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Use of a hand-held computer to audit construction fall prevention effectiveness

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Abstract

West Virginia University (WVU) has developed and deployed a computerised field audit to assist in the conduct of a safety intervention research project. The audit tool is used in the field on a touch screen hand-held computer to monitor construction contractor compliance with a fall hazard management program provided by WVU. The field audit provides feedback to contractors, determines whether contractors can retain a Fall-Safe designation from WVU, and provides data to WVU on the impact of its intervention efforts. The software is custom designed and incorporates questions that determine compliance with OSHA standards relating to falls. The audit tool generates percentage scores that indicate contractor successes in managing fall hazards. The tool is intended to be field- and user-friendly. The tool has been field-tested through 62 audits as plans are underway for its expansion and future development.

Keywords: computer, software, audit, construction, safety, falls

Introduction

The use of computer applications to collect and analyse data saves time, reduces effort, returns coherent results, and costs less overall than paper methods of data collection. In the field of occupational safety, for example, the computer has been used as a statistical analyst to assist plant safety officers with the preparation of month-end accident reports. For a large factory with a large number of departments, this would be a task that would require the plant safety officer to perform around 1000 calculations per month. This could take up to three days of desk-bound activity that could otherwise have been spent on the shop floor [1].

Computer programs have also been implemented in safety analysis and multimedia-based software for monitoring the safety of critical equipment or structures. One example is the monitoring of the safety and maintenance needs of cooling towers over their working lifetime. Developed software constantly measures the strength of the towers in terms of bonding losses in the external side of the tower shell and the corrosion of the steel bars. By looking at historical data of how towers failed in the past, the software first performs structural analysis. This is followed by a safety analysis then maintenance tracking procedures to maintain deteriorating sections to prevent potential failures. The software identifies exactly which section needs attention and the type of attention needed [2].

In another application, a checklist was developed and was loaded on a computer. The checklist contains 20 questions concerning ergonomic physical stressors in the workplace (i.e., contact with sharp edges, tool vibration, materials handling, etc.). The computer program was used to provide an instant response to the user, and assist with the final analysis of the entries [3]. Applied to occupational safety and health, the digital revolution makes possible activities that could not be readily accomplished without computer applications.

This paper reports on the development and use of a fall prevention audit tool used as a checklist for compliance with OSHA's Fall Prevention Standards [4]. The computerised audit is used in the field on a touch screen computer by faculty of West Virginia University conducting third party audits of contractor performance. Results are reported to employers to assist in compliance, and used for research by WVU faculty. The audit tool is employed as part of a partnership between the university and contractors called the Fall-Safe partnership.

Falls in construction

Falls are the leading cause of death in the construction industry [5]. While the construction workforce represents 5% of the USA's workforce, it accounts for 49.6% of fall fatalities [6]. In West Virginia, the construction industry accounts for more than a third of all (fatal and non-fatal) occupational falls [7]. A study of 182 claims reported to the West Virginia Bureau of Workers' Compensation reveals that the leading categories for type of work surfaces from which a fall occurred were ladders (33.5%) and scaffolds (13.7%) [7]. This same study reports that the five leading reported causes of falls were slippery substances on surfaces (17%), slips or trips (13.9%), loss of balance (7.7%), unsafe equipment (6.6%), and a ladder slipping/skidding (7.7%). In this

study, 70% of the claims for compensation from falls reported falling 10ft or less.

Techniques for preventing construction falls are well known. For example, simple techniques such as minimising work at heights, proper maintenance, placement and tieing off of ladders, and appropriate climbing technique will go far to prevent many of the ladder falls identified in the study cited above [7]. However, the dynamic nature of the work at a construction jobsite and the transient nature of the workforce make control of simple hazards relatively difficult [8]. If the technical means to prevent many construction falls exists, an effective preventive intervention may be one that maximises the use of the well-known fall prevention technologies.

Fall-safe construction fall prevention program

Funded by the Center to Protect Workers' Rights and the National Institute for Occupational Safety and Health, West Virginia University's Safety and Health Extension has devised a partnership program between the university and individual contractors as a vehicle to prevent construction falls in West Virginia. The thrust of the partnership is to create an organisational intervention that will provide construction organisations (contractors) with the knowledge, accountability and incentives to improve their management of construction site fall hazards. Contractors and West Virginia University (WVU) sign a formal contract agreeing that the contractors will conduct fall prevention programs specified by WVU. WVU provides contractors with training, consultation, and marketing and public relations concerning contractors' efforts to prevent falls. The contractor must demonstrate that his/her company is carrying out the required fall prevention programs in order to obtain and maintain the public status of a 'Fall-Safe Contractor'. WVU staff verifies compliance with Fall-Safe programs by quarterly site audits using a hand held computerised audit tool developed specifically for this program.

Development of a hand-held computerised audit tool

As part of this intervention project the investigators developed the hand-held computerised audit tool to accomplish three separate objectives:

- Provide feedback to participating contractors on how they are performing in controlling fall hazards on their construction sites.
- Provide accountability of the contractor to WVU that the contractor is successfully managing their fall hazards and implementing the major elements of the Fall-Safe system.
- Provide research data that shows whether participating Fall-Safe contractors are improving their fall prevention performance compared to non-participating contractors.

The computerised audit tool allows WVU staff to perform quarterly audits of Fall-Safe contractor sites. The tool contains a checklist for auditing a contractor's site specific fall prevention program (program management) and a separate checklist for auditing the contractors ability to control potential fall hazards (site audit) by the proper use of engineering, personal protective, or administrative controls. The program audit elements are based on the Fall-Safe Contractor's Guide to Fall Hazard Management [9]. The field audit elements are based on OSHA's 1926 Subpart M [4].

For Fall-Safe contractors, audits are conducted quarterly on a surprise basis to contractors' construction sites. Results indicating successes and failures are reported to the contractors. Contractors must maintain a percentage score of at least 70% for both program and field conditions audits. If a contractor scores below 70% for either the program management or field audit on two successive quarterly visits, they lose the Fall-Safe designation.

Results are also tabulated for all contractors to evaluate success or failure of the intervention program. Audits are also conducted for a 'control' group of contractors who do not implement the Fall-Safe prevention program. Baselines scores are recorded before contractors implement the Fall-Safe program elements. Quarterly measures are taken for both intervention and control contractors for a year-and-a-half. Change in score for participating and control contractors are compared to evaluate the impact of the Fall-Safe program.

The audit software was custom developed for use for the Fall-Safe program. It was intended to run with the Fujitsu Stylistic pen computer, although the software will run on any computer equipped with Windows 95 or higher. The Fujitsu computers are pen driven and do not have an attached keyboard. For this reason the computers use hand writing recognition software along with a pull-up on-screen keyboard.

Design of the audit tool software

The audit software tool is designed as a dynamic survey generator: only questions that pertain to the audited site get added to the survey. The advantage to the auditor and the contractor is that a survey and its corresponding results report pertain only to the risk exposures at their site at the time of the survey. This shortens survey administration time and decreases the size of the report presented to the contractor.

The audit tool was developed using Delphi, an object-oriented Pascal language development environment. Delphi was chosen for its ease of development and speed of the executable file generated. The pen-based application stores the data on the local hand-held using Paradox files. The data from a hand-held computer can export selected audits to an ASCII text file that can be imported by a central or master computer. This allows the auditing organisation to centrally maintain, store, and analyse data from multiple handheld units.

Data is reported using Crystal Reports, which allow the use of predefined reports. This also allows a user

who is familiar with Crystal Reports to create their own custom reports. Crystal Reports can also be used to generate ASCII text files that can then be uploaded into the user's preferred statistical analysis tool such as SAS.

The prototype software was initially field-tested twice by two different WVU faculties. Based on these tests, revisions were made and the software was again field-tested twice by two faculties prior to full field implementation.

Audit tool content

The development of the exposure and intervention audit list came from an intensive sequential analysis of 29 CFR OSHA Construction Regulations that apply to falls in construction. These include Subpart M (fall protection), Subpart L (scaffolding) and Subpart X (ladders and stairways). Currently the exposure questions are being updated to include Subpart R (steel erection) and more information from scaffolds, ladders and stairways [4].

The audit consists of two major sections. The first of these is a program audit that evaluates whether a contractor is implementing program and policy elements of the Fall-Safe program (Figure 1). This program element includes site specific planning, worker and management training, daily site inspections, and a functioning fall prevention committee.

The second audit is a field audit that seeks to measure how well a contractor is managing his/her construction site fall hazards. Specifically, this audit identifies fall hazard exposures and scores a contractor on how well these exposures are controlled.

The on site fall hazard control audit tool is organised around several tiers of questions. These questions include information concerning employer, construction site, location within site, fall hazard exposures at each location, and interventions or controls for each fall hazard exposure.

Once past the entry of demographic information, the audit calls for the identification of sites where workers can be exposed to fall hazards. (Figure 2 shows the software screen and Table 1 a complete list of fall exposures.) Within each of these exposures are listed potential hazard controls for the fall hazards. For example, under walking/working +6ft, the software generates a list that includes guardrail system, personal fall arrest or safety nets. If guardrail system is chosen then the software generates an additional series of detailed choices including (in this example) wood, wire rope, structural steel, pipe, or prefabricated (Figure 2). Once an exposure and intervention have been identified, the audit tool generates a list of questions that are answered yes, no, or N/A by the field auditor (Figure 3).

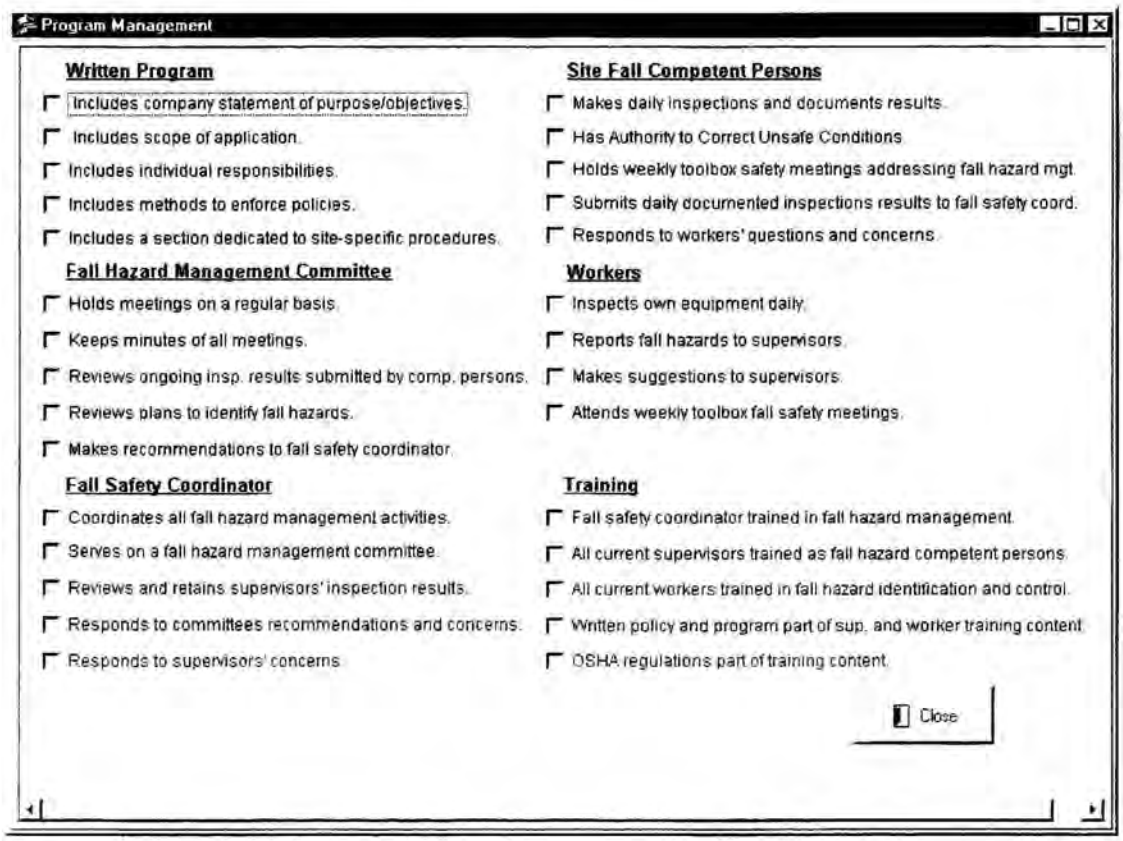

Figure 1. Fall-safe audit program screens

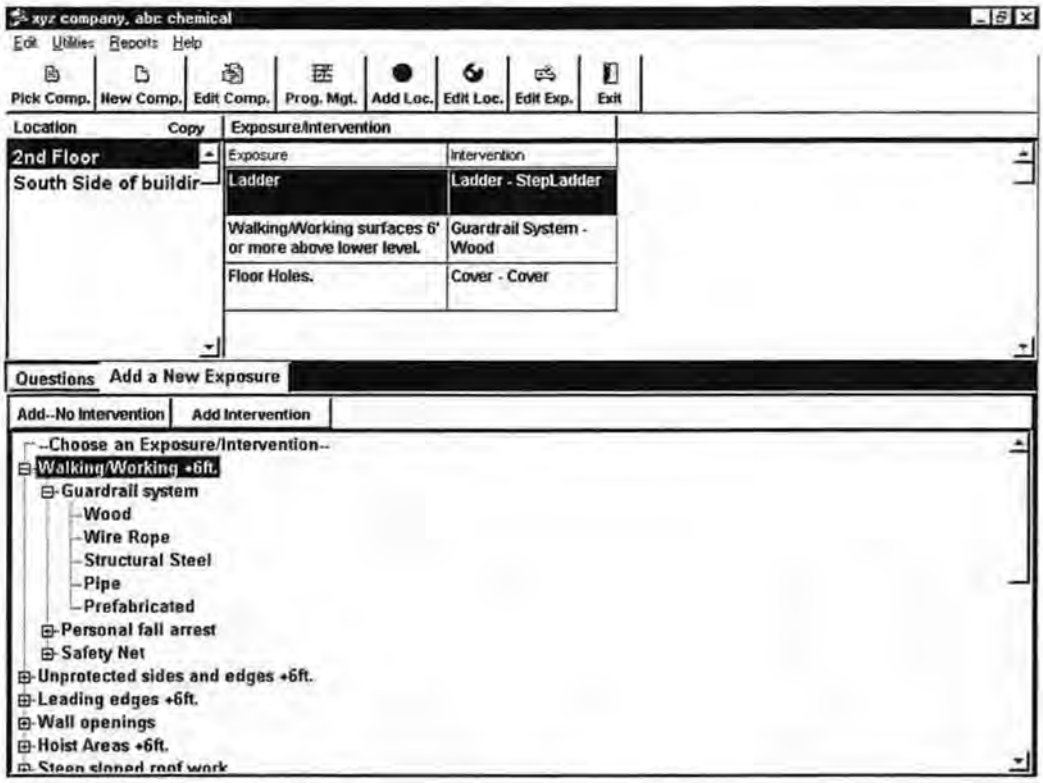

Figure 2. Main screen fall-safe audit (partial list of exposures)

Walking/working + 6ft
Unprotected sides and edges + 6ft
Leading edges +6ft
Wall openings
Hoist areas +6ft
Steep sloped roof work
Working over dangerous equipment
Other walking/working surface +6ft
Floor holes
Form work
Ramps and runways
Over dangerous equipment +6ft
Excavations
Wells, pits, shafts
Overhand bricklaying
Low sloped roof work
Precast concrete work +6ft
Ladder
Aisles, passageways and work areas
Scaffolding
Aerial lifts

Table 1. Fall hazard exposures contained in the fall-safe audit tool

The hard copy version of the audit is approximately 60 pages long. If a hard copy was to be used in the field, an auditor would need to carry multiple copies to allow for the possibility of more than one of each kind of exposure (roof edge, roof hole, etc.). The wish to reduce dependence on this amount of paper was the main motivation for development of the computerised audit tool. Its main advantage is that auditors only see screens and lists that are needed on a particular site and have one sheet of the audit to deal with at a time.

Steps to conduct a fall-safe audit

To date, WVU Safety and Health Extension has conducted 62 audits. What follows is a step-by-step guide to conducting an audit with this software:

1. Open the audit tool (Figure 2)
2. Enter a company name or choose an old one (Figure 2)
3. Complete program management audit (Figure 1)
4. Identify a location on the construction site (Figure 2)
5. Identify a fall exposure or exposures at that location i.e. low sloped roof (Figure 2)
6. Identify the fall prevention system used to control that exposure, i.e. wooden guardrail (Figure 2)
7. Evaluate the control of the exposure using the check list questions (Figure 3)
8. Move on to another exposure at the same location, or move to another location (Figure 2)

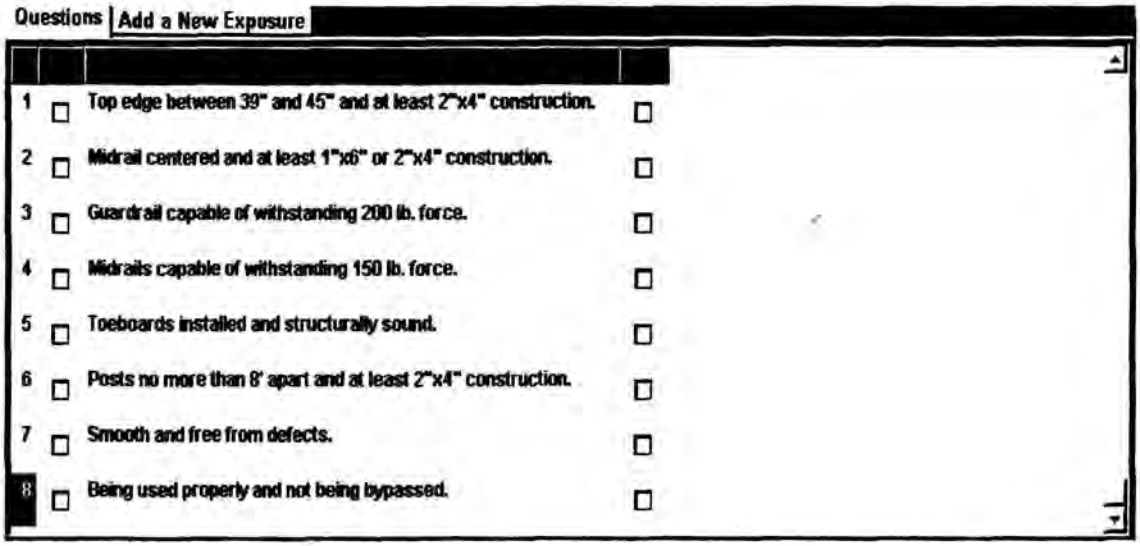

Figure 3. Fall-safe audit compliance checklist screen for walking/working, wood guardrail

The Fall-Safe audit software automatically updates and saves the data entered during the audit. Once complete, the audit can be formatted into a printable report and can be uploaded to a main database that stores the data for statistical analysis.

Audit tool scoring system

As noted above, the Fall-Safe site hazard control audit consists of a list of possible fall exposures (i.e. sloped roof, pit, scaffold, ladder, etc.) followed by a list of possible control measures for the identified fall exposure (e.g. edge guarding, ladder tie-off, warning lines, harness and lanyard, etc.). For each exposure the audit software calculates a raw score representing the percentage of possible control criteria which have been satisfied by the contractor. For example, a contractor would be graded 0.60 for guardrails where 60% of the listed criteria were met ('yes' answers = 0.6 possible applicable answers). This raw score is then weighted by an algorithm that favours engineering control over personal protection. It also rewards a contractor for using redundant or backup fall prevention systems, i.e. guard rails and harnesses.

Table 2 illustrates the weighting system used by the Fall-Safe fall hazard control algorithm. Score additions due to redundancy of control cannot bring an exposure score over 1.0. For example, if a contractor was working on a flat roof site, and erected a guardrail which was graded at 0.6 and also used personal fall protection which was graded as 0.8, the score would be computed as in Table 2.

Total score for a contractor on a site is the arithmetic mean of all of the adjusted exposure scores. Reports are generated for each contractor for their program management and site audit scores. As noted above, a contractor must maintain scores of 70% on both management and site audits to retain status as a Fall-Safe contractor. (See Figures 4 and 5 for examples of program and site audits reports.)

Audit tool feedback and results

The audit reports have also been used as a feedback mechanism for the intervention contractors. A copy of the audit is sent to the contractor. The report includes percentage scores on the program management and site audits. It also tells the contractor where that company's scores rank with other participating contractors. The contractor is also sent detailed analysis which includes each exposure and intervention score, as well as summaries of the contractor's scores for types of exposures. For example, a contractor would be able to know how well he/she controlled fall hazards on roof edges, or scaffolds, or ladders. Reports are accompanied by narrative descriptions and colour photos taken on site that illustrate successes and failures.

Control	Primary control	Redundant control
Engineering control	0.9	–
Personal protective equipment	0.8	0.4
Nets	0.7	0.2

Table 2. Weighting factors for hazard control audit

7/10/00 **Company: xyz company** Visit Date: **1/1/00**

Location: **South Side of building** Number Exposed: 2

Exposure: Walking/Working surfaces 6= or more above lower level

		Possible	Score
Intervention:	Guardrail System	90%	67.5%
1.	Top edge between 39" and 45" and at least 2"x 4" construction.	1	
2.	Midrail centered and at least 1" x 6" or 2" x 4" construction.	1	
3.	Guardrail capable of withstanding 200 lb. Force.	1	
4.	Midrails capable of withstanding 150 lb. Force.	1	
5.	Toeboards installed and structurally sound.	0	
6.	Posts no more than 8' apart and at least 2" x 4" construction.	1	
7.	Smooth and free from defects.	0	
8.	Being used properly and not being bypassed.	1	

Raw Score: 75% **Adjusted Score:67.50%**

Location Summary Score: **67.50%**

Location : **2nd Floor** Number Exposed: 5

Exposure: Ladder

		Possible	Score
Intervention:	Ladder	90%	67.5%
1.	Correct size for the job.	1	
2.	Fully opened and spreader bars locked.	1	
3.	Firm foundation for ladder feet.	1	
4.	Proper climbing procedures being used.	0	
5.	Three point contact rule being followed.	0	
6.	Free from obvious defects.	1	
7.	Worker not standing on top 2 steps.	1	
8.	Being used properly and not being bypassed.	1	

Raw Score: 75% **Adjusted Score: 67.50%**

Exposure: Floor Holes

		Possible	Score
Intervention:	Cover	90%	90%
1.	Designed to support 2 times the intended load.	1	
2.	Secured.	1	
3.	Color coded or labeled.	1	
4.	Installed so as to eliminate tripping hazards.	1	
5.	System free from obvious defects.	1	
6.	Being used properly and not being bypassed.	1	

Raw Score: 100% **Adjusted Score: 90.00%**

Location Summary Score: **78.75%**

Site Summary: **18** **Points out of** **22** **Total Managed Score:** **73.13%**

Figure 4. Sample site audit report

Sample Program Management Audit Report

Fall-Safe Program Management and Related Functions

Company:	XYZ company	**Visit Date:**	1/1/00
Site:	ABC Chemical Co., Inc.	**Workers Managed:**	25
Contact:	John Doe	**Print Date:**	7/10/00
Address:	Anywhere WV		

Written Program

1. Includes company statement of purpose and objectives.	1
2. Includes scope of application.	1
3. Includes individual responsibilities.	1
4. Includes methods to enforce policies.	1
5. Includes a section dedicated to site specific procedures.	0
Score:	**4**

Fall Hazard Management Committee

1. Holds meetings on a regular basis.	1
2. Keeps minutes of all meetings.	0
3. Reviews ongoing inspection results submitted by competent person	1
4. Reviews plans to identify fall hazards.	0
5. Makes recommendations to fall safety coordinator.	1
Score:	**3**

Fall Safety Coordinator

1. Coordinates all fall hazard management activities.	1
2. Serves on a fall hazard management committee.	0
3. Reviews and retains supervisors inspection results.	1
4. Responds to committees recommendations	1
5. Responds to supervisors concerns.	1
Score:	**4**

Site Fall Competent Person

1. Makes daily inspections and documents results.	0
2. Corrects unsafe conditions.	1
3. Holds weekly safety meetings addressing fall hazards	0
4. Submits daily inspection results to fall safety coordinator	1
5. Responds to workers questions and concerns.	1
Score	**3**

Workers

1. Inspects own equipment daily.	1
2. Reports fall hazards to supervisors.	1
3. Make suggestions to supervisors.	1
4. Attends weekly toolbox fall safety meetings.	1
Score	**4**

Training

1. Fall safety coordinator trained in fall hazard management	1
2. All current supervisors trained as fall hazard competent persons.	1
3. All current workers trained in fall haz. ID	1
4. Written policy and program part of supervisor and worker training content.	0
5. OSHA regulations part of training content.	1
Score	**4**

Total Management Points	**22**
Total Management Score:	**76%**

Figure 5. Sample program management audit report

Comparison of change in contractor scores between an intervention and control group of contractors provides evaluation of the efficacy of the Fall-Safe intervention. Baseline and four quarterly audit series have been completed to date. The research protocol calls for another two quarters of measurement. Results of mean intervention and control contractor scores on program and site audits can be seen in Figures 6 and 7. While intervention contractors have improved program and site scores more than control contractors, this difference in improvement is not significant at p # 0.05. It is not anticipated that significant difference can be detected with the current contractor population. Additional funding has been obtained to increase the contractor pool from 16 (10 intervention 6 controls) to 60 (40 intervention, 20 controls.) St. Paul Construction (St. Paul, Minnesota) and Construction Safety Council (Chicago, Illinois) will be cooperating to recruit and administer Fall-Safe to these additional contractors.

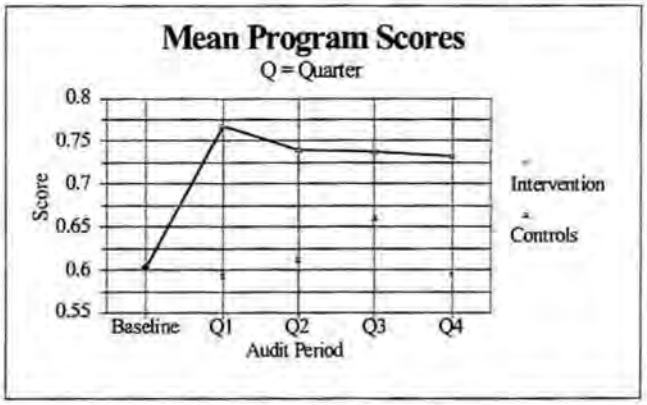

Figure 6. Comparison of program audits for intervention and control contractors

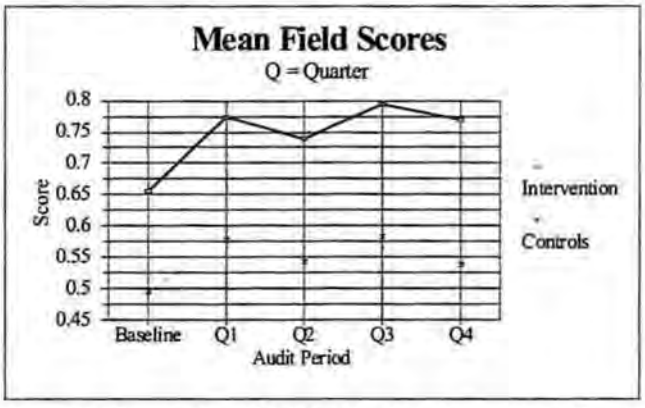

Figure 7. Comparison of field audits for intervention and control contractors

Discussion

The software provides great support to safety and health practitioners as a checklist. While it contains a large amount of data and checklist items, it prompts the inspector with all of the pertinent audit questions, one exposure at a time, in a well-organised manner. This reduces the chances of human error due to forgetting or overlooking an unsafe condition.

At the end of an audit, the program provides the user with a printable report with detailed audit data results. This assists contractors in managing their fall hazards and directing corrective attention where it is needed. The audit tool also provides the gatekeeper function of maintaining quality control over the WVU Fall-Safe designation.

As noted above, the audit tool has also provided useful research data as part of the Fall-Safe intervention research project. Preliminary data has been reported, and will likely achieve statistical significance with the addition of 40 additional participating contractors in the next three years [10]. For purposes of this research, the difference between change in intervention and control contractors score is defined as the measurement of impact of the Fall-Safe intervention. While the researchers consider this a stronger measure of impact than participant opinion or changes in knowledge following training, there has been no validation that the measured impact results in decrease of fall injuries. Such validation would require a much larger study to obtain statistical power.

One interesting preliminary finding is the increase in audit scores for control contractors. While the Fall-Safe Audit tool was intended as a measurement device, apparently the appearance of an auditor with an audit tool can alone bring about improvements in control of fall hazards.

The program has proved itself to being user-friendly. To date no gremlins have occurred that have resulted in the loss of any audit data. The ease and consistency of use may be due in part to its use by only three WVU faculties. While it appears that typical safety professionals could easily use the audit tool as a convenient checklist with little training, substantial training would be required if precision and replicability are needed for research or gatekeeper purposes. (WVU has provided training to St. Paul and Construction Safety Council staff on the use of the audit tool.) If the software becomes more widely disseminated, training will become an important issue. A training manual has been developed for that purpose.

Field use of the audit has revealed some problems which need to be corrected. While the computer has a built-in light control, the amount of sunlight affects how well the screen can be viewed. Hand writing recognition is not accurate or precise, requiring pre-entry of company information and editing following the conduct of an audit. The handheld computer also causes distraction to workers in the workplace.

The current version of the software does not allow an immediate save of the entered information. The inspector would have to completely exit the program for the software to save entered information. This poses a potential problem if the computer is to lose power for some reason. Another weakness of the current version of the software is the need to bring the software to the software developer to change or add questions to the audit tool.

Finally, the cost of the touch screen computer may limit the possible dissemination of the Fall-Safe audit. WVU is currently developing a version of the audit for use with much less expensive palm hardware using Pocket PC operating system.

As with other custom software development projects, the Fall-Safe audit tool is constantly under development. In the near future several improvements are planned. The software is currently being expanded to include areas of the OSHA standards that deal with falls in ironwork that were not included on the first version. WVU is also planning to expand content areas to include OSHA's other three areas of emphasis in conducting construction inspections. These include electricity, caught between and struck by hazards [11]. Other planned improvements are the development of a user-friendly method for adding and editing questions. Longer range, WVU looks to widely disseminate the audit tool, perhaps through a web-based system that would allow for the return of audit data to WVU for research purposes.

Conclusion

WVU has developed a computer-based audit tool to assist in its Fall-Safe fall prevention and research activities. This tool has facilitated field audits of fall prevention activities by construction contractors that allows the simple presentation and use of voluminous checklist material on a hand-held touch screen computer. The audit tool has been an efficient tool that provides feedback to contractors, gatekeeper information to WVU. It appears that the conduct of an audit and the reports generated contribute to improvements in contractor control of fall hazards. The computerised audit system also facilitated gathering of research data needed to determine the usefulness of the Fall-Safe partnership system. While originally conceived as a limited tool to designed to assist in the evaluation of a single intervention research project, it appears that dissemination of the Fall-Safe audit by itself may have merit as an intervention. Computerised audits based on the Fall-Safe audit may be successfully applied to the control of other safety and health risk factors.

Acknowledgements

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