Computer Assisted System for Enhancing the Application of Ergonomics in Manufacturing Systems

Qutubuddin S M syedqutub16@gmail.com
Associate Professor, Industrial & Production Engg. Dept.
PDA College of Engineering,
Gulbarga-585102, INDIA

Hebbal S S shivahebbal@yahoo.co.in
Principal
PDA College of Engineering,
Gulbarga-585102, INDIA

ACS Kumar acskumar@yahoo.com
Principal
P.Indra Reddy Memorial College of Engineering,
Chevella, Hyderabad, INDIA

Abstract

The current paper focuses on the need and a plan for the development of a Computer Assisted Interactive and Intelligent Ergonomics System which, through a user friendly consulting mode presents the guidelines and formalized procedures for the application of ergonomics knowledge and data in manufacturing organizations. The system is expected to allow a production engineer or supervisor or even a worker with minimal ergonomics knowledge, to understand, analyze and find solutions to problems related to industrial ergonomics. A survey which is conducted in this regard is also described in this paper and through the outcome of the survey it is shown that the poor acceptance and application of ergonomics is due to lack of exposure to ergonomics knowledge and non-availability of ergonomics knowledge in a suitable form for its application in manufacturing systems.

Key words: Ergonomics, Computer Aided Systems, Anthropometric Data and Work Place Design

1. INTRODUCTION

Ergonomics is a science focused on the study of the 'fit' between people and their work, and decreased fatigue and discomfort through product and work place design. It is the study of people while they use equipment in specific environments to perform certain tasks. Ergonomics aims to make sure that tasks, equipment, information and the environment suit each worker. Ergonomics seeks to minimize adverse effects of the environment upon people and thus to enable each person to maximize his or her contribution to a given job. [1]

Failure to realize the significance of ergonomic principles / knowledge and data and apply for the design of their work systems and products may have serious repercussions, on not only for individuals, but whole organizations. In the literatures there are reports which indicate that many well-known accidents might have been prevented if ergonomics had been considered in designing the jobs and the work systems within which people worked.

However, the available literature reveals that there is still a low level of acceptance and limited application of ergonomics in the manufacturing industries. It is recognized that ergonomic expertise has not been adequately utilized in industrial planning practices in manufacturing organizations and significance of application of ergonomics principles for day to day operations / activities is yet to be recognized in developing countries.

Hence, there is an urgent need for implementation of ergonomics knowledge in the design of workplace, work environment and decision-making as well as in the design and use of products, machines, equipment and production systems. For this to happen in the modern enterprises ergonomics and safety considerations need to be integrated into the design, analysis, and implementation phases of the system.

The poor acceptance and application of ergonomics is due to lack of knowledge and training in ergonomics. With this idea the authors have started a long term research activity to identify strategies for the application of ergonomics standards and / principles in the manufacturing organizations. As a part of this research activity, the current paper reports the plan for development of the computer assisted software package and its applicability in manufacturing industries. The possibilities of development and application of expert systems for industrial ergonomics are examined and discussed in this paper and then the details of developing a computer assisted system for ergonomics are presented.

2. SIGNIFICANCE OF ERGONOMICS

As highlighted above, Ergonomics can be defined simply as the study of work and more specifically, as the science of designing the job to fit the worker, rather than physically forcing the worker's body to fit the job. Adapting tasks, work stations, tools, and equipment to fit the worker can help reduce physical stress on a worker's body and eliminate many potentially serious, disabling work related musculoskeletal disorders (MSDs).[2]. It draws on a number of scientific disciplines, including physiology, biomechanics, psychology, anthropometry, industrial hygiene, and kinesiology. If work tasks and equipment do not include ergonomic principles in their design, workers may have exposure to undue physical stress, strain, and overexertion, including vibration, awkward postures, forceful exertions, repetitive motion, and heavy lifting. Recognizing ergonomic risk factors in the workplace is an essential first step in correcting hazards and improving worker protection [2].

Ergonomists, industrial engineers, occupational safety and health professionals, and other trained individuals believe that reducing physical stress in the workplace could eliminate up to half of the serious injuries each year. Employers can learn to anticipate what might go wrong and alter tools and the work environment to make tasks safer for their workers.

The application of ergonomic principles in the workplace can result in the following [2, 3]:

- Lower injury rates as MSD incidences go down
- Increased productivity by making jobs easier and more comfortable for workers
- Improvement in product quality and productivity
- Reduced absences because workers will be less likely to take time off to recover from muscle soreness, fatigue, and MSD-related problems
- Reduced turnover as new hires are more likely to find an ergonomically designed job within their physical capacity
- Lower workers' compensation claims due to improved health and safety of workers
- Increased worker comfort and Reduced worker fatigue
- Improved morale of workers
- compliance with government regulations
- job satisfaction and lower lost time at work

The above discussions can be summarized as that, when ergonomics is applied to working places and products it is necessary to take into consideration the people who are using them and when products fit the user, the result can be more comfort, higher productivity, and less stress. Ergonomics can be an integral part of design, manufacturing, and use. Knowledge about how the study of anthropometry, posture, repetitive motion, and workspace design affects the user is critical to a better understanding of ergonomics as they relate to end-user needs. [4]

To assess the fit between a person and his work, ergonomists have to consider many aspects. These include [1]:

- the job being done and the demands on the worker
- the equipment used (its size, shape, and how appropriate it is for the task)
- the information used (how it is presented, accessed, and changed)
- the physical environment (temperature, humidity, lighting, noise, vibration) and
- the social environment (such as teamwork and supportive management)
- all the physical aspects of a person, such as:
    - body size and shape
    - fitness and strength
    - posture
    - the senses, especially vision, hearing and touch, and
    - the stresses and strains on muscles, joints, nerves.

By assessing these aspects of workers, their jobs, equipment, and working environment and the interaction between them, ergonomists are able to design safe, effective and productive work systems. Ergonomics can also reduce the potential for ill health at work, such as MSDs, aches and pains of the wrists, elbow, shoulders and back. It also considers the layout of controls and equipment and suggests that these should be positioned in relation to how they are used. Those used most often should be placed within the easy reach of the worker without the need for stooping, stretching or hunching.

3. SURVEY ABOUT THE LEVEL OF APPLICATION OF ERGONOMICS

As a part of the proposed research work which has been outlined above, a survey was carried out to know about the level of awareness and understanding about the ergonomics principles in manufacturing organizations, the need of these principles and identify the issues or problems related to the application of ergonomics. The parent organization of corresponding author is a 50 year old educational institute which has a large alumni database which indicates that the alumni are occupying top key positions in reputed manufacturing organization of south as well as western parts of India. Through these alumni contacts this survey has been conducted. Personal / telephonic discussions, communication through e-mail and postal approaches are used.

A sample of 1200 people was selected and each member is communicated with the purpose of survey and survey form. From this group 806 sent their responses of which 650 are found to be useful for our work.

The data collected from all the respondents was compiled, organized and arranged systematically using statistical methods. Different inference methods were used for drawing conclusions about the awareness and level of application of ergonomics in manufacturing industries. However the overall detail of the survey is beyond the scope of this paper, hence, the details of the analysis of survey is not presented here.

Several hypotheses were formulated and tested with the survey data. A sample of hypotheses that are formulated for this survey is:

In the manufacturing sector majority of the organizations, to be specific more than 60% of the organizations are aware about the significance of ergonomics knowledge and data.

The major cause of lesser application of ergonomics principles in manufacturing organization is non-availability of ergonomics knowledge in a well defined form and also proper guidelines for its application

For the enhancement of ergonomics application to manufacturing organizations more than 75 % of the organizations prefer to employ a user friendly interactive computer assisted system which permits a user to obtain information with little ergonomics knowledge

On the basis of survey results the major issues related to the implementation of a strategy for the application of ergonomic knowledge and data in the manufacturing systems are identified. These issues are described in the following section i.e. section 4

The following is the survey sheet which contains the queries used for the survey:

Survey Sheet for Awareness of Ergonomics Principles & Data and Application to Manufacturing Industries

Name of the Correspondent :

Designation :

Name of Organization :

01. Are you aware of ergonomics principles and their application to manufacturing organizations? YES / NO (write Y or N) **If the reply is ' No ' GO TO 'Important Note Prior to Query number 7'** **If the reply is ' Yes ' GO TO Next Query**	
02. Whether the ergonomics knowledge and data are employed in your organization? YES / NO (Write Y or N) **If the reply is 'No' GO TO Query no 07** **If the reply is 'Yes' Proceed to next query**	
03. In which of the following areas ergonomics principles and data are being used. **(Reply by entering 'Yes' for used and 'No' for not used)**	
• **Work place design**	
• **Product design**	
• **Working environments**	
• **Process / job design**	
• **Material handling**	
• **Work schedule determination**	
• **Training and Development**	
• **Selection of employees**	
• **Assignment of jobs to employees**	
04. Does your organization have Anthropometric database? YES / NO (Write Yes or No)	
05. Does your organization have any other database related to ergonomic knowledge? YES / NO (Write Yes or No)	

06. In your view which of the following benefits are being achieved by your organization by the application of ergonomics principles and knowledge **Enter '√' for Benefit and ' X ' no benefit**	
• **Improvement in productivity**	
• **Better quality**	
• **Good and safe working environment**	
• **Reduction in workers complaints**	
• **Reduction in worker turn over**	
• **Meeting the challenges of global competition**	

Important Note Prior to Query no 7

Kindly Go through the following information and after considerable thinking reply to the following queries

Ergonomics is defined as the design of the workplace, equipment, machine, tool, product, environment, and system, taking into consideration the human's physical, physiological, biomechanical, and psychological capabilities, and optimizing the effectiveness and productivity of work systems while assuring the safety, health, and wellbeing of the workers [6].

Ergonomics is also referred as Human Factors Engineering which deals with the application of information about human behavior, capabilities and limitations to the design of systems, machines, tools, tasks / jobs, environments, etc. for productive, safe and effective human use [1]

07. In which of the following areas you would recommend the application of ergonomics . **(Reply by entering '√' for recommending and ' X 'for not recommending)**	
• **Work place design**	
• **Product design**	
• **Working environments**	
• **Process / job design**	
• **Material handling**	
• **Work schedule determination**	
• **Training and Development**	
• **Selection of employees**	
• **Assignment of jobs to employees**	

08. In your view which of following reasons are responsible for lack of use of ergonomics in manufacturing activities. **(Rank them from 1 to 5 on the basis of their priority)**	
• **Not aware about ergonomics**	
• **Necessary information is not available**	
• **Information is available but not in user friendly form**	
• **Information available and is understood but not able to apply to the design of work systems and products.**	
• **There are reservations / uncertainties / doubts about the significance or usefulness of ergonomics**	
09. Suggest the suitable means of providing exposure to ergonomics **(Rank them from 1 to 5 on the basis of their priority)**	
• **Through training**	
• **Through quality circle activities**	
• **Through a user friendly system which provides ready information about the ergonomics knowledge and data, guidelines , formalized procedures through an interactive session.**	
• **Through Consultants**	
• **Through Awareness programs**	
• **By recruiting new employee who possesses the necessary expertise about the ergonomics and assigning the responsibility of introducing the elements of ergonomics in the design of working system to these new employees.**	

An example from the results of survey conducted, in which 650 responded the questionnaire, for query number 1, about the awareness of ergonomics principles and their application to manufacturing organizations, 400 respondents answered they are aware of ergonomics principles and their application to manufacturing organizations.

For query number 8, 430 respondents mentioned that ergonomics information is available and understood but it is difficult to apply, as it is not in a user friendly form and have certain doubts/reservations about it, and this was considered as one of the reasons responsible for lack of use of ergonomics in manufacturing activities.

For query number 9, asking the respondents to suggest the suitable means of providing exposure to ergonomics and applying ergonomics in their organizations, 395 respondents

believed that a user friendly system which provides ready information about the ergonomics principles, guidelines and formalized procedures through an interactive means as the possible way to apply the ergonomic principles and data without specific ergonomics knowledge by the engineers, supervisors and even the workers. However the overall detail of the survey is beyond the scope of this paper, hence, the details of the analysis of survey is not presented here.

4. ISSUES RELATED TO THE APPLICATION OF ERGONOMICS

As mentioned above a detailed analysis has been carried out on the basis of survey responses with the help of statistical inference methods. The details of analysis are not presented in this paper as it does not fit into the objective of this paper, however some of the major out comes of this survey which are relevant to this paper are listed below.

- The application of ergonomic expertise including anthropometric and working environment related data, in manufacturing industries in not to the level of expectations.

- The overall opinion in manufacturing industries leads to the conclusion that the significance of ergonomics knowledge is acknowledged and it is agreed that there is an urgent need for implementation of ergonomics knowledge in design of manufacturing systems and related decision-making processes.

- Most of the organizations do not possess the expertise necessary for applying ergonomic principles to the design of industrial workplaces and products and even if it is available they are finding it difficult to use it for manufacturing activities in the existing form. Further proper guidelines and procedures required for the application of ergonomic knowledge and data are not available

- There is a need for compiling the ergonomics knowledge and data, representing systematically in a user friendly and acceptable form and make it available to manufacturing organizations in the form of well defined systems

- Information technology and computers are currently playing a very important role in the automation and improvement of almost all manufacturing activities and therefore, it is advisable to extend their application to the management and representation of huge amount of ergonomic information for its implementation.

- The availability of a user friendly intelligent computer assisted system which supports the application of ergonomics information for the day to day activities is the need of the hour for manufacturing industries to overcome the gap between experts and users of industrial ergonomic knowledge and data.

5. A REVIEW ON COMPUTER ASSISTED SYSTEMS FOR ERGONOMICS

As pointed out in the previous section, the efficient and expected level of application of ergonomics principles for manufacturing organization and its fruitful results are possible only when, the computer-assisted systems are realized which can be used by any one (even with a little knowledge of ergonomics) in an interacting or consulting mode, in which guidelines, necessary data and solutions are presented through a question/answer dialogue between the user and the system.[5]. In this direction attempts are being made to apply computer-assisted systems of which some are in the form of expert systems to support problem-solving and decision-making activities related to industrial ergonomics. A sample of works reported in the literature about the application of computer for the realization of ergonomics systems is presented below.

Shikdar et al [6] have developed a computer software package which can be used as a self-assessment tool to evaluate ergonomic improvement potential of production systems by engineers, managers and safety professionals. It is reported that production managers of

manufacturing industries with no prior knowledge of ergonomics were able to identify ergonomic deficiencies successfully (81%) in the shop floors as a result of the application of the ergonomic assessment tool. This enabled them to formulate intervention strategies to improve ergonomic conditions in their industries. The software package is user friendly, self-explanatory and provides relevant information, data and guidelines.

Jeffrey et al [7] have described an interactive Ergonomics CAD system (ErgoCAD) developed to allow human factors designers to determine the appropriate dimensions of an industrial workstation for a given population. ErgoCAD is a means by which individuals, not necessarily familiar with ergonomic principles, can interact with CAD software thereby designing an ergonomic workstation

The main fact that is highlighted here is, the human factors engineer relies upon the successful integration of anthropometric data bases with ergonomic design principles when designing the human-machine interface.

Chen et al [8] have reported a work on the development of an interactive computer-assisted Ergonomics Analysis System (EASY). The system consists of three major components a) the Ergonomics Information Analysis System (EIAS) for evaluation of tasks by the worker, b) the Physical Work Stress Index (PWSI) used by the supervisor or the ergonomist for further investigation of problem situations, and c) the Dynamic Lifting Analysis System (DLAS) for manual material handling tasks. Extensive use of menus for database entry/editing and analysis provides an efficient and friendly interface design.

The expert system proposed by DeGreve and Ayoub [9] only provides work station designs based on anthropometric data. It gives critical dimensions of interest to the user in designing the work station as well as other anthropometric information of interest for further work with the work station. This system does not address standard times, performance on a given task or the body posture while at the work station, nor will it, for example, address biomechanical and physiological stress while performing the activity. Laring [10] et al has presented a tool that helps to meet the needs of concurrent engineering: a Knowledge Based System (KBS) that supports the design of a workplace, by a production engineer, in a CAD environment. The production engineer is asked to specify three structures: the products and parts of products, a plan for the work process and the layout of the workplace. The KBS subsequently performs an ergonomic analysis and presents an assessment to the production engineer, who then decides if any changes in any one of the three structures are necessary.

Moty and Khalil [5] have presented a work to demonstrate the use of personal micro-computers to individualize the design of the sitting workplace. Engineering static and functional anthropometry as well as ergonomic design principles is implemented. This work presents a computer model for individualizing the design of the regular sitting workplace. The model considers the human characteristics such as dimensions, capabilities and limitations as emphasized by ergonomics and motion study principle in the design of tools and equipment. The computer algorithm combines inputted static and functional anthropometric data with principles of body mechanics and energy saving techniques to produce an optimal sitting workplace design.

Asawarungsaengkul et al [12] have proposed a decision support system for designing effective noise hazard prevention (NHP) strategies which consists of four modules: (a) database, (b) input, (c) algorithms, and (d) solution. The user can choose among single-, two-, and three-approach solution procedures. Heuristic and genetic algorithms are used to determine appropriate noise controls (NCs). From the given noise condition and NC budget, NHP recommends a minimum-cost NHP strategy that prevents any worker's daily noise exposure from exceeding the permissible level. If the budget is insufficient, NHP is able to search for a feasible noise hazard strategy that requires a minimum NC budget.

Chen and Yeung [13] reported a work to discuss the effect of nurse shift job on circadian rhythm, work stress, and some important ergonomics criteria and also review and compare different nurse

shift scheduling methodologies via the criteria of flexibility, consideration of nurse preference, and consideration of ergonomics principles. A hybrid expert system, entitled NURSE-HELP, is developed to facilitate the nurse scheduling process with an emphasis on considering ergonomics criteria. The evaluation of the system is done by comparing 18 sets of four-week schedules generated by the head nurses manually and by NURSE-HELP. The quality of the schedules is measured by the following four criteria: minimum staff level not satisfied, day off request not granted, backward rotation, and maximum consecutive work periods on the night shift. The results show that NURSE-HELP is superior to the head nurses in preparing schedules, both in terms of time and quality.

Azadeh et al [14] have presented a study is to design a fuzzy expert system for performance assessment of health, safety, environment (HSE) and ergonomics system factors in a gas refinery. The work proposed is expected to lead to a robust control system for continuous assessment and improvement of HSE and ergonomics performance. The importance of this study stems from the current lack of formal integrated methodologies for interpreting and evaluating performance data for HSE and ergonomics. Three important reasons to use fuzzy expert systems are (1) reduction of human error, (2) creation of expert knowledge and (3) interpretation of large amount of vague data. To achieve the objective of this study, standard indicators and technical tolerances for assessment of HSE and ergonomics factors are identified. Then, data is collected for all indicators and consequently, for each indicator four conditions are defined as ‘‘acceptance”, ‘‘low deviation”, ‘‘mid deviation” and ‘‘high deviation”. A membership function is defined for each fuzzy condition.

The above literature review reveals that computer assisted expert systems have been developed for a single ergonomic factor or few ergonomics factors are taken into consideration with respect to a specific problem such as, for designing a workstation or workplace or noise control or for scheduling of manpower etc.
But a computer assisted system that covers the total ergonomics aspects of workplace design, work environment, posture evaluation, giving ergonomic knowledge and training etc. which can be used as a self-assessment tool to evaluate ergonomic improvement potential of production systems by engineers, managers and supervisors and safety professionals is the need of the hour.

The current work highlights the need for compiling the ergonomics knowledge and data, representing systematically in a user friendly and acceptable form and make it available to manufacturing organizations in the form of well defined user friendly intelligent computer assisted system, which supports the application of ergonomics information for the day to day activities for manufacturing industries to overcome the gap between experts and users of industrial ergonomic knowledge and data.

6. FEATURES OF PROPOSED COMPUTER ASSISTED SYSTEM

Identifying and Understanding the need of the manufacturing organizations, a user friendly Computer Assisted Interactive and Intelligent Industrial Ergonomics System (CAIIIES) has been developed. For this the ergonomics standards, knowledge and data has been collected from various sources, classified, compiled and arranged systematically. The following are the features and functions of the proposed system.

1. The system presents an overview of Ergonomics, its principles, data and also how benefits are derived by applying the principles of ergonomics and ergonomics data for the design of workplace and product. In this regard the knowledge of the human body necessary for this purpose is outlined. In particular it describes following concepts precisely;
    - Explains the concepts of anthropometric data and describes how measurements of human characteristics can be used for the design of workplace, working environment and product

- Analyzes properties and effect of illumination, noise and temperature and explains how proper illumination and control of noise and temperature leads to a safer and better workplace by reducing worker fatigue.
- Explains feasible ways to recognize proper sitting positions and to design seating arrangements to minimize stress to the human body and maximize comfort.
- Highlights the significance and the benefits of proper selection and strategic arrangement of controls and displays for the machining operations.

2. It allows the user to select the Guidelines for the following activities for a specific working situation and also permit to perform these activities
   - to identify and analyze the problems related to ergonomics,
   - assess the level of application of ergonomics
   - apply ergonomics principles and data
3. It provides well defined procedures and demonstrates how working systems can be designed that matches with the characteristics and capabilities of available work force and how to increase employee motivation through better working conditions leading to safety, health, comfort and productivity. Specifically procedures are made available to perform the following tasks
   - to enter anthropometric data of a user population and then obtain the output in the form suggested values for the design of workplace and product
   - Suggestions for illumination, noise and temperature for a given working system.
   - Posture analysis through the various available ergonomic evaluation tools, checklists, questionnaires etc.
   - Suggested values for proper sitting positions within a given set of working conditions.
   - Selection and strategic arrangement of controls and displays for a specific machining operation.
4. It serves as a user manual for applying ergonomics knowledge and data for manufacturing organization. Even a user with a little ergonomics knowledge can use this as a starting point from which expertise can be received to find ergonomic solutions to design of work systems.

7. CONCLUSION

An understanding of ergonomics while designing a workplace can improve day to day routine works in a manufacturing organization and at the same time enhance work quality and productivity, by eliminating the risks of MSDs, aches, pain and stresses at work. However, the expected level of application of ergonomics in manufacturing systems is yet to be achieved, since the complete information about ergonomics standards and data is not available. An extensive survey which was carried out as a part of the proposed work revealed the need of ergonomics related information and data, and also significant issues related to application of ergonomics in manufacturing organizations. The survey also leads to the identification of a strategy to develop a computer assisted system for ergonomics which is proposed in the current paper. The proposed system is expected to enhance the level of application of ergonomics knowledge and data in manufacturing systems, and results in safe and healthy working conditions and also increase in quality of work and productivity.

8. REFERENCES

[1] Health and Safety Executive leaflet, “Understanding ergonomics at work”, available at website www.hse.gov.uk/pubns/indg90 2003

[2] U.S. Department of Labor, Occupational Safety and Health Administration, Ergonomics: The Study of Work, 2000 (Revised) www.osha.gov

[3] Jeffrey E. Fernandez- Ergonomics in the workplace, Facilities 13(4), 20–27 1995

[4] Scott Openshaw, Allsteel and Erin Taylor, Allsteel - Ergonomics and Design: A Reference Guide, Allsteel Inc. availabe at www.allsteeloffice.com 2006

[5] Elsayed Abdel Moty and Tarek M. Khalil - Computer Aided Design of the sitting Workplace

[6] Ashraf Shikdar, Saeed Al-Araimia and Bill Omurtagb- Development of Software Package for Ergonomic Assessment of Manufacturing Industry, Computers & Industrial Engineering 43(3) 485–493 2002

[7] Jeffrey E. Fernandez, Robert J. Marley and Osama K. Eyada - Ergocad: An Ergonomic CAD System, Computers & Industrial Engineering, 18 (3) 313-318, 1990

[8] Jen-Gwo Chen, Robert E. Schlegel and J. Brian Peacock - A Computer-Assisted System for Physical Ergonomics Analysis, Computers & Industrial Engineering, 20(2) 261-269, 1991.

[9] Thomas B. Degreve and M.M. Ayoub- A Workplace Design Expert System, International Journal of Industrial Ergonomics, 2(1) 37-48, 1987

[10] J. Laring A, C, K.-J. Falk B, R. Kadefors A, C, and R. Ortengren C - Computer Aided Workplace Design: An Approach to Create a Tool for the Production Engineer, International Journal of Industrial Ergonomics 17 (4) 323-330, 1996

[11] Elsayed Abdel-Moty and Tarek M. Khalil- Computer Aided Design of the Sitting Workplace, Computers & Industrial Engineering 11(1-4) 22-26 1986

[12] Krisada Asawarungsaengkul, Suebsak Nanthavanij and Junalux Chalidabhongse – Decision Support System for Designing Effective Noise Hazard Prevention Strategies, International Journal of Occupational Safety and Ergonomics 13 (4) 451–470 2007.

[13] Jen-Gwo Chen and Tony W. Yeung - Development of a hybrid expert system for Nurse shift scheduling, International Journal of Industrial Ergonomics, 9 (4) 315-327 1992

[14] A. Azadeh, I.M. Fam , M. Khoshnoud and M. Nikafrouz - Design and Implementation of a fuzzy expert system for performance assessment of an Integrated health, safety, environment (HSE) and ergonomics system: The case of a gas refinery, Information Sciences 178 4280–4300 2008