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CSHM: Web-based safety and health monitoring system for construction management

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Abstract

Introduction: This paper describes a web-based system for monitoring and assessing construction safety and health performance, entitled the *Construction Safety and Health Monitoring* (CSHM) system. **Method:** The design and development of CSHM is an integration of internet and database systems, with the intent to create a total automated safety and health management tool. A list of safety and health performance parameters was devised for the management of safety and health in construction. A conceptual framework of the four key components of CSHM is presented: (a) *Web-based Interface* (templates); (b) *Knowledge Base*; (c) *Output Data*; and (d) *Benchmark Group*. **Results:** The combined effect of these components results in a system that enables speedy performance assessment of safety and health activities on construction sites. With the CSHM's built-in functions, important management decisions can theoretically be made and corrective actions can be taken before potential hazards turn into fatal or injurious occupational accidents. **Impact on Industry:** As such, the CSHM system will accelerate the monitoring and assessing of performance safety and health management tasks.

Keywords: Safety and Health Management; Performance Parameters; Performance Assessment; Internet; Database and Knowledge-based Systems

1. Introduction

Safety and health issues at construction sites have gained industry-wide attention, with an increasing number of centers and commissions in different parts of the world promoting construction safety and health. These organizations include the National Occupational Health and Safety Commission in Australia, the Occupational Safety and Health Administration in the United States, the Health and Safety Commission in the United Kingdom, and the Occupational Safety and Health Council in Hong Kong. Many of these organizations are governmental bodies, serving to promote occupational safety and health at work. Their functions include: promoting safety and health in the community; education and training; consultancy services; research and strategies development; and information dissemination (Health and Safety Commission [HSC], 2002; Occupational Safety and Health Administration [OSHA], 2002; Occupational Safety and Health Council [OSHC], 2002). They strive to ensure safe and healthy construction sites, and their efforts have brought about a change of culture among management and front-line workers: from the traditional "not-my-business" attitude to that of "everybody's business" (Levitt & Samelson, 1993).

Meanwhile, academics and professionals are extensively researching occupational safety and health problem areas in the construction industry. These studies can be categorized under three main topics: (a) workers' behaviors and attitudes (Cox & Cox, 1996; Lingard & Rowlinson, 1997); (b) training and workshops (Glendon & McKenna, 1995; Goldenhar, Moran, & Colligan, 2001; Hammer, 1989); and (c) effective management and performance measurement evaluation (Raouf & Dhillon, 1994).

With respect to workers' behaviors and attitudes, the Behavior-Based Safety model (BBS) developed by DePasquale and Geller (1999) has been widely adopted by the industry as the basis for design of safety and health workshops, induction talks, charters, and other safety endeavors. In essence, the model advocates the use of "goal-setting" as a motivational technique to set out the safety goals of the organization and points out the responsibilities of various

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parties accordingly. In addition to bringing about a change of safety culture, previous studies suggested that the BBS model can facilitate interpersonal trust, management support, and active employee participation (Bandura, 1997). While industry training and workshops are useful to kick-start a safety and health campaign, its success, to a large degree, depends on a well-planned site safety and health management system (Elbeltagi & Hegazy, 2002). A typical management system generally consists of three limbs: (a) Goal; (b) Process; and (c) Evaluation. It is at the initial stage when the team sets out 'goals' as to the project policy in relation to safety and health. The team manager then arranges and sets out details of the policy. Throughout the course of construction, regular meetings are held to evaluate performance results, making sure that the standards are met and performance results are consistent with the overall safety and health policy. If the results show the contrary, immediate corrective actions are taken. Such a management arrangement is instrumental in preventing improper behaviors (e.g., insufficient safety precautions, improper working methods, lack of protective gear) that may lead to serious accidents. For this reason, the importance of a safety and health management system, in particular the measurement and evaluation of performance, cannot be over-emphasized.

Despite the vast volumes of work on safety and health management, most are concerned with the first two limbs: (a) *Goal* (how to set up project goals) and (b) *Process* (how to implement a management system). A lot of work has been done on the value and culture of safety management systems (Krause, 1993; Smallwood, 2002). Others turn to the actual implementation of safety and health management systems, such as the opportunities/benefits provided (Ray & Rinzler, 1993) and the barriers encountered (Hinze, 1997; Levitt & Samelson, 1993). There is relatively little work done in relation to the third limb *Evaluation*; that is, the systematic measurement and assessment of performance (safety and health efforts and results; Geller, 1998). McAfee and Winn (1989) and Cooper, Philips, Sutherland, and Makin (1994) recommended the use of incentives and performance assessment to enhance workplace safety. In their studies, empirical results suggested that systematic measurement and assessment of performance is a useful device to improve safety conditions and reduce accidents. Several possible methods to measure whether the efforts made were effective and whether the performance results have been met to satisfy the safety objectives, include checklists, inspections, attitude surveys, walk-throughs, and document and record analysis (Haupt, 2002).

This paper demonstrates that the process of taking performance measurement can be streamlined through integration with database, web, and expert systems. The paper focuses on the design and development of a prototype of a web-based safety and health monitoring system. In fact, there have been successful applications of web and database technologies in other areas of construction management; for instance, the use of *QUALICON* in construction quality management (Battikha, 2002), the *Partnering Temperature Index* in measuring both "soft" and "hard" management issues (Cheung, Suen, & Cheung, submitted for publication), the *Risk Register Database* in managing project risks (Patterson & Neailey, 2002), and the measuring of cost and quality (Construction Industry Institute [CII], 1989).

2. Aims and Objectives

This paper describes the design and development of a prototype web-based safety and health monitoring system for construction projects—Construction Safety and Health Monitoring (CSHM). CSHM can be used as a detector of potential risks and hazards and, more importantly, a warning sign to areas of construction activities that require immediate corrective action. The ability to identify safety and health hazards as early as possible is vital to a project of any size and scale because "prevention is always better than cure" (Nikander & Eloranta, 1997). It is anticipated that CSHM can facilitate speedy safety and health management. However, CSHM is not intended, in any way, to replace the current practice of safety and health management. Instead, it adopted the Safety and Heath Management Model (OSHC, 2002) as the basis for its system design. To make good use of the advent of IT and database technologies, all of the functions of CSHM were designed to be web-based, thus enabling remote access, speedy data collection, retrieval, and documentation. Furthermore, a *Knowledge Base* was included in the design to enable online expert advice and instructions. In achieving this, the major objectives are as follows:

- Developing a **Web-based Interface** for management and assessment of data related to safety and health performance. The interface should enable automated collection, measurement, assessment, storage, and presentation of data;
- Developing an exclusive ***Knowledge Base*** for Safety and Health Management. That is, rules, guidelines, best practices, and so forth, for the prevention and resolution of hazards and unconfirmed practices. These are derived from the practical experience of experts and professionals in the field;
- Developing a portal to handle key **Output Data** in a systematic manner. For instance, key and operational data are separated automatically through preset functions such that only data of great importance (i.e., total fatal incidents per month) to senior management are summarized into the executive summary report. Data of less importance, such as those related to operation activities, are stored in the project report; and;
- Setting up a framework for the design of **Benchmark Groups**. Organizations or parties interested in knowing more about the industry "benchmarks" or "standards" in

a particular area of safety and health management can form a benchmark group. The main purpose is to share and compare the performance results. Benchmarks can be derived from the data collected.

The overall conceptual framework for the development of web-based safety and health monitoring system is illustrated in Fig. 1. In Fig. 1, the four key components of CSHM, including web-based interface, knowledge base, output data, and benchmark group are displayed. It is through their combined effect that enables speedy online performance assessment and management of safety and health activities.

The following sections describe the four key components of CSHM:

3. Web-based Interface

The interface is the gateway to access the vast data contained in the CSHM, which is accessed via the internet domain address. It is also the point where project data are

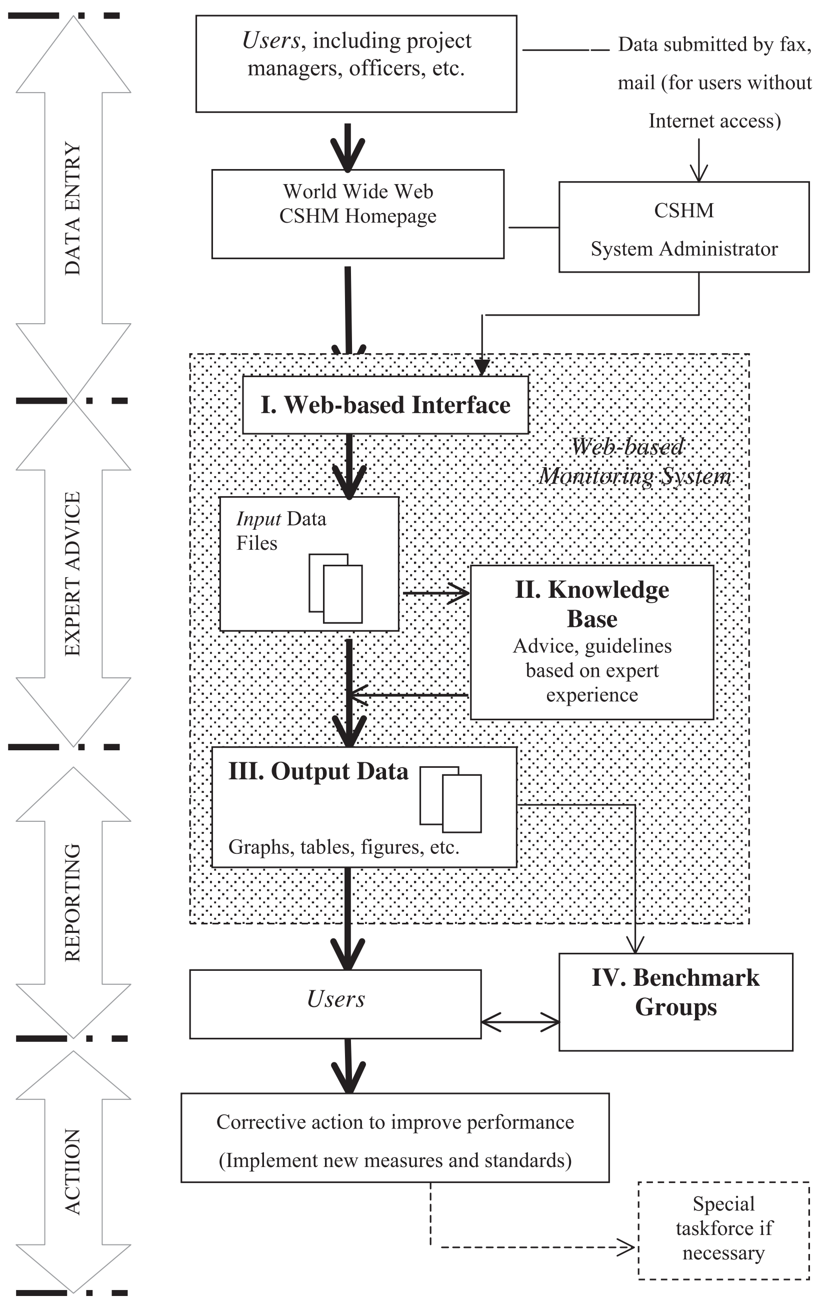


Fig. 1. Conceptual Framework of CSHM.

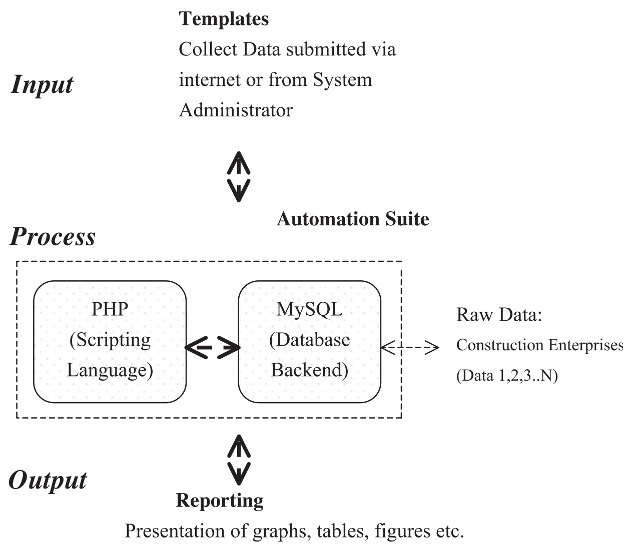


Fig. 2. Computing Components of CSHM.

input, sorted, and stored automatically in accordance to the preset conditions. The interface consists of the *Account Login* and *Data-Entry* templates. These are designed to enable speedy and systematic data collection and assessment.

3.1. Account Login

By entering the correct username and password, the user can access to the various built-in functions: *Contract*; *Survey*; *Graph*; *Accoun*t; and *Help*. These serve to enable the user total control of the data (from reporting to saving, to comparing and assessing the data).

3.2. Developing Data-Entry Templates

A sound safety and health management depends on a sound monitoring system, which in turn is subject to the following questions: *What* data can be used to reflect the current performance?; and *How* is this data collected and interpreted? These questions are answered by a list of safety and health performance parameters and a systematic approach of handling data. Indeed, developing "parameters" for the measurement and assessment of project performance has been the core subject of effective management. There is a wide range of tools to assist management in measuring and assessing various aspects of project performance, for instance, in financial performance (Sanger, 1998; Ghalayini & Noble, 1996), in partnering relationship (C21, 1999; DERT, 2000), in quality assurance (CII, 1989; Battikha, 2002), and in environmental impact (Environmental Protection Department [EPD], 2002). However, in safety and health management a coherent approach is lacking (as raised in the preceding section). Existing measurement tools tend to rely heavily on "manual" data collection and interpretation; such an approach is losing place in modern society with the wide application of internet and database technologies. An automated and internet-based monitoring system can remove geographic barriers and reduce time in transferring data; in addition, it can enable exchange of massive volumes of information at high speed and at relatively low cost (Deng, Li, Tam, Shen, & Love, 2001). For this reason, CSHM, by making use of the templates (computer-aided data entry forms), is capable of ascertaining current performance figures in an automated manner. The ability to conduct online data collection and transfer saves time and expense. Fig. 2 shows the various computing components of CSHM.

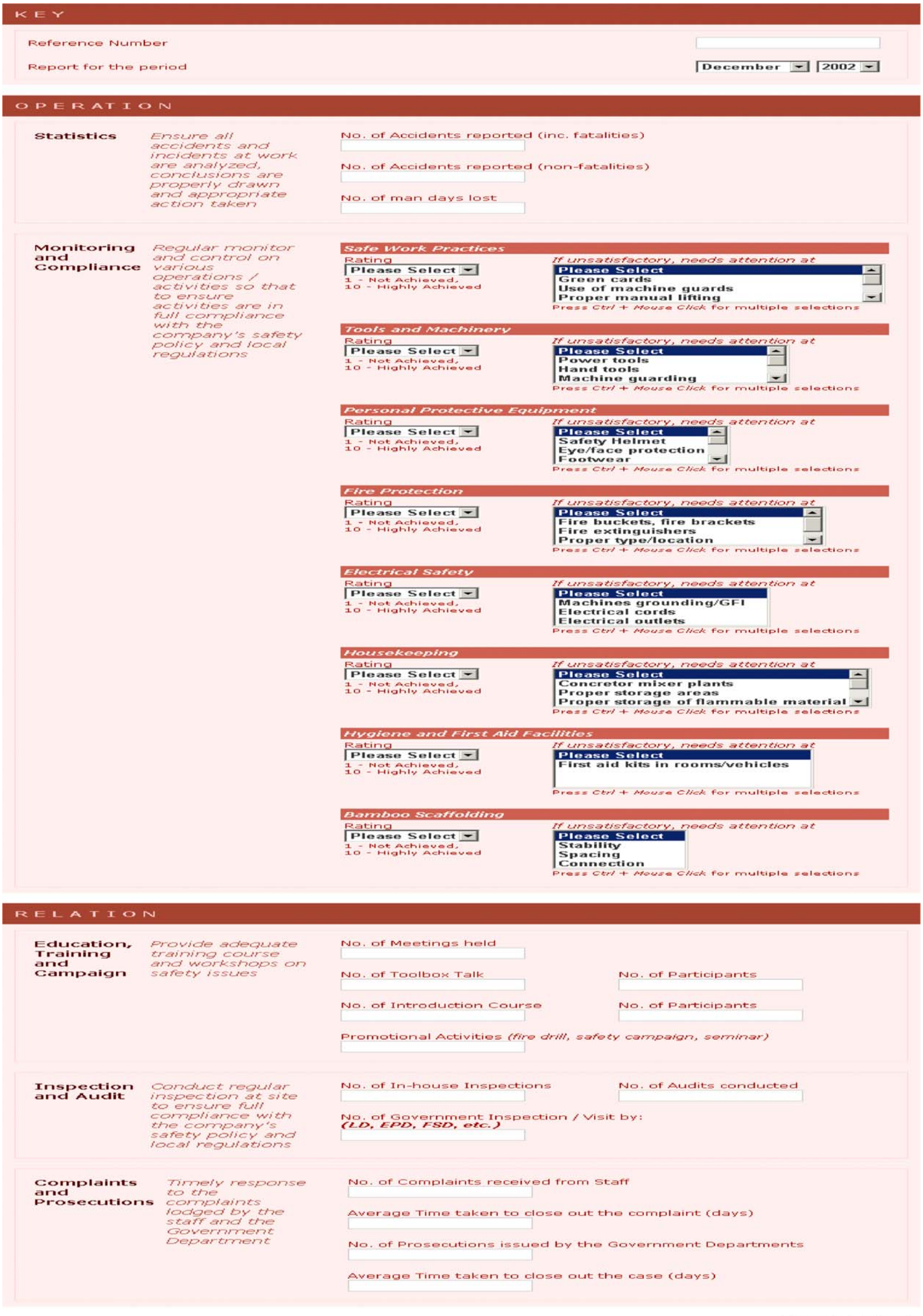
3.3. Design of Template

Relevant data (those related to safety and health performance) are input into the template by the project administrator. The content and design of templates depend on the number of performance parameters, which in turn depends on a number of factors, such as the size and scale of projects, the current law and regulations, and the market situations. Hence, like any project performance

Table 1
Summary of Key Parameters

Operation
Statistics
–Number of Accidents reported (nonfatalities)
–Number of man-days lost
Monitoring and Compliance
–Safe Work Practices
–Tools and Machinery
–Personal Protective Equipment
–Fire Protection
–Electrical Safety
–Housekeeping
–Hygiene and First Aid Facilities
–Chinese Bamboo Scaffolding*
Relation
Education, Training, and Campaign
–Number of Meetings Held
–Number of Toolbox Talk
–Number of Participants
–Number of Introduction Course
–Number of Participants
–Promotional Activities
Inspection and Audit
–Number of In-House Inspections
–Number of Audits Conducted
–Number of Government Inspection/Visit by LD, EPD, FSD, etc.
Complaints and Prosecutions
–Number of Complaints received from the Staff
–Average Time Taken to Close out the complaint (days)
–Number of Prosecutions issued by the Government Departments
–Average Time Taken to close out the case (days)

* Should be included for projects carried out in Hong Kong and China.



KEY

Reference Number

Report for the period December 2002

OPERATION

Statistics — *Ensure all accidents and incidents at work are analyzed, conclusions are properly drawn and appropriate action taken*

No. of Accidents reported (inc. fatalities)

No. of Accidents reported (non-fatalities)

No. of man days lost

Monitoring and Compliance — *Regular monitor and control on various operations / activities so that to ensure activities are in full compliance with the company's safety policy and local regulations*

Safe Work Practices
Rating: Please Select (1 - Not Achieved, 10 - Highly Achieved)
If unsatisfactory, needs attention at: Please Select; Green cards; Use of machine guards; Proper manual lifting
Press Ctrl + Mouse Click for multiple selections

Tools and Machinery
Rating: Please Select (1 - Not Achieved, 10 - Highly Achieved)
If unsatisfactory, needs attention at: Please Select; Power tools; Hand tools; Machine guarding
Press Ctrl + Mouse Click for multiple selections

Personal Protective Equipment
Rating: Please Select (1 - Not Achieved, 10 - Highly Achieved)
If unsatisfactory, needs attention at: Please Select; Safety Helmet; Eye/face protection; Footwear
Press Ctrl + Mouse Click for multiple selections

Fire Protection
Rating: Please Select (1 - Not Achieved, 10 - Highly Achieved)
If unsatisfactory, needs attention at: Please Select; Fire buckets, fire brackets; Fire extinguishers; Proper type/location
Press Ctrl + Mouse Click for multiple selections

Electrical Safety
Rating: Please Select (1 - Not Achieved, 10 - Highly Achieved)
If unsatisfactory, needs attention at: Please Select; Machines grounding/GFI; Electrical cords; Electrical outlets
Press Ctrl + Mouse Click for multiple selections

Housekeeping
Rating: Please Select (1 - Not Achieved, 10 - Highly Achieved)
If unsatisfactory, needs attention at: Please Select; Concretor mixer plants; Proper storage areas; Proper storage of flammable material
Press Ctrl + Mouse Click for multiple selections

Hygiene and First Aid Facilities
Rating: Please Select (1 - Not Achieved, 10 - Highly Achieved)
If unsatisfactory, needs attention at: Please Select; First aid kits in rooms/vehicles
Press Ctrl + Mouse Click for multiple selections

Bamboo Scaffolding
Rating: Please Select (1 - Not Achieved, 10 - Highly Achieved)
If unsatisfactory, needs attention at: Please Select; Stability; Spacing; Connection
Press Ctrl + Mouse Click for multiple selections

RELATION

Education, Training and Campaign — *Provide adequate training course and workshops on safety issues*

No. of Meetings held

No. of Toolbox Talk — No. of Participants

No. of Introduction Course — No. of Participants

Promotional Activities *(fire drill, safety campaign, seminar)*

Inspection and Audit — *Conduct regular inspection at site to ensure full compliance with the company's safety policy and local regulations*

No. of In-house Inspections — No. of Audits conducted

No. of Government Inspection / Visit by: ***(LD, EPD, FSD, etc.)***

Complaints and Prosecutions — *Timely response to the complaints lodged by the staff and the Government Department*

No. of Complaints received from Staff

Average Time taken to close out the complaint (days)

No. of Prosecutions issued by the Government Departments

Average Time taken to close out the case (days)

Submit Reset

Fig. 3. Data-Entry Template on Screen.

measurement tool, the set of performance parameters adopted is unique. In theory, there is no strict rule as to the total number. However, to avoid "over-measure," prioritization of parameters is needed. In this study, the parameters adopted are mainly derived from two sources: (a) an intensive literature review, followed by (b) interviews with experts in the field.

The safety management guide developed by OSHC (1999) provides a starting point. The guide introduces the basic principle and methodology in the development, implementation, assessment, and maintenance of a safety management system. Under its assessment sections, typical performance parameters to measure effectiveness of safety and health management are provided. In essence, the parameters can be divided into two main themes: statistical and functional. The former is mainly a collection of statistics, such as the number of accidents reported, the number of man-days lost, and so forth. The latter covers reports of evidence of certain non-conformance activities, including reports on safe work practices, tools and machinery, personal protective equipment, and bamboo scaffolding. A total of 10 key parameters were selected by the researchers, and they formed a basis for discussion in the interviews with experts and professionals in the field. In the interviews (10 professionals, including project directors, senior managers, contract administrators, and safety officers), experts were asked to assess the relevance of these 10 parameters to the industry. The 10 parameters include:

- Number of accidents reported;
- Number of man days lost;
- Safe work practices;
- Personal protective equipment;
- Fire protection;
- Electrical safety;
- Housekeeping;
- Hygiene;
- First aid facilities
- Bamboo Scaffolding

It is worthwhile to mention that the use of bamboo scaffolding is a unique feature in Chinese construction. Because of its wide application in construction projects in Hong Kong and China, particularly in residential projects, it is included as one of the key parameters.

The comments received were mainly positive; however, suggestions were made to include measurements of training, inspection, complaints, and so forth. For education and training, it was suggested that parameters such as number of meetings held, number of tool talks, and number of participants should be included. For inspection, parameters should include number of in-house inspections, number of government inspections, and so forth. For complaints and prosecutions, parameters such as number of complaints received from staff and average time to close out complaints should be recorded. The addition of human-relation-related parameters can be supported by the Behavior-Based Safety model (DePasquale & Geller, 1999), which highlighted the importance of workers' attitudes and relationships among parties. Therefore, for ease of categorization, the above parameters were divided into two main headings: *Operation* (include both statistical and functional parameters) and *Relation* (those parameters that relate to human-relationships, such as those parameters suggested by the interviews).

Table 1 summarizes the key parameters for measurement of safety and health performance. These parameters form the basis for the design and development of the *Data-Entry* template, as shown in Fig. 3. As parameters can be quantitative or qualitative in nature, methods of measurement vary. For qualitative parameters, measurements are taken by the user giving a "score" for each parameter (qualitative). Further explanation of the scoring method is given in the *Data-Entry Process* section.

4. Knowledge Base

The *Knowledge Base* contains a summary of expert advice and guidelines that are vital for safety and health management. It plays a supporting role to complement the automated assessment system by providing practical advice to problem areas identified. Upon completion of data entry via the template, the built-in program will automatically highlight those parameters that are underperformed (see scoring system in later section). Expert advice will be given automatically to the underperformed parameters from the *Knowledge Base*. For instance, data provided in relation to the parameter "personal protective equipment" indicates that workers are not wearing safety belts at work, a warning sign will be displayed right next to that parameter, and by clicking on the warning sign, practical suggestions will be given on the screen (see Fig. 6). The practical suggestions are in fact collected from and based on expert experience and professional practices in the field. In order to develop the *Knowledge Base*, the research team conducted one-on-one interviews with 10 well-recognized experts in the area, with an aim to derive a set of safety and health practices that are useful to resolve common problems.

5. Data-Entry Process

Before explaining the Data Output component of CSHM, a brief account on how CSHM works in practice is necessary. As mentioned previously, CSHM is operated through a web-based interface. After successfully entering the contract details, the user can begin the data-entry process. The user can give a "score" by selecting the box within the *Rating Box* (for parameters under the *Operation* category, except for those under the *Statistics* sub-section), under which a Likert Scale of 1 to 10 is available (1-not achieved, 10-highly achieved). Further, the user can highlight those areas

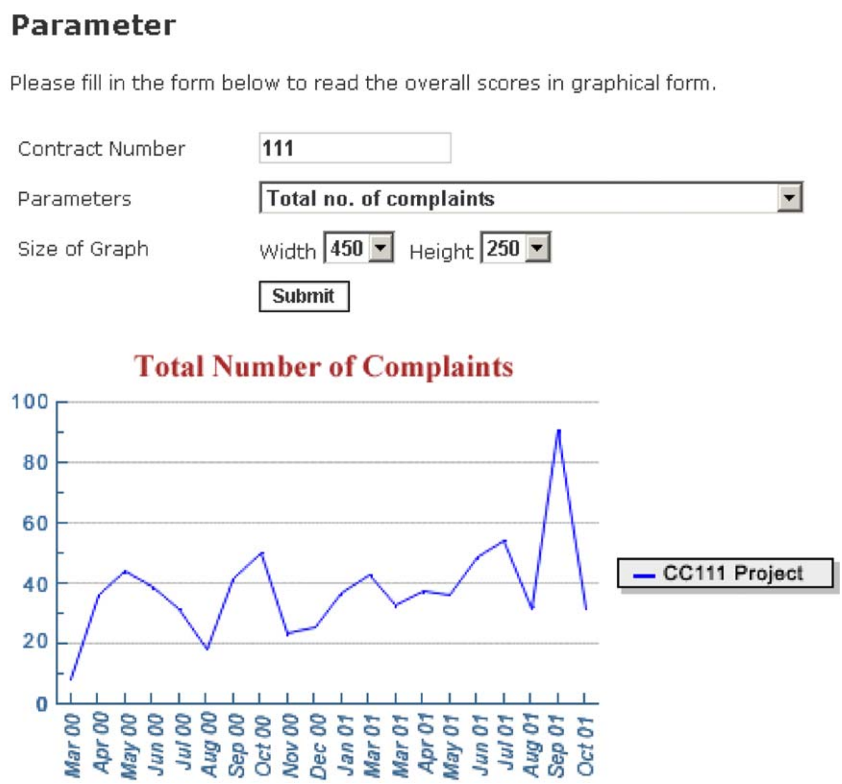


Fig. 4. Graphical Presentation Function—Parameter.

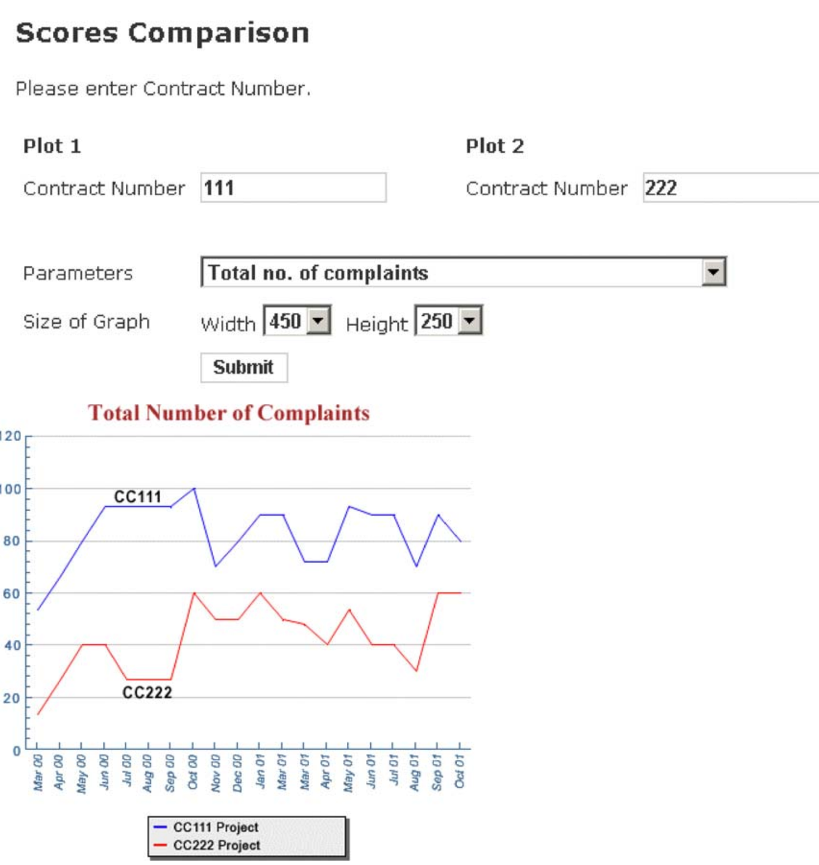
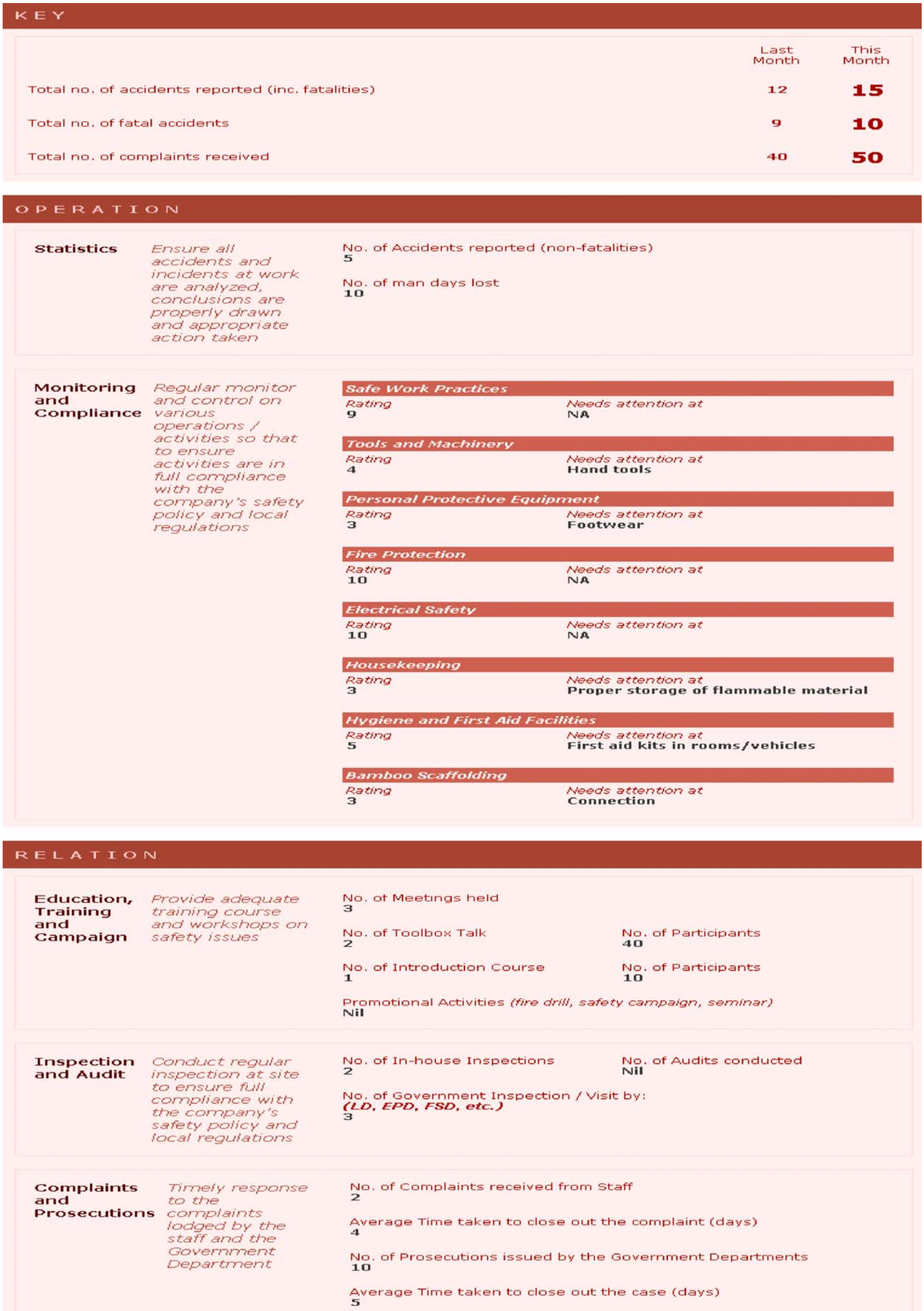


Fig. 5. Graphical Presentation Function—Compare.


KEY

	Last Month	This Month
Total no. of accidents reported (inc. fatalities)	12	15
Total no. of fatal accidents	9	10
Total no. of complaints received	40	50

OPERATION

Statistics — *Ensure all accidents and incidents at work are analyzed, conclusions are properly drawn and appropriate action taken*

No. of Accidents reported (non-fatalities)
5

No. of man days lost
10

Monitoring and Compliance — *Regular monitor and control on various operations / activities so that to ensure activities are in full compliance with the company's safety policy and local regulations*

	Rating	Needs attention at
Safe Work Practices	9	NA
Tools and Machinery	4	Hand tools
Personal Protective Equipment	3	Footwear
Fire Protection	10	NA
Electrical Safety	10	NA
Housekeeping	3	Proper storage of flammable material
Hygiene and First Aid Facilities	5	First aid kits in rooms/vehicles
Bamboo Scaffolding	3	Connection

RELATION

Education, Training and Campaign — *Provide adequate training course and workshops on safety issues*

No. of Meetings held
3

No. of Toolbox Talk
2

No. of Participants
40

No. of Introduction Course
1

No. of Participants
10

Promotional Activities *(fire drill, safety campaign, seminar)*
Nil

Inspection and Audit — *Conduct regular inspection at site to ensure full compliance with the company's safety policy and local regulations*

No. of In-house Inspections
2

No. of Audits conducted
Nil

No. of Government Inspection / Visit by: *(LD, EPD, FSD, etc.)*
3

Complaints and Prosecutions — *Timely response to the complaints lodged by the staff and the Government Department*

No. of Complaints received from Staff
2

Average Time taken to close out the complaint (days)
4

No. of Prosecutions issued by the Government Departments
10

Average Time taken to close out the case (days)
5

Fig. 6. Executive Report Template on Screen.

in need of special attention by dragging the "need attention" boxes provided. For other parameters (such as those under the *Relation* category and under the *Statistics* subsection), the user simply inputs the score for each parameter into the space provided. By simply clicking on the "Submit" button at the bottom of the template, the completed data-entry will automatically transform into data and stored in the MySQL database. Data stored in the MySQL Database is partitioned according to the project details (i.e., project reference number, month and year, etc.; see *Computing Components*). The *Data-Entry* template in an on-line environment can be found in Fig. 3.

6. Output Data

The *Output Data* contains key project data in the form of tables, graphs, and figures. These are the basis for management decision-making and are extremely useful for meeting discussions and presentations.

6.1. Dissemination of Collated Data-Graphical Presentations

CSHM allows the user to monitor the project performance over a certain period through analysis of the scores given to each parameter. Key data can be transformed into charts, curves, and tables within seconds by the MySQL database. In sum, there are three options available for data dissemination: (a) *Trend/Movement*; (b) *Comparing between Projects*; and (c) *Executive Report*.

6.1.1. Trend/Movement

Very often, particularly when making important decisions, simply studying performance over a month's time is not good enough. Before any solid observation can be made, it is necessary to study the performance over a period of three months or more to really understand the movement pattern/trend. Hence, CSHM allows the user to choose the movement/trend of the key parameters (See Fig. 4), including the following:

- Total number of accidents reported, including fatalities;
- Total number of fatal accidents; and
- Total number of complaints received.

Fig. 4 also shows the trend in the total number of complaints received in a hypothetical project over a period of one year.

6.1.2. Comparing between Projects

In addition to the above function, CSHM also allows the user to compare key parameters between projects (see Fig. 5). In Fig. 5, the comparison function is illustrated in the default screen. By studying and comparing the movements of the two curves, management can better understand the differences/similarities in safety and health performance between two projects. As such, management and workers can identify ways for future improvement.

6.1.3. Executive Report

The Executive Report is indeed a summary report of the data input, with warning signs attached to the underperforming parameters. An *Executive Report* template is displayed in Fig. 6. It is worth noting that figures shown in brackets are in fact the "previous" month's figures. This arrangement helps to facilitate comparison of current and last month's data. Different from the *Data-Entry* template, the *Executive Report* contains a section of *Key Parameters* (i.e., the total number of fatal accidents), which are the most important figures/data from senior management point of view.

7. Potential Use of the CSHM: Benchmarking

Project data can also be used to set up benchmarks for the industry by using the *Compare* graphical function mentioned previously. Interested groups and organizations can form *Benchmark Groups*, which are comprised of professionals in the same field. Each *Benchmark Group* should have its set of goals and objectives in order to devise a set of exclusive "benchmarks" or "standards" by comparing the key output data of different projects. In doing so, both strengths and weaknesses can be identified and "best practices" can be developed to improve the industry standard. Like any organization, a systematic and well-structured framework is needed for the successful implementation of a *Benchmark Group*. The following are the key ingredients for successful benchmarking:

- Planning – set out goals;
- Organizing – break into distinct groups if necessary;
- Comparing – share and compare data from different projects;
- Reporting – draw up benchmarks; and
- Testing – benchmarks are tested in real-life situations

8. Computing Components

The advancement in web and database technologies makes the concept of "online monitoring" a reality. Web-based CSHM automates the monitoring process. In addition, the web-based feature of CSHM removes geographic barriers and reduces time between data input and report generation. Furthermore, CSHM enables exchange of massive volumes of information at high speed and at relatively low cost (Deng, Tam, Shen, & Love, 2001). CSHM also reduces human and mathematical errors as data are now directly entered by the user and data collection and calculation is now performed by the computer. In these contexts, CSHM is a total automated monitoring system and its various computing components are explained in this section. The key computing components of CSHM, including *PHP Programming Languages*, *MYSQL Database Backend*, computing specification, and technical support requirements are discussed in the following sections.

8.1. PHP Programming Languages

To design the *Automation* suite, the very first task is to select the programming languages. Various programming languages are available, including ASP, C++, PERL, Python and PHP (PHP Hypertext Preprocessor). The *Automation* suite must provide database support, a user-friendly interface, a security system, and a stable internet connection. PHP, an advanced programming language that facilitates interactive interface and supports powerful database (thus requiring relatively less resources; PHP, 2000), is adopted as the programming language for the *Automation* suite. To support the PHP in constructing a database for data collection and retrieval, an open source database known as "MySQL" is used. It is one of the most popular open source databases designed for speed, power, and precision in mission critical, heavy load use (MySQL, 2002). Its advantages are fast search and short processing time, and can handle a vast volume of data with robust reliability.

8.2. Hardware and Software Specifications for Server

The hardware specification for the server to support CSHM functions depends on a number of factors, such as the size of database, the number of construction projects involved, the number of users' access in a specific time frame, and so forth. Table 2 summarizes the hardware requirements for the set-up of server. As an example, for a construction project with a 2-year contract period and a total of 30 end-users involved, the size of database should be no less than 2MB. The minimum hardware requirements as listed in Table 2 are capable of handling data of about 1,000 construction contracts. The suggested hardware requirement is designed to handle complex and large-scale construction projects with an extremely large amount of project data.

Since the *Automation* suite relies on the PHP programming (PHP, 2000) and the MySQL database backend (MySQL, 2002), the web server was designed to be compatible with the PHP and MySQL functions. The software package "phpMyAdmin" (phpMyAdmin, 2002) was used to support the web server as it enables effective management of database (See Table 2).

Table 2
Summary of Computing requirements

For the Server	
Hardware Requirements (minimum)	Recommended for Complex Construction Projects
• Intel Celeron 1 GHz • 256 MB SD Ram • 20 GB 7200rpm hard drive • Generic main board with on-board display card and sound card • Generic 10/100 PCI LAN Card connected to the Internet • Generic IDE CD-Rom • Generic floppy disk drive • Generic CRT/LCD Monitor • Generic keyboard and mouse • Optional uninterrupted power supply (UPS) system	• Intel Platinum 4 1.8 GHz • 1 GB DDR Ram • 80 GB 7200rpm hard drive • Generic main board with on-board display card and sound card • 3Com 10/100 PCI LAN Card connected to the Internet • Generic IDE CD-Rom • Generic floppy disk drive • Generic CRT/LCD Monitor • Generic keyboard and mouse • Optional uninterrupted power supply (UPS) system
Software Requirements	
• Operation System Red Hat Linux 7.3 or above • Web Server Apache 1.3.23 or above • FTP Server ProFTP 1.2.6 or above • Secure Socket Layer OpenSSL 0.9.6b or above • Secure Telnet Service OpenSSH 3.1 or above	• Programming Language PHP 4.2.2 or above • Database Server MySQL 3.23.52 or above • Dynamic Image Creation Package GD-Library 1.8.4 or above • Database management tool for system Administrator—phpMyAdmin 2.3.1 or above
For the End Users	
Hardware Specifications	Software Specification
• Intel Celeron 1 GHz • 64 MB SD Ram • 3.2 GB 7200 rpm Hard Drive • Generic main board • Generic display card • Generic 10/100 PCI LAN Card or 56 Kbps Internal/External Modem • Generic CRT/LCD monitor • Generic keyboard and mouse	• Microsoft Windows 95, 98, 2000, ME, XP or above • Microsoft Internet Explorer 5.0 or above/Netscape 4.0 or above/AOL Browser 5.0 or above

8.3. Initial and Running Costs of the Server

The initial costs vary, depending on the memory capacity of the server required. In fact, all the software requirements mentioned in Table 2 can be obtained from the internet or in the Red Hat Linux 7.3 package without charge (Red Hat Linux, 2002). Hence, with the minimum hardware requirements as stated in Table 2, the initial costs for setting up the server should not exceed US$2,000. However, this does not include the set-up charge of the internet connection service. Long-term running costs depend on the number of technical support staff hired and the speed of the internet connection (as a general rule, the faster the speed the higher the connection costs). Generally speaking, the running costs for internet connection should not exceed US$100.

8.4. Hardware and Software Specifications for End-user

There is no specific hardware requirement for end-users; a generic personal computer (PC) with internet connection can be used to access the server. Table 2 provides a summary of the hardware and software specification details for end users.

8.5. Training for Technical Support Staff

Since the *PTI Automation Suite* is built on the Linux Server, it is recommended that technical staff should have sound knowledge of the internet, as well as skills in server administration, networking, and system security. Online training on Linux System is available in the Red Hat Homepage (RedHat.com, 2002) and the Red Hat Certified Engineer Program (Red Hat Certified Engineer [RHCE], 2002). The administration tasks of *PTI Administration Suite* are rather simple and can be managed by people with general computing and internet knowledge. To maintain the *Automation* suite, it is suggested that the database should be backed up regularly for security purposes. In addition, technical support staff should be prepared to answer questions or problems raised by the end-users.

9. Perceived Benefits of CSHM

CSHM is a powerful monitoring and assessment tool. It is capable of reducing a significant amount of time for data-collection and dissemination of collated data. It helps project managers and administrators assess safety and health performance in a timely manner. Performance parameters can be added or reduced to reflect the current industry environment. Such flexibility is essential to cope with the increasing complex and fast-changing social, legal, and political environments. CSHM facilitates automatic, online instant graphical presentation of the performance data of construction enterprises, hence making it possible for construction enterprises to make important decisions (i.e., to take immediate corrective actions in areas that are under-performing) anytime, anywhere. A follow-up evaluation exercise to confirm that the abovementioned benefits continue would be instrumental. This follow-up is now being planned and will be implemented when experience of its use accumulates.

10. Concluding Remarks

The developed CSHM streamlines the safety and health performance measurement and assessment process through its web-based interface, database, and expert systems. The web-based interface enables speedy collection of safety and health performance data through the internet, and the collected data are stored in the database and then assessed by the expert system. The final product in this process is the *Executive Report*, which contains instructions, advice, and graphical presentations of important data all in one sheet. The primary purpose of CSHM is to reduce occupational accidents by directly observing and instantaneously assessing the data submitted in order to take fast and educated preventive and corrective measures. However, CSHM is not intended to replace management involvement in making decisions, particularly those involving human factors. Rather, the web-based monitoring process is to improve efficiency and accuracy and serves as a complement to managerial and leadership competence. The proposed CSHM enables construction management to examine safety and health performance and compare their findings with others within the field through *Benchmark Group*. Only by comparing performance, weaknesses, and strengths can corrective measures be identified and implemented to improve the overall industry standard. With the well-structured IT networks in most international cities, the proposed CSHM will be a valuable asset to safety and health management in construction.

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