage during construction b) Location of utilities b) Location of water lines

Figure 5. Visual as-builts for the home-owner

Any homeowner who has remodeled a house or changed the landscape around the house can appreciate the benefit of having visual as-builts available. Having a depository of such information for utilities in streets and right-of-ways would undoubtedly allow us to reduce the many accidents caused by the lack of data about there exact location.

The Integrated Wireless Site

Commonly, housing construction, unlike the finished building, does not have an Internet access. Nevertheless, access points to the web are not too far away. This situation requires the utilizing of long-range wireless transmission from the site to an access point. In order to test such a system, the author installed a Wi-Fi network on NC State campus during the construction of a new undergraduate teaching laboratory (USTL.) Fig. 5 presents the set-up and some hardware.



a) Wireless camera on adjacent roof G

b) Camera, antennas, and repeaters to cover USTL site

Figure 6. Long-haul Wi-Fi network for building construction on NC Campus

The station labeled Ga in Fig. 6 b) indicates the location of the main hub on the roof of a building. It consists of one video camera, one long haul antenna, and one repeater that covers the entire USTL site. In order to cover the wireless camera inside the building additional repeaters were installed. The cameras are programmed to capture and upload pictures to the server based on a specified time interval between 1/10 second per frame to 1 frame per week. M represents the router with access to the internet.

As part of the study various members of the project team, including owner and the future user, were surveyed to assess value. Not surprisingly, the rating varied with the role and location of each team member. For example, the GC who was on site every day did not value the system as much as the specialty-subcontractor for the Greenhouses from Asheville, NC or the mechanical engineer stationed in Charlotte, NC. By far the highest rating was given by the owner represented by a project-manager working for NC State. He had to manage the construction of 3 projects simultaneously and found the visual access from his office invaluable and a big time saver. One user of the facility, a professor in Botany, has stored the downloaded frames of the daily progress as well as the visual as-builts and will use it for her classes in the future.

The field test of the IWS demonstrated the potential of such as system when fully implemented. It also highlighted the shortfall of the present managing paradigm when a truckload of material arrived at 8:05 AM one morning together with the crew of a sub-contractor, 8 laborers and supervisors, ready to unload the tractor-trailor. Because the GC wanted to finish some work on site-preparation, the truck was not able access the site and had to stay parked on the road leading onto the campus. This in turn caused a dangerous bottle-neck for the traffic which was naturally heavy at that time of the day. Since nobody was assigned to direct traffic, the project manager came personally to take over that job after he had observed the situation on the IWS. In addition, the parked trailor interrupted the work of a surveying crew since the tractor-trailer was parked exactly in the line of sight of one critical station. This entire situation continued until about 10:00 AM and was watched by the subcontractor in Asheville. It became obvious that a collaborative working relationship between GC and sub-contractor with a potential value-sharing arrangement could have saved a significant amount of money (for the sub-contractor and the trucking company) and, in addition, would have allowed the 8 laborers to achieve high productivity for that day.

Summary

The example of the tractor-trailer unable to access the site for 2 hours, idling a crew of 8 and a surveying crew while creating a traffic hazard in the process, demonstrates the need for a paradigm shift in construction. The biggest barrier to this shift is the traditionally adversarial relationships between general contractors, the many sub-, and sub-sub-contractors or material suppliers where open communication is considered a detriment to he profit-margin and information created by different participants is not kept secret, if at all. This paper argues that the adoption of win-win coalition building strategies by two or more project participants will create the necessary incentives to make an Integrated Wireless Site (IWS) a very profitable technology. In addition, the paper presents the results of testing a prototype wireless site network for building contractor that provides value added information to the owner/user, sub-contractors, engineer/architect, inspectors. With the help of several examples a variety of uses and benefits of an IWS were highlighted. The results of field test show promise in drastically improving the ease of communication between contractors, suppliers, and homeowners. It is felt that automatic machine-machine communication (telemetry) will enter the construction site as soon as each machine will be equipped with its own IP address, on-board sensors, storage device, and transceiver for Wi-Fi application.

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