Development and Application of SAPR Software for Computer Aided Safety and Productivity Measurement in the Cement Industry

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Abstract: This paper presents a procedure for assessing safety and labor productivity using a computer-aided analysis system. The software system for safety and productivity, named SAPR, was developed based on labor working time, hazard analysis, and factors affecting productivity. The developed software consists of three major models - hazard identification, occupational illnesses, and labor productivity - connected through correlated linkage technique which is coded using Microsoft Access and Visual C#. In order to verify the integrated model, SAPR went through several tests and user evaluations for the various parameters depending on the type of industry. The software was then validated by data collected from the cement industry. The novelty of SAPR is that it can be used to assess the various workplace hazards and simultaneously measure labor productivity while providing information on injuries and occupational illnesses. This computer-aided approach provides a comprehensive analysis of workplace depending on the type of industry.
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1. Introduction

Safety is considered as a major issue in the industrial sector and has been recognized as a cost adding factor to organizations. Safety issues or the lack thereof will decrease productivity and also increase the possibility of the industry being closed down. Therefore an improvement in industrial safety will lead to the overall improvement of work practices while contributing to the productivity of the employees.

1.1 Computer Aided Productivity

There have been many attempts to integrate both safety and productivity for various types of industries. Labor productivity is a critical item of concern in industrial engineering. Researchers such as Czumanski and Lading [6] introduced an approach for providing the possibility to identify and prioritize the various impacts on labor productivity. Liu et al. [3] managed to integrate work flow variation and labor productivity. Few have attempted to enhance safety in the industry. The indicators for safety were studied by Veltri et al. [1]. Their findings concluded that safety is related to various individual indicators depending on internal and external performance. As safety deteriorates, product quality and plant performance will suffer or decrease. Soham and Rajiv [4] stated that there are five factors affecting employee's productivity such as delay in payment delay, labor skills, technical specification clarity, material shortage, and motivation of labor motivation.

1.2 Computer Aided Safety

Health and safety imply the prevention of accidents and control of activities that cause ill health in the workplace. Health may be defined as the good condition of body or mind and safety is the condition of not being exposed to danger or risks. Accidents are any unexpected events that lead to injury, ill health, loss of property or damage to plant or materials. An accident is considered as a near miss if there is no injury or loss occurring. Identifying hazards is the first step in prevention. Hazard identification is used to examine the workplace for hazards. Checklist related to the hazards identification and action item for determining the degree of OSHA is used in recent work by Alan H. Stern in [7], Arusharka Sen in [8], and Z. Labovská, J. Labovský, et al. in [10].

The application of a computer based system in safety was discussed by many researchers in the past. Kim et al. [2] presented a methodology in which a computer-aided system is used for analyzing human error in railway operations.

Occupational safety and health have a strong effect on financial, customer and internal business processes. Occupational safety and health management has shifted from a narrow view with a regulatory compliance orientation to a complex and more linked to technical aspects of occupational risk and workers' control [11].

The injuries and illnesses occurring in the industry were studied by Wei Chen et al. [11]. Results show that the adoption of the OHSAS 18001 is strongly related to the objective safety variables. Therefore it is suggested that the managers need to use this framework as a mechanism to improve safety conditions at the workplace. Meanwhile, the areas of human-resource management and workplace health are now addressing the links between working conditions and productivity. In the workplace health promotion, there are many literatures as examples of programs that meet health and financial criteria for success such as in [16]-[18], most of whom strived to find the relation between safety and performance of the workplace as well as techniques to predict the cost of productivity loss due to health and safety issues.

The benefits and challenges of using an integrated safety management system have been discussed for the aircraft maintenance [21] and cement [22] industries. Sinelnikov et al. [23] used leading indicators to measure occupational health and safety performance. Yeow et al. [24] studied the effect of ergonomic improvements on quality, productivity, occupational health and safety and cost effectiveness in manufacturing.

Continuous improvement is a management philosophy based on employees' suggestions, and can be applied in services [25]-[30] as well as in manufacturing processes [31]-[40] Safety is the foundation for continuous improvement. An improvement in industrial safety will lead to continuous improvement as employees desire to work in healthy and safe environments, which means that the critical foundation of any improvement effort is not about being faster or better — but rather about being safer.

2. Methodology

A healthy and vital workforce is an asset to any organization in the world. The system that monitors condition of human health and workforce satisfaction plays an important role in success of the organization. Therefore workplace health management and health promotion are relevant to management of organizations.

2.1 SAPR Procedure and Information Flow

The development of SAPR began with the identification of two crucial industrial parameters, viz. safety and productivity. The software procedure and information flow is shown in Fig. 1 and explained below.

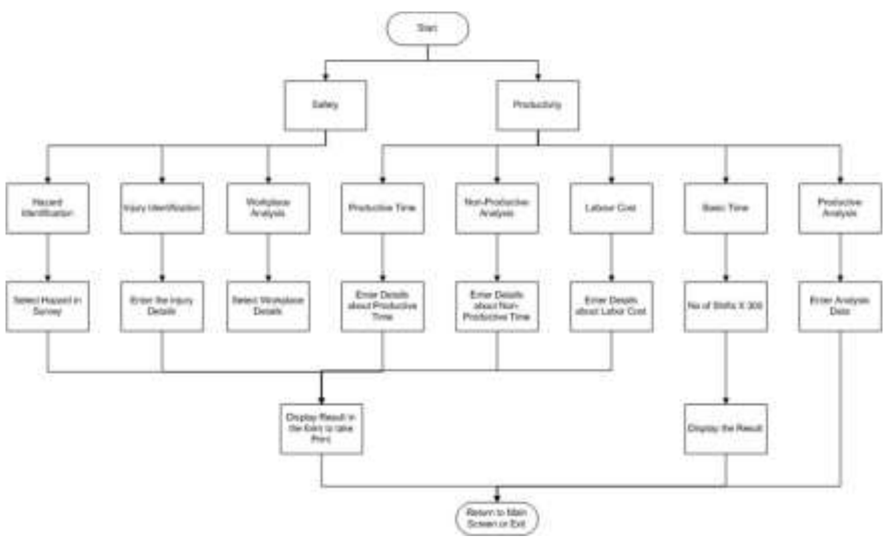

Figure 1. The SAPR software procedure and information flow

* If Safety is selected then three options are present which include the hazards to be identified, injuries occurring and the workplace analysis.
* If Hazards is selected, the various hazards occurring are listed and this will be presented in the final form to print.
* In Injuries, the various injuries are selected and sent to the form for display.
* In Workplace Analysis, the various factors affecting are selected for the report.
* If Productivity is selected, the user has the option to enter the productive time, non productive time, labor cost, basic time and the productivity analysis details.

* In Basic Time, time is calculated based on the number of shifts per day and the total number of days.
All these details are presented into the final form as a report.
* The user can return to the main screen or exit from the program after the report has been processed.
The development procedure consists of four steps starting with selection of workstations to be analyzed. Detailed steps of analysis are explained in later sections.
First Step: The first step is to provide a checklist for the hazard identification. The checklist consists of 16 commonly used areas in industry such as chemical, compress, mechanical, rotating, pressures and others hazard. The checklist is used to identify a potential hazard which later the authors try to eliminate.
Second Step: Through injuries and occupational illness's model, both models to be analyzed in details and ends after evaluating the workstations through hazard's report and injury report (Workplace Report). This step focuses on the measurement of labor productivity in the cement industry. Productive time for every labor is calculated by the program using data gathered over the course of the year. The total productive time and non-productive time for all labor were measured each year by the program and full paid time like meetings, breaks, training, etc. can be calculated by using this software.
Third Step: Improve the working conditions of labor, including health and lead to improved productivity. Working conditions and workplace assessment are corner stone for productivity improvement.
Fourth Step: Finally the system will generate the report. SAPR report consists of labor productivity and workplace, which include both of hazard identification analyses and injuries and occupational illness's analyses.

2.2 SAPR Modules

In the workplace evaluation modules, the software consisted of the two main modules - safety and productivity.

a. Safety model

One of the objectives of this work is to provide a source for identification of the injuries and illnesses occurring in the cement industry. The expected benefits from the SAPR software are a significant decrease of injuries, decrease in absenteeism and lost workdays and reduction in labor cost. Personal injuries are serious because they can lead to lost production time.

b. Productivity model

There are a lot factors that effecting the labor productivity. Factors of productivity may include direct labor, direct materials, capital or overhead as shown in Table 1.

A partial productivity measure with a comparison of results over time will determine whether the relationship between inputs and outputs has bettered or deteriorated. Labor productivity measures the amount of goods and services produced by one hour of labor. Growth in labor productivity depends on three major factors: physical capital investment, latest technology and human capital. Labor productivity relates output to the labor hours' use factors affect health, technology, labor productivities, time, technology, quality, materials, supervision and skills.

Labor productivity model shows the relation between the productive time and non- productive time. The time taken by labor to carry out an operation consists of basic work content as work-hours and total ineffective time from human resources contribution. The basic work content is the time taken to perform the operation if the specification of the product were perfect. It is the minimum time theoretically required to produce one unit of output. Nonproductive time is the time during which no effective work is being performed. The normal hours of work are the standard 40-hour week. This study is concerned with reducing and measuring ineffective labor time to increase labor productivity. It provides information for labor- cost control.

Labor productivity based on gross output is denoted by

$$L_{po} = \frac{Q_o}{QL_i} \qquad (1)$$

where
L_{po}= Labor productivity, based on gross output.
Q_o = Quantity index of gross output
QL_i = Quantity index of labor input
Labor productivity based on value added is denoted by

$$L_pV_a = \frac{QV_a}{QL_i} \qquad (2)$$

where
L_pV_a = Labor productivity, based on Value added.
QV_a = Quantity index of Value added.
QL_i = Quantity index of labor input
Multifactor labor productivity based on value added is expressed as

$$L_pMFE = \frac{QV_a}{QL_iC} \qquad (3)$$

where
L_pMFE = Labor productivity multifactor productivity (MFE), based on Value added
QV_a = Quantity index of Value added.
QL_iC = Quantity index of combined labor and capital input

Labor productivity, or output per hour, is calculated by dividing an index of real output with an index of hours worked of all employees and is denoted by

$$L_p = \frac{H_{ro}}{H_w} \qquad (4)$$

where
L_p = Labor productivity, or output per hour
H_{ro} = Real labor hour output
H_w = Hours worked

The term labor cost is used as a generic term covering different types of labor costs like unit labor costs, total labor costs and gross wages. Labor cost is difficult to control due to which higher levels of payment may be made for the much lesser amount of actual work despite being easy to calculate.

$$\text{Labor Cost, } L_c = H_{ro} \times RH \qquad (5)$$

where
H_{ro}: Real labor hour output
RH: Labor Rate per Hour

TABLE 1: THE MAIN TYPES OF PRODUCTIVITY

<table>
<tr><td colspan="4">The Main Types Of Productivity</td></tr>
<tr><td colspan="4">Productivity may be defined as the ratio of output to some or all the resources used to produce the output. men, materials, machines, methods, money, energies, etc. are inputs.</td></tr>
<tr><td rowspan="7">Partial Productivity</td><td>Type</td><td>Equation</td><td rowspan="7">Some uses:
1. To understand the effect of increase/decrease in hiring of labor and to see how they perform
2. In material management
3. In financial assessment
4. In marketing management
5. In the analysis of the system</td></tr>
<tr><td>1. Labor productivity or human productivity</td><td>output/human input</td></tr>
<tr><td>2. Material productivity</td><td>output/material input</td></tr>
<tr><td>3. Capital productivity</td><td>output/capital input</td></tr>
<tr><td>4. Energy productivity</td><td>output/energy input</td></tr>
<tr><td>5. Advertising and media planning productivity</td><td>output/advertising and media planning</td></tr>
<tr><td>6. Other expense productivity</td><td>output/other expense input</td></tr>
<tr><td></td><td>Definition</td><td colspan="2">Equation</td></tr>
<tr><td>Total Factor Productivity (TFP)</td><td>TFP is a variable accounting for effects in total output not caused by traditionally measured inputs of labor and capital.</td><td colspan="2">$Y = A \times K^{\alpha} \times L^{\beta}$ (6)
It represents total output (Y) as a function of total-factor productivity (A) capital inputs (K), labor input (L), and the two inputs are respective shares of output (contribution capital input share e of contribution on for K and L respectively). An increase in output or L will lead to increased output.</td></tr>
<tr><td>Total Productivity</td><td>It is the ratio of tangible output and tangible input</td><td colspan="2">Total productivity: sum of all tangible outputs sums of all tangible inputs</td></tr>
</table>

2.3 Construction of SAPR software

The SAPR program opens with open file's screen, and a case study can be selected. The Help screen can be displayed by help or F1. The Home Screen as shown in Fig. 2 has links to the other screens in the program such as the Productive time screen, the Non-productive time screen, Basic time screen, Labor cost screen, Workplace screen, Labor productivity screen, Workplace report (injuries & hazards), labor productivity report and a new case screen.

Figure 2. Main Screen – SAPR Homepage

The productive time screen as shown in Fig. 3 consists of the main menu such as labor details can be entered with information like employee type, position descriptions (i.e., duties and responsibilities), required experience, skills, and knowledge. Other data fields in this screen include the total number of jobs, total number of employees, measuring hours worked, normal hours, overtime and absences, measures of labor input, average hours paid per person, total hours worked, total employment cost, supervision including wages as well as other costs including quality costs, total employment costs, and intervention costs.

The equation for remuneration or earnings is the hours worked times the rate per hour.

Figure 3. Productive Time Screen

Two main sections of the non-productive time screen as include:

1. Absenteeism rates - number of days absent per month.
2. Real time worked - number of hours spent on performing tasks divided by the total number of available hours.

Other data entry fields include absences, forms of absences, holidays, sick leave, vacation time, lost workdays, travel delay, insurance and diseases.

The screen in Fig. 4 includes details about the occupational death cause type in percent, the nature of injury by number and percent (sprains, strains, fractures, cuts, bruises, etc.), the body part injured by number and percent (head, eyes, hand, wrist, etc.), the source or cause of injury by number and percent (worker motion/position, hand tool, machinery, etc.), accident type by number and percent (struck by an object, fall, slip, lifting, fires, etc.) as well as occupational illness by number and percent (skin diseases and respiratory disorders, hearing loss, poisoning, etc.).

Figure 4. Fatality and Injury Screen

The Labor productivity formula will be applied, and the following fields are used as shown in Fig. 5: total labor cost, direct cost, indirect cost, accidents, damages, absenteeism, turnover, costs of non-safety and ill-health, labor cost, injury cost, direct cost, indirect cost, overtime, training, supervision, waste and rework and lost production time.

Figure 5. Labor Cost Screen

The hazard checklist includes various possible hazards, including chemicals, compressed gas cylinders, electrical, ergonomic hazards (manual material handling, environment, etc.), fire and heat hazards, housekeeping, exits, falls and slips, walking/working surfaces, etc. Hazards identification screen is displayed in Fig. 6 and workplace analysis screen is displayed in Fig. 7.

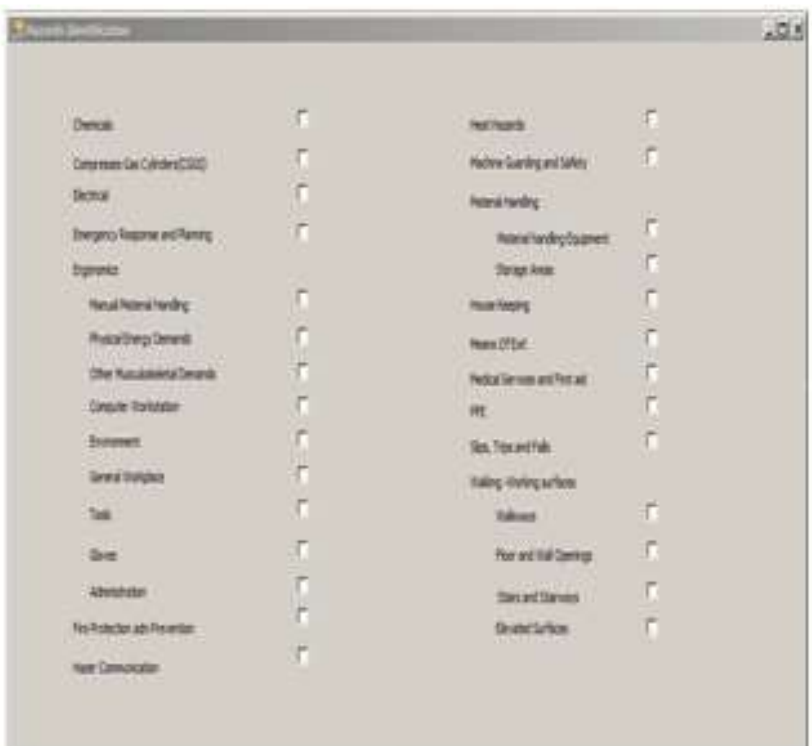

Figure 6. Hazards Identification Screen

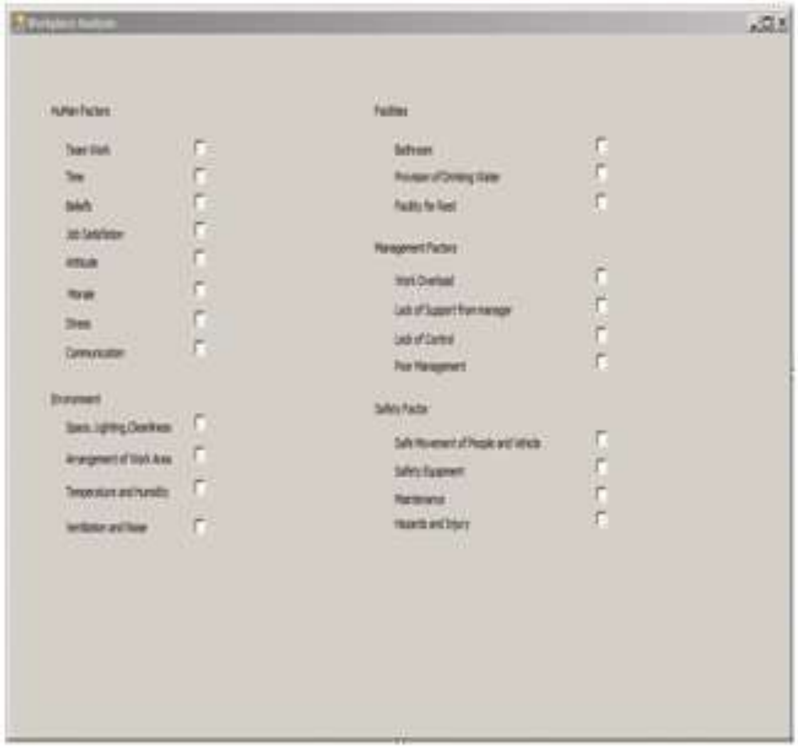

Figure 7. Workplace Analysis Screen

This basic time depicts the standard work hours at the organization usually denoted by a standard eight-hour shift × number of shifts × 300 days or as 40 hours per week.

The prototype of SAPR was first tested as an informal test through discussions during a seminar as part of the activities of the Industry Liaison Committee at the Faculty of Engineering in King Abdulaziz University, Rabigh. The second test is the pre-field test through discussions with colleagues and PhDs who have research and consultancy experience in the field of safety and productivity as expert groups. The third test is a field test through discussions with ten field investigators from three cement companies. Expert reviews by safety experts comprised the fourth test.

All the comments, observations and modifications required were considered and included in the SAPR edited version. Nevertheless, some minor modifications are required in order to ensure its practical use as the perfect conditions assumed to never occur in cement industry.

3. Conclusion

SAPR software with its safety and productivity modules is intended to help identify and reduce risks associated with industrial hazards, assist the progress of work-related activities and recognize solutions in terms of workers and workplace. It helps to analyze labor productivity through safety issues, impact of the workplace and hazard identification. The SAPR procedure underwent subjective evaluation by four experienced field investigators. Its utility has been established in labor productivity analysis, workplace evaluation and hazard identification in the cement industry, although development of its improved version and few modifications of cost rating factors are needed to ensure practicality of its implementation in commercial industries. Further research should aid in adding features to support the workplace analysis. Although SAPR was developed specifically for the cement industry, it has the potential to be utilized in other industries where safety and its impact on productivity is a major concern. This can be made possible after minor modifications, including the customization of industry specific factors. The examination of SAPR application in other domains represents another potential future effort.

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