Application of Hands-Free Communication Technology in Construction Surveying and Building Layout

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Efficiency and quality of communications on construction sites are significant issues with respect to productivity. Before the advent of the hand-held two-way radio in the mid-twentieth century, communication on construction sites was limited to hand signals and human voice. Since that time, the two-way radio and more recently cellular/mobile phones have been the preferred method of communication for certain construction tasks. However, these devices still have critical limitations; for example two-way radios cannot free both hands of the users when the microphone must be keyed. Hands-free communication technology (HFCT) allows two or more people to converse effectively with full duplex capability and in a hands-free manner. This paper describes a pilot study, and a subsequent quantitative study of field testing HFCT on construction surveying activities; the latter of which was conducted in conjunction with a lab-based surveying course in an accredited U.S. construction management program. The testing was designed and executed to simulate the atmosphere of a construction site, and quantitative results suggest that HFCT could have a positive impact on productivity in construction surveying and building layout.

Key Words: Communication, Hands-free Technology, Construction Surveying, Building Layout, Productivity

Introduction

"Effective communication is hindered by the ruggedness of the construction environment where the sources and receivers of process information are geographically dispersed and continuously moving around a congested and 'noisy' site area" (Lee & Bernold, 2008.) Inventions such as the two-way radio have done much to improve communication on construction sites, particularly related to overcoming the frequent, and in many cases, constant background noise. Workers commonly use two-way radios while performing tasks such as steel erection, concrete pumping, and construction layout. Though the two-way radio has greatly improved the ability of workers to communicate by eliminating the requirement of a line of sight, its use also seriously inhibits the functionality of the user's hands because it requires activation by keying a microphone each time the user needs to communicate. In the case of hoisting, workers must often guide a heavy load with one hand while communicating via radio with the other. This process is further complicated when the worker must also use his free hand to steady himself. Also, two way radios are "half-duplex," meaning that a party using it can either talk or listen, but not both at the same time; as opposed to a telephone on which conversations are full "duplex," allowing multiple users to communicate freely and simultaneously. These inhibited functionalities can adversely affect the productivity and safety of construction workers when using these devices on the jobsite.

Literature Review

There is evidence supporting the rapidly increasing demand of hands-free communication devices in different sectors of industry (Carroll, 2001). Many efforts have been undertaken researching the application of hands-free communication technology (HFCT) in other industries, such as consumer electronics (Biggs, 2005) and medical care (University, 2004). Unlike other major economic sectors however, the construction industry is characterized by activities which are discontinuous, dispersed, diverse, and distinct (Low & Tan 1996; Wood, 2003). HFCT implementation in the construction industry has proven to be more difficult than in other industries such as manufacturing (Nielsen, et al., 2007). This difficulty in implementing HFCT in construction is also reflected in the fact that there have been few significant studies done regarding its efficacy and usage in the construction industry. This lack of published information supports the need for research in this area.

Because of the increasing demand for the improvement of communication on construction sites and the significant strides made by the HFCT industry to provide reliable services, recent advancements seem to be particularly promising for use in construction (Nuntasunti & Bernold, 2006). Before the advent of the hand-held two-way radio in the mid-twentieth century, on-site communication was limited to hand signals and the limits of the human voice. Since that time, the two-way radio has been the preferred method of communication between construction field workers and has been synonymous with the construction industry.

Over the past twenty years, there have been several advancements in using other means to improve effective communication and productivity in construction. Lee and Bernold (2008, p.31) note that “one of the main drivers are the cellular phones which, after their first introduction into the U.S. market in the mid-1980s, experienced a strong development on the consumer market but also in the construction industry.” In addition, the use of wireless data transfer technology to enhance communication on construction jobsites has drawn much attention. In 2008, Lee and Bernold developed and tested the functionality of an agent-based wireless fidelity (Wi-Fi) network at a structural steel construction site. In a different study, Lee et al. (2006) conducted a study on utilization of wireless video control and radio frequency identification (RFID) technology on tower cranes. With technologies such as these, tower crane operators were found to have an enhanced view of the work space and various other functions providing up-to-date material status. Cranes equipped with these technologies can also provide faster information flow with greater accuracy and improved driving efficiency. The results of both studies confirmed considerable improvement in operational speed and significantly enhanced performance in workplace safety and communication efficiency.

Many other recent advancements show promise for improving productivity. Major communications technology companies regularly release new models of two-way radios and cell phones that are more durable and easier to use than the previous model (RCR Wireless News, 2005.) Motorola© has created a type of business two-way radio to provide an instant communication network among construction workers. The radios are built to withstand adverse weather conditions, shock and tough drops. It features a newly designed chip and acoustic cabinet that provides clearer audio at higher volumes. To keep everyone on the same channel and code, the radios can also be set on tamper-proof manager lockout. The one-watt radios offer a range up to five miles, 200,000 sq ft or up to 15 floors; the two-watt radios provide a range up to six miles, 250,000 sq ft or up to 20 floors (Two-way radio, 2003.)

Voice clarity has been a significant hurdle in the use of HFCT, however many companies have recently introduced products that are receiving favorable reviews. Aliph© has developed a new headset that has a sensor built-in the user’s unit that gently touches the cheek. The headset identifies vibrations of the user’s cheekbone and uses them to filter out background noises (Baig, July 7, 2008).

Methodology and Results

To determine if HFCT could have a positive impact on productivity in construction, a two-part methodology was utilized. The first phase was a pilot study that involved field testing with construction professionals on various activities including concrete pumping, construction surveying and materials hoisting. Through observations, questionnaires, and interviews of construction field professionals who were given the HFCT devices to use, the study concluded that HFCT had potential to improve efficiency through improved construction communication.

Based on favorable results, the pilot study provided rationale for a controlled quantitative study, for which the researchers used construction surveying and layout as a basis. The research was conducted in conjunction with a lab-based construction surveying course in an ACCE accredited construction management program in the U.S. In this study, hands-free communication devices were tested on realistic construction activities by a significant sample size of users who had a relatively consistent level of experience. The testing was also designed and executed cautiously to simulate other major factors of a construction site that might affect the results, controlling as many variables as possible. The research methodology was approved by the university’s IRB, and all human subjects were given the choice to participate. Their identity in the results of the study was kept anonymous, and their participation had no impact on their academic grade. Details of the quantitative study are also provided below.

Hands-Free Communication Devices Used for Testing

No HFCT communication system that is manufactured specifically for the construction industry was identified; the hands-free communication devices and related accessories tested in both the pilot study and the quantitative study were provided by CoachComm®, who provides HFCT devices to many U.S. athletic programs. The "Connex Headset System" provided by them for this research was full "duplex", and was battery powered (See figure 1.)

Figure 1: A set of hands-free communication system used for testing.

Pilot Study – Method and Results

As a representative sample, one of the pilot study efforts undertaken used construction surveying as its basis. The testing was conducted by a field engineer and a rodman on the jobsite of 3-story 43,000 square feet office building. The building's steel structure had already been completed and partition layout work was about to begin on the elevated floor slabs. According to the workers, two-way radios would typically have been used as the communication device for this task. After a brief introduction and demonstration on how to use the hands-free communication devices, the construction workers used the hands-free gear to lay out the interior and perimeter partitions of the building. During the test, the field engineer read points on a set of construction plans and simultaneously used a total station to take shots for these points from a hill about 150 feet from the structure. Meanwhile, the rodman carried a laser prism and was moved throughout the structure at the direction of the field engineer. The testing lasted for about three hours, and was observed in its entirety by the researchers.

Through field observation and interviews, it became clear that the two-man crew was able to perform more efficiently using the hands-free communication device. The field engineer was able to speak conversationally with the rodman and give directions whether he was shooting a distance or flipping through the construction plans. More importantly, the rodman was able to use both of his hands to keep the prism plumb while communicating with the field engineer at a distance of 150 feet (a task that is considerably more difficult while using one hand to press a button on a two-way radio that is usually used for such activity). According to the field engineer, accuracy might have been positively affected as well due to the fact that the workers were able to focus solely on their task.

As noted above, although the results of this pilot study were encouraging, the sample size was not significant enough to draw a legitimate conclusion, but was compelling to undertake quantitative research.

Quantitative Methodology

The study was conducted in conjunction with a lab-based construction surveying course offered in August of 2008; 72 undergraduate juniors and seniors volunteered to participate in the study. The student participants were randomly divided into 24 surveying “parties,” with 3 students in each party. For the purpose of the study, the parties' data was referenced by party number only in an effort maintain anonymity. This testing involved two separate activities: 1) a leveling circuit and 2) a building layout exercise, each of which took place in an open field whose topography was similar to a graded construction site (Figure 2). Twelve sets of HFCT gear were utilized, for each of which the base stations were set up at a centralized location to maximize reception. There were two trials for each activity so that repeated measurements could be taken with respect to activity duration and productivity.

Table 1 – Quantitative ‘Repeated Measures’ Outline

	Day-1		Day-2	
	Activity-1: Leveling Circuit		**Activity-2: Building Layout**	
	Trial 1	Trial 2	Trial 1	Trial 2
Performing with HFCD*	12 parties: 1,2,3,4,6,7,8,9, 10,11,12,13	11 parties: 14,15,16,17,18, 20,21,22,23,24,25	12 parties: 1,2,4,7,8,10,11, 16,20,21,24,25	11 parties: 3,6,9,12,13,14, 15,17,18,22,23
Performing without HFCD*	11 parties: 14,15,16,17,18, 20,21,22,23,24,25	12 parties: 1,2,3,4,6,7,8, 9,10,11,12,13	11 parties: 3,6,9,12,13,14, 15,17,18,22,23	12 parties: 1,2,4,7,8,10,11, 16,20,21,24,25

*Note: * Hands-free communication device.*

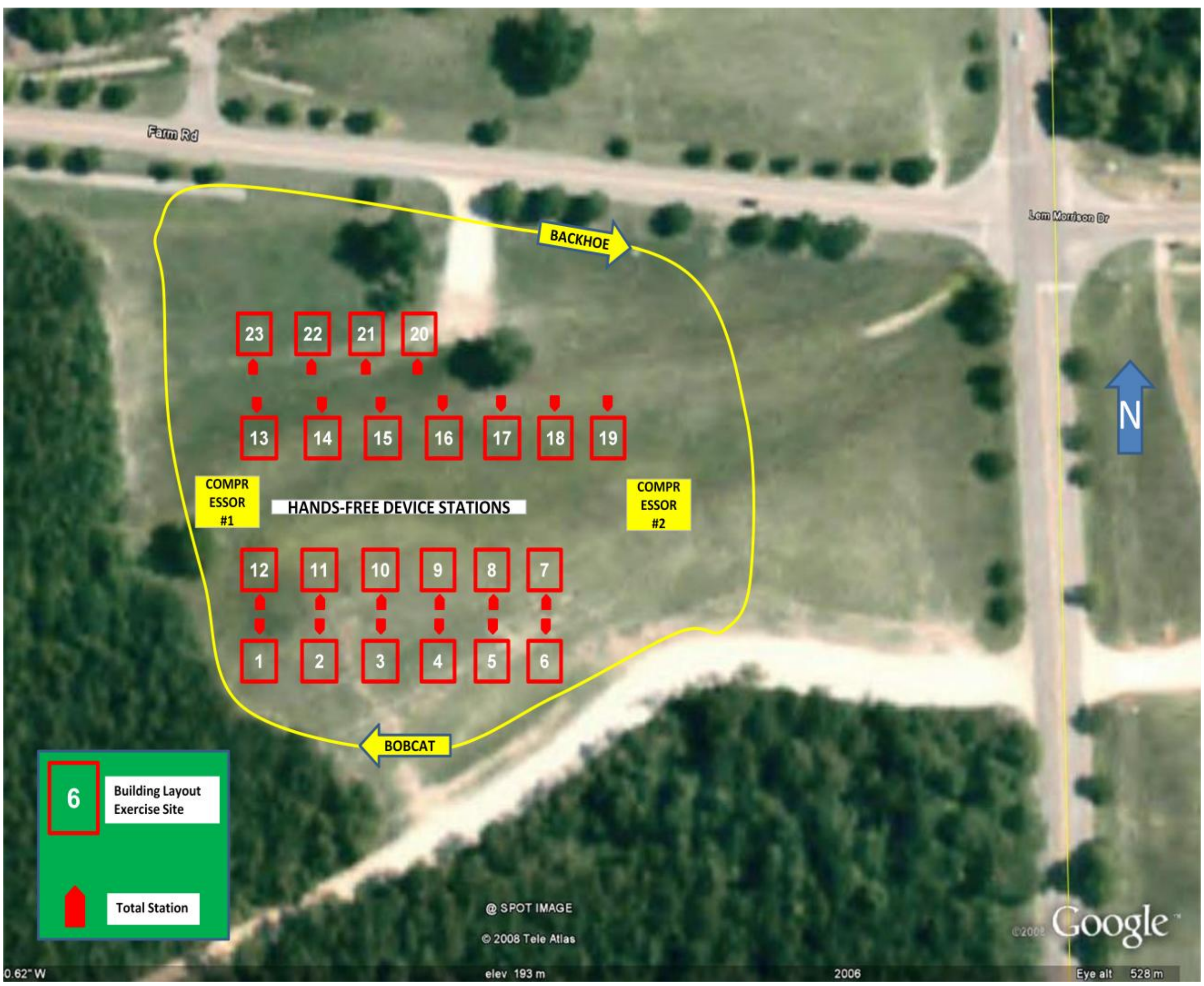

Figure 2: Site arrangement of testing activity 2 - building layout; including background noise locations.

During the design of the testing, variables that could influence the validation of the results were identified by the researchers and corresponding steps were taken to eliminate or reduce their effects:

- *Background noise.* The testing took place in an open field with relatively low levels of ambient noise. In order to imitate the background noise of a construction site, two compressors, a backhoe and a bobcat were used to provide a consistent level of noise throughout the activities (Figure 2).
- *Surveying gear*. The study used surveying instruments comparable to those used by construction professionals: CST 24x instrument levels, and TCR-405 PowerLieca total stations.
- *Surveying activities.* The testing implemented realistic surveying activities; closing a leveling loop to set project benchmarks, and the layout of shallow and deep building foundations.
- *Background experience provided.* Prior to the leveling trials of the field testing, the students ran two closed level loops and one open level loop, each with a minimum of 6 turning points. They also performed one exercise where they installed a benchmark at a desired elevation from an original benchmark of known elevation. Prior to the building layout trials, students completed 3 rectilinear layout exercises, including slab on grade corners, shallow foundations, and caisson centers.
- *Weather*. Outdoor testing was performed during sequential days in which the weather was similar with respect to cloud coverage and temperature.
- *Subjects' levels of experience.* The researchers chose to use students for the testing to provide a consistent level of prior experience, conscious that this could produce a learning effect; but in favor of using professionals whose measurement of experience could be subjective. As part of the associated class, students completed two exercises in each of the respective activity types, prior to the activities used in the study.
- *Learning effect.* A conscious decision was made for each party to repeat similar exercises at the risk of experiencing additional learning effect which might impact results, as opposed to a significantly different exercise for which the 'repeated measure' criteria could be suspect.

Quantitative Results and Analysis

Leveling

The testing results shown in Table 2 indicate that the use of HFCT had no positive impact on the completion time of the leveling circuit. In fact, in the first trial, the average time to complete the exercise for those not using the HFCT gear was longer than those who did. In the repeated measure, there was an identifiable shorter duration for those who used the gear. The researchers believe that the results of the first trial suggest that even though there was benefit in communication by utilizing the gear, there was a greater negative impact caused by parties having to familiarize themselves with the gear.

The average time to complete the task from one measure to the next shows that there was indeed a learning effect for the subjects to perform this specific construction activity, having shortened from 55.99 minutes to 43.28 minutes.

Building Layout

The testing results for the building layout exercise (Table 3) suggest that using HFCT had some amount of positive impact on the completion time. On average in the first trial, groups using hands-free devices for communication completed the exercise 14.65 minutes earlier than the groups that did not. However, because of the learning effect, the average of time saved by the use of hands-free communication devices demonstrated by the repeated measure was reduced to only 0.08 minutes in the second trial. The results, however, suggest that a small number of parties' atypical results contributed to the average being relatively small. The researchers plan to conduct further and more detailed statistical analysis on the data to provide a more refined conclusion.

Table 2 - ***Result of each group's completion time of the leveling circuit.***

	Trial 1		Trial 2		
	Start Time: 11:35AM Weather: Sunny Temperature: 85°F		Start Time: 4:05PM Weather: Sunny Temperature: 88°F		
Group Number	**Hands-Free Used? (Y/N)**	**Completion Time (Minutes)**	**Hands-Free Used? (Y/N)**	**Completion Time (Minutes)**	**Δ of Time**
1	Y	59.8	N	38.5	-21.3
2	Y	71.0	N	50.7	-20.3
3	Y	57.9	N	45.2	-12.7
4	Y	60.0	N	38.0	-22.0
6	Y	64.0	N	48.0	-16.0
7	Y	59.0	N	42.8	-16.2
8	Y	62.0	N	48.3	-13.8
9	Y	64.3	N	46.3	-18.0
10	Y	54.1	N	45.8	-8.3
11	Y	55.0	N	47.5	-7.5
12	Y	63.0	N	49.9	-13.2
13	Y	46.7	N	34.3	-12.3
14	N	54.6	Y	46.0	-8.6
15	N	43.5	Y	30.2	-13.3
16	N	33.3	Y	31.3	-2.0
17	N	64.1	Y	48.8	-15.3
18	N	41.7	Y	36.4	-5.3
20	N	51.8	Y	59.8	7.9
21	N	53.4	Y	43.2	-10.3
22	N	43.9	Y	39.6	-4.3
23	N	62.0	Y	35.1	-26.9
24	N	55.7	Y	46.5	-9.2
25	N	67.0	Y	*	
Average completion time		55.99		43.28	-12.71
Average completion time WITH hands-free comm.		59.72		41.69	-18.03
Average completion time WITHOUT hands-free comm.		51.92		44.60	-7.32
Time saved by hands-free comm.		-7.80		2.91	

Note: * *The completion time of the trial-2 was not reported by group-25.*
** *Students in groups 5 and 19 decided not to participate in this study; their results are excluded.*

Table 3 - ***Result of each group's completion time of the building layout exercise.***

	Trial 1		Trial 2		
	Start Time: 8:40AM Weather: Sunny, 85°F		Start Time: 3:30PM Weather: Sunny, 90°F		
Group Number	**Hands-Free Used? (Y/N)**	**Completion Time (Minutes)**	**Hands-Free Used? (Y/N)**	**Completion Time (Minutes)**	**Δ of Time**
1	Y	60.00	N	66.13	6.13
2	Y	69.50	N	71.83	2.33
4	Y	60.00	N	41.73	-18.27
7	Y	55.57	N	43.67	-11.90
8	Y	69.82	N	74.23	4.42
10	Y	39.00	N	47.53	8.53
11	Y	66.00	N	72.73	6.73
16	Y	70.32	N	33.43	-36.88
20	Y	55.22	N	62.00	6.78
21	Y	61.63	N	44.73	-16.90
24	Y	64.15	N	44.17	-19.98
25	Y	61.00	N	64.33	3.33
3	N	80.12	Y	70.07	-10.05
6	N	57.00	Y	58.30	1.30
9	N	65.47	Y	52.40	-13.07
12	N	72.47	Y	58.17	-14.30
13	N	101.90	Y	53.40	-48.50
14	N	80.78	Y	42.70	-38.08
15	N	84.00	Y	72.53	-11.47
17	N	108.80	Y	74.43	-34.37
18	N	59.12	Y	40.63	-18.48
22	N	62.72	Y	49.03	-13.68
23	N	63.25	Y	38.37	-24.88
Average completion time		68.17		55.50	-12.66
Avg. completion time <u>with</u> HFCT		61.02		55.46	-5.56
Avg. completion time <u>w/out</u> HFCT		75.97		55.54	-20.42
Time saved by hands-free comm.		14.65		0.08	

Summary and Conclusions

Efficient and quality communication is a key factor for a productive construction site. New technology holds promise for many industries, construction certainly included. In this paper, hands-free communication technology is introduced and a study to determine whether this technology would yield significant improvements in the productivity for certain construction activities was reported.

In this study, each set of the hands-free gear provided two separate channels for communication. Since the gear was designed for U.S. athletic programs, it did show some limitations with respect to how it would be used in a construction environment:

- Each set allowed a maximum of only five users.
- Because the gear utilized relatively high radio frequencies, it worked best when there were no dense objects between the belt packs and the base station.
- To maintain a quality conversation, the belt packs could be no more than 200 yards from their base station.

The data collected from the quantitative phase suggests that HFCT could have potential benefit for building layout tasks, but may or may not for leveling activities. The researchers believe that the dynamics of the initial use of the HFCT equipment may have impacted the leveling task results; although it was difficult to quantify largely because of the inexperience of the participants. The anecdotal results of the pilot study also suggest that HFCT could have positive impacts on many other construction activities, specifically concrete placement and hoisting. The researchers plan to expand the statistical analysis of the data to more accurately reflect the potential benefits of using HFCT in construction.

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