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Integrated health, safety, environment and ergonomics management system (HSEE-MS): An efficient substitution for conventional HSE-MS

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This study presents a framework for development of integrated intelligent human engineering environment in complex critical systems. Health, safety, environment and ergonomics (HSEE) is developed by integration of conventional health, safety and environment (HSE) with job systems by re-engineering organizational structures and teamwork through electronic data interchange. HSEE has been found superior over conventional HSE through identification of major problems with ergonomic factors in power plant.

Keywords: Environment, Ergonomics, Health, Management system, Re-engineering, Safety

Introduction

To be successful in losses prevention, organizations must construct[1] a solid foundation built by organization's clear vision. A healthy corporate culture is based on positive and respectful values, principles, and beliefs towards safety, health and interaction with environment[2]. By establishing and integrating these fundamental themes into a common managed system, organizations will then be able to build meaningful standards and applied procedures/practices resulting in reduction/ elimination of injury causes, losses to environment, property, process, equipment, materials, as well as personal injuries and adverse health effects[3].

Safety, Health and Environmental Management Disciplines

Principles of safety management are applied to activities that identify and quantify the risk of personal injuries and all types of property damage in workplace[4]. This application involves understanding and anticipating legal, technical, economic, social, cultural and physical environmental factors affecting the organization[5]. Safety management discipline[6] consists general rules, behavior based performance, work permits, general promotion, product safety, fleet safety, off the Job safety, workplace violence, and security. Health management system aims to anticipate, recognize, evaluate and control all health hazards in work environment and to provide appropriate resources for overall health and wellness of all workplace parties[7]. Elements within this discipline include occupational hygiene, medicine, wellness, and psychosocial risk management.

An environmental management system provides framework for an organization to achieve and sustain performance in accordance with established goals and in response to constantly changing regulations; social, financial, economic and competitive pressures related to environmental risks[8]. Environmental management discipline contains elements of waste management for both hazardous and non-hazardous waste, pollution prevention for air, water, soil, and ground water, and community involvement as for flora, fauna and humans.

Ergonomics Management Discipline

Traditional human engineering techniques are concerned with improving interface design between human operators and machines. Operators' error should

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be seen as the result of human variability, which is an integral element in human learning and adaptation[9]. In fact, organizational errors are often the root causes of human errors and man-machine failures[10]. Also, interface systems must be matched with operators' capabilities. Therefore, there is a need for an integrated design between health, safety, environment and ergonomics (HSEE). Integration of HSEE in context of information technology (IT) and integration of job design and organizational design in context of re-engineering enhance reliability and productivity of manufacturing systems[11].

Intelligent Ergonomics

An intelligent ergonomics approach attempts to create equilibrium between organization, operators and HSE through the utilization of electronic data interchange (EDI), usability design and re-engineering. It focuses on overall "people-technology-HSE" systems and is concerned with impacts of technological systems on organizational, HSE and personnel sub-systems. The role of human operators responsible for such systems has changed from a manual, or man-in-loop, controller to a "supervisory controller" who is responsible for overseeing one or more computer controllers who perform the routine, frequently occurring control functions. Therefore, in an intelligent ergonomics environment, interface systems must be matched with operators' capabilities and HSE. Decision styles model is an ideal tool for assessing coordination and creating a match between operators and machines (interfaces). This model suggests that environmental load systematically affect complexity of information processing in persons in an inverted-U-shape function[12]. Environmental load is sum of information complexity, noxity or negative input, eucity or positive input and uncertainty; each individual or group can be considered to have a unique and consistent curvilinear information pattern.

In an intelligent human engineering environment, interface system is continuously designed and adjusted with evolving and emerging developments and IT. Recent development in this area is referred to as Error Tolerant Interface Design. Interface design should aim at making boundaries of acceptable performance visible to operators while the effects of committed errors are observable and reversible. To assist operators in coping with unforeseen situations (health, safety and environmental issues), interface design should provide them tools to make experiments and test hypothesis without having to carry them directly on potentially irreversible processes.

Integrated Management Systems (IMS)

Integrated systems form a "system of systems" where individual systems retain their identity. Proposed changes[13] to ISO 9000 series indicate a move from a system-based approach to a process-based one, employing a model that shows relationship of main elements of ISO 9001 and ISO 9004. IMS is increasingly seen as part of the organization's management portfolio. IMS is required to implement an environmental management system (EMS) and/or an occupational health and safety management system (OH&SMS) in addition to a quality management system (QMS).

Re- Engineering for Health, Safety, Environment and Ergonomics (HSEE)

Fundamental causes of organizational errors are uncertainty, time pressure, and missed signals of deterioration[14], attributed to inadequate organizational structures, deficient procedures and ignorance of warning signals. While many American companies[14] suffer from high levels of hierarchy, Japanese companies[15] have either terminated it completely or reduced it considerably. In fact, Kyocera Company of Koyoto, Japan, operates successfully with a zero level of hierarchy (amoeba system). Real trick in designing highly reliable system[16] is ability to achieve centralization and decentralization in organizational systems. IT could drive a complex manufacturing system toward centralization and decentralization if its capabilities are understood and adjusted with organizational structures[17] and human systems. Re-engineering is collection of activities and mechanisms required to change from hierarchical to horizontal, flat and cross-functional structures based on teamwork within an organization[18].

Electronic Data Interchange (EDI)

EDI[19,20] is electronic, computer-to-computer exchange of information in a structural format between organizations or between various units within an organization[21]. Application of EDI involves conversion of HSEE documents into structural, machine-readable formats so that a computer in HSEE unit within a company can receive and process related data from other unit's computer (Fig. 1). These documents are in conjunction with health, safety, environmental and ergonomics programs. EDI technology has numerous benefits[22-24] and

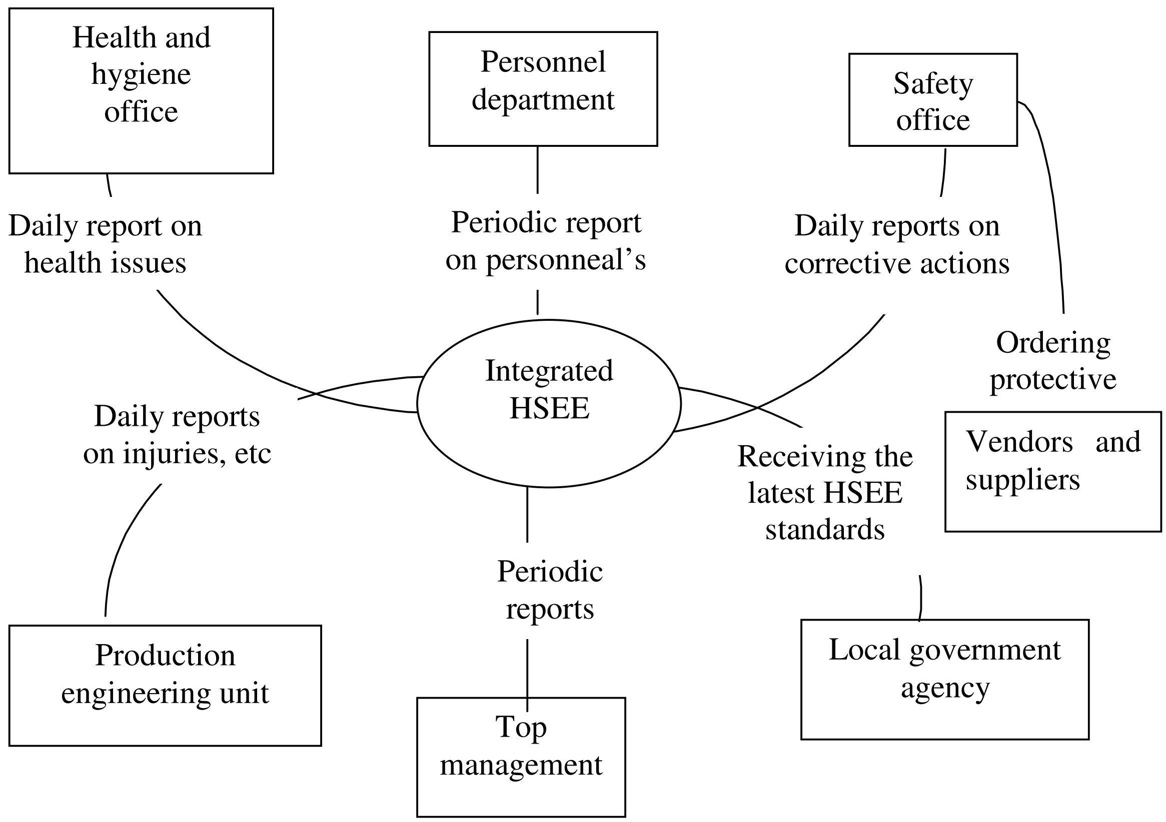

Fig. 1—Role of EDI in integrated HSEE

can bring about a production system with following advantages: i) Exchange time between units is greatly reduced; ii) Human errors are reduced; iii) Less paper woks as paper-based systems are replaced by a faster and more accurate electronic system; iv) Filing costs are minimized; v) Quality of exchanged information between units are improved; and vi) Faster response to required information.

This study presents integrated health, safety, environment and ergonomics management system (HSEE-MS). Design elements of intelligent ergonomics factors are a prerequisite for development of integrated HSEE (Fig. 2). HSEE-MS (Fig. 3) is integrated rather than conventional and requires a systemic effort throughout organization.

Materials and Methods

Maintenance and operation operators of a conventional power plant were studied and divided into two groups: i) Operators who believe there could be a better job design (therefore stress on HSEE); and ii) Operators who believe the current system of job design are okay (and believes HSE is sufficient). Two groups were tested with respect to job pressures, which are defined as workload level, time considerations and stress. Also, two groups of operators with and without inter-organizational issues and two groups of operators having and not having problems with organizational procedures were compared statistically. Kruskasl-Wallis test performs an analysis that is very similar to an analysis of variance (ANOVA) on the ranks. The test is conducted when assumptions for parametric ANOVA cannot be made[25]. Furthermore, it assumes independence between subjects in conditions. The test statistic is calculated as

$$H = \frac{12}{N(N+1)} \sum \frac{T_i^2}{n_i} - 3(N+1) \qquad \ldots(1)$$

where, N= total number of subjects, n_i= number of scores in each of the two condition, T_i= total of the rank in each of the two conditions.

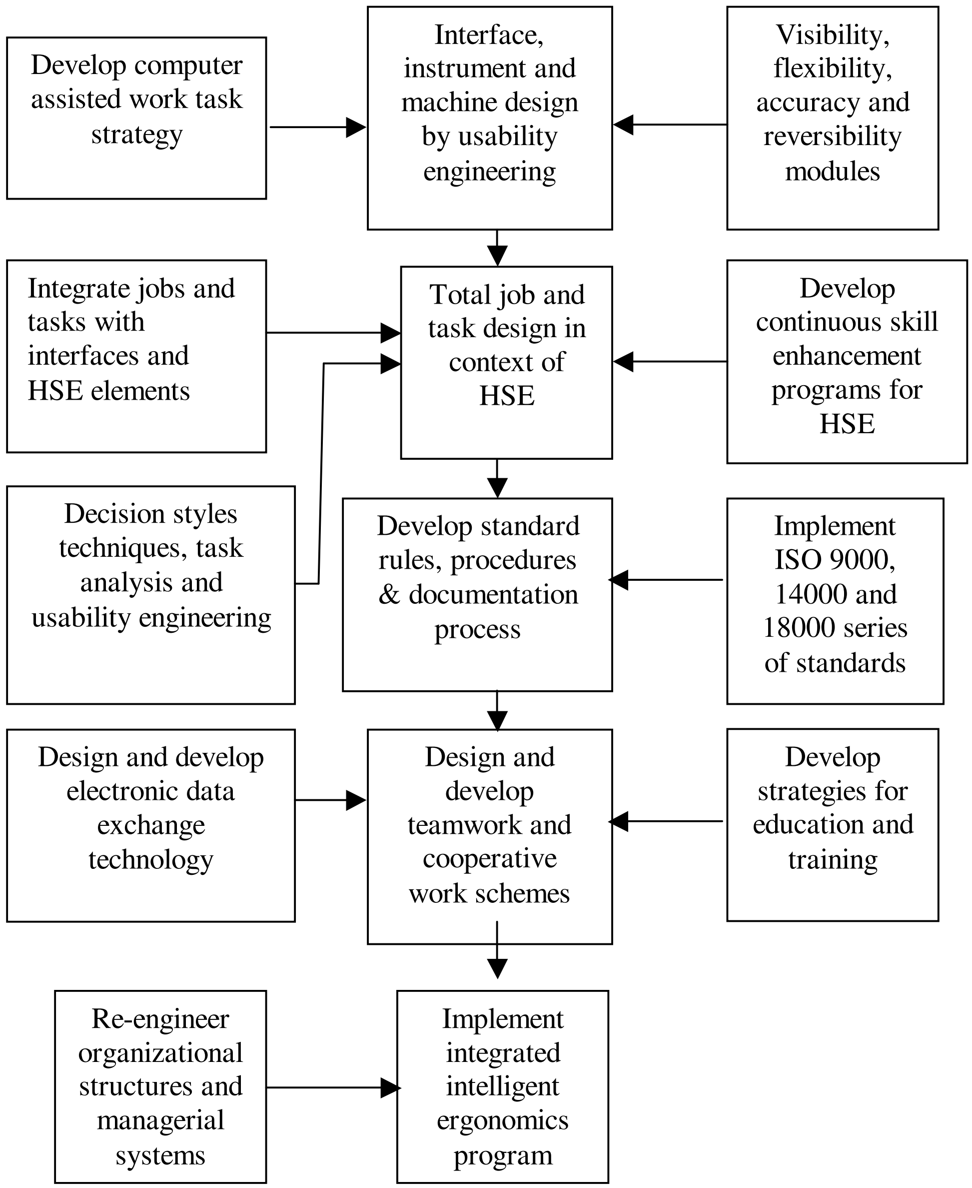

Fig. 2—Elements of intelligent ergonomics program in context of HSEE

Value of H (Table 1) is then compared with table value of chi-square with 1 degree of freedom at the chosen level of significance to reject null hypothesis.

To present the importance of teamwork and communication and information exchange, maintenance and operation operators were studied by non-parametric statistical analysis. Cramer's Phi statistic tests null hypothesis (H_0) of no correlation between two variables against alternative hypothesis (H_1) of correlation between two variables (Table 2). Test of hypothesis is in following general format: H_0= selected factors are not correlated with job pressures; and H_1= otherwise.

Cramer Phi coefficient is a correlation index for K by L matrices and its maximum value does not depend on the number of levels of variables (K and L). It is the extended version of Phi coefficient. The range of this coefficient regardless of the values of L and K is always between 0 and 1. If K and L are defined such that L≤K, Cramer's Phi Coefficient is defined as follows:

$$\phi' = \sqrt{\frac{\chi^2}{n(L-1)}} \qquad \ldots(2)$$

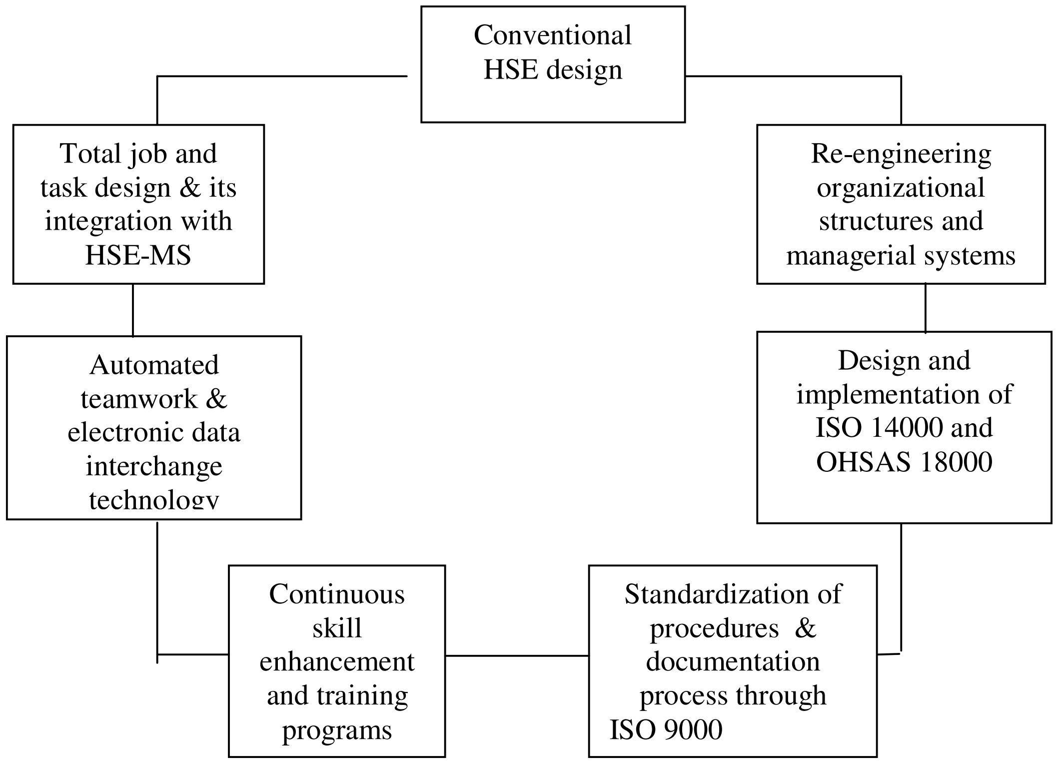

Fig. 3—Integrated health, safety, environment and ergonomics

where, numerator value of Chi-square is found from appropriate table with 2 degrees of freedom at the chosen level of significance, n is total number of subjects and L is number of levels of first variable. Above statistic would test null hypothesis (Ho) of no correlation between two variables against alternative hypothesis (H1) of correlation between two variables.

To present the importance of information exchange in context of integrated HSEE and consequently importance of EDI for such integrated design, maintenance and operation operators of a thermal power plant were studied by non-parametric statistical analysis. Cramer's Phi statistic tests null hypothesis (H_0) of no correlation between two variables against alternative hypothesis (H_1) of correlation between two variables (Table 3). Hence, test of hypothesis is in following format: H_0= quality and suitability of information is not correlated with job pressures; and H_1= otherwise.

Results and Discussion

Difference between Two Types of Operators

First test examines differences between operators who receive on-job training and the ones who receive no on-job training in respect to the level of job pressures. From the results of Kruskal-Wallis through SPSS, there is significant difference between two groups ($P< 0.05$) and operators who receive no on-job training report higher (30%) level of job pressure (time and production pressures). Next test examines previous two groups in respect to quality of perceived information from supervisors. A significant difference ($P< 0.01$) is observed between operators who receive on-job training and the ones who receive no on-job training in lieu of the quality of information they receive from supervisors. Quality of perceived information from supervisors is higher (30%) for operators who receive on-job training. Also, operators who received training related to accident mitigation and prevention and safety issues are compared with the ones who don't receive such training in regard to job pressures by Kruskal-Wallis. Null hypothesis is rejected at $P< 0.01$ and a significant difference ($P< 0.05$) is observed between two groups in respect to job pressures. In fact, operators who do not receive safety training report higher level of job pressure (40%).

The difference between operators who are capable of locating non-routine (emergency at work) with the ones who don't have this capability in relation to quality of information they perceive from co-workers is examined.

Table 1—Results of Kruskal-Wallis test on difference on ranks

Difference in mean ranking of 2 groups of operators		Response variable	Significance level for rejection	Improvement in mean response ranking[1], %
Group I	Group II			
Operators with on- job training	Operators with no on- job training	Job pressures	0.0924	30 (I)
Operators with on- job training	Operators with no on- job training	Quality of perceived information from supervisors	0.0856	30 (I)
Operators with safety and accident prevention training	Operators with no training	Job pressures	0.0100	40 (I)
Operators capable of locating emergency situations	Operators not capable of locating emergency situations	Quality of perceived information from co-workers	0.0694	45 (I)
Operators having problems with organizational procedures	Operators having no problem with organizational procedures	Quality of perceived information from co-workers	0.0609	40 (I)
Operators having problems with organizational procedures	Operators having no problem with organizational procedures	Quality of perceived information from supervisors	0.0003	60 (II)
Operators having problems with organizational procedures	Operators having no problem with organizational procedures	Job pressures	0.0009	50 (II)
Operators having problems using procedures during emergency	Operators having no problem using procedures during emergency	Quality of perceived information from supervisors	0.0011	50 (II)
Operators who are rewarded for teamwork	Operators who are not rewarded for teamwork	Job pressures	0.0030	70 (I)
Operators who are rewarded for teamwork	Operators who are not rewarded for teamwork	Quality of perceived information from supervisors	0.0041	40 (I)
Operators who violate safety procedures	Operators who don't violate safety procedures	Job pressures	0.0054	50 (I)
Operators who can easily communicate with supervisors	Operators who cant easily communicate with supervisors	Job pressures	0.0073	58 (II)
Operators who can easily communicate with supervisors	Operators who cant easily communicate with supervisors	Quality of perceived information from supervisors	0.0164	40 (I)
Operators with problems with co-workers	Operators with no problem with co-workers	Job pressures	0.0139	45 (I)
Operators with problems with co-workers	Operators with no problem with co-workers	Quality of perceived information from supervisors	0.0123	32 (I)
Operators with individual decision making capability	Operators with no individual decision making capability	Quality of perceived information from supervisors	0.0454	30 (I)
Operators believing a better job design is required	Operators believing current system is okay	Job pressures	0.0010	300 (I)

[1]Latin number in parentheses indicates group number

A significant difference is observed between two groups in lieu of quality of information they perceive from co-workers at $P< 0.01$. Operators who are capable of locating emergencies report higher quality of perceived information (45%) from co-workers. Also, operators who have problems using organizational procedures during routine situations are compared with the group who do not report any problems in respect to the quality of

Table 2—Test of correlation between job pressures and selected ergonomics factors

Human engineering factors	Cramer's Phi	Significant level (α)
Usefulness of informal information exchange	0.43	0.00017
Reward for teamwork by supervisors	0.55	0.00002
Supervisors' monitoring and assessment at work	0.40	0.00900

Table 3—Test of correlation between job pressures and quality of information

TSD factor	Cramer's Phi	Significant level (α)
Suitability of perceived information from supervisors	0.56	0.00000
Suitability of perceived information from co-workers	0.45	0.00008
Ease of contact with supervisors	0.50	0.00002

information they perceive from co-workers. Null hypothesis is rejected and it is observed that two groups of operators differ significantly ($P< 0.01$) in the quality of information they receive from co-workers. Operators who don't have any problem using organizational procedures report higher quality of perceived information from co-workers. Next, same groups of operators were compared in regard to the quality of information they perceive from supervisors. Null hypothesis was rejected at $P< 0.01$ and it was observed that the ones who do not report any problem with organizational procedures also report higher (60%) quality of perceived information from supervisors. The same two groups of operators are examined in lieu of job pressures. Null hypothesis is rejected at $P< 0.01$ and hence, it is observed that operators who do not report any problem with organizational procedures also report lower (50%) level of job pressures. Operators who have problems with using procedures during emergency (non-routine) situation are compared with the ones who do not such problems in respect to the quality of information they perceive from co-workers. Null hypothesis is rejected and it is concluded that two groups differ significantly ($P< 0.01$). Moreover, operators who report no problem with procedures during emergency situations also report higher (50%) quality of perceived information from co-workers.

Operators who are rewarded by supervisors for teamwork are compared with the ones who are not rewarded in respect to job pressures (production and time pressures). Null hypothesis is rejected at $P< 0.01$ and it is concluded that two groups differ significantly in lieu of job pressures. Hence, operators who are rewarded for teamwork report lower (70%) level of job pressures. The same two groups were compared in respect to the quality of information they perceive from co-workers. Null hypothesis is rejected at $P< 0.01$ and it is concluded that operators who are rewarded for teamwork report higher (40%) quality of perceived information from co-workers.

Operators who violate safety procedures due to job pressures are compared to operators who don't violate safety procedures due to job pressures in respect to the level of job pressures. Null hypothesis is rejected at $P< 0.01$ and operators who violate safety procedures due to job pressures report higher (45%) level of job pressures during routine situations. The same two groups are compared in lieu of the quality of information perceived from co-workers. Null hypothesis is rejected at $P< 0.01$ and it is concluded that operators who don't violate safety procedures due to job pressures report higher (50%) quality of perceived information from co-workers.

Operators who can easily communicate with supervisors were compared with the ones who can't easily communicate with supervisors in respect to the level of job pressures. Null hypothesis is rejected at $P< 0.01$ and two groups were found to differ significantly in lieu of job pressures; operators who can't easily communicate with supervisors report higher (58%) level of job pressures. Preceding groups were compared in respect to the quality of information they perceive from supervisors. Null hypothesis is rejected at $P< 0.01$ and operators who can easily communicate with supervisors reported higher (40%) quality of perceived information from supervisors.

Operators who report problems with co-workers due to inter-organizational issues were compared with ones who don't have such problems due to inter-organizational issues in respect to the level of job pressures. Null hypothesis is rejected and two groups were found to differ significantly at $P< 0.01$. Operators who do not report problems with co-workers due to inter-organizational issues report lower (45%) level of job pressures. Preceding groups were compared in lieu of the quality of information perceived from supervisors. Null hypothesis is rejected at P< 0.01 and operators who don't report problems with co-workers due to inter-organizational issues also reported higher (32%) quality of perceived information from supervisors.

Operators who feel they have freedom to make decisions without continuous contact with others (particularly supervisors) were compared with the ones who feel they don't have freedom to do so in respect to the quality of information perceived from supervisors. Two groups were found to differ significantly in respect to the quality of information perceived from supervisors (P< 0.05). Operators who report that they have freedom to make decisions without continuous contact with others also report higher (30%) quality of perceived information from supervisors.

Operators who believe there could be a better job design were compared with the ones who do not believe there could be a better job design in respect to the level of job pressures. Null hypothesis is rejected and two groups were found to differ significantly at P< 0.0. Operators who believed that there could be a better job design reported higher (300%) level of job pressures.

Influence of HSEE Factors on Human Performance

It is observed that HSEE factors significantly influence human performance and therefore they must be considered (Table 1) and designed concurrently with the local factors in order to optimize human performance in particular and the system in general[26]. Usefulness of information exchange is correlated with job pressures at work (Table 1). Job pressures are reported lower as the quality and usefulness of information exchange increases. Also, a job pressure is positively correlated with teamwork. Operators who are rewarded for teamwork report lower level of job pressures and consequently produce higher performance. Supervisors' monitoring and assessment in context of information exchange system could also lower job pressures, because such data is constantly flowing between managers and employees. In summary, these findings suggest the positive impacts of teamwork and well-designed information exchange systems on human performance and the need of integration of ergonomics factors with HSE. To further then investigation and robustness of the study, two thermal power plants were also examined and very similar findings were realized. There is a need for an accurate reliable modern information system, which allows effective teamwork and information interchange between HSEE elements of large complex organization.

Suitability (quality) of perceived information from co-workers and supervisors are correlated with job pressures. Job pressures are reported lower as the quality and usefulness of perceived information increases. In addition, ease of contact is positively correlated with workload. An efficient user-friendly information exchange system may result in lowered workload. In summary, these findings, verified and validated in two thermal power plants, suggest positive impacts of user-friendly interface and well-designed information exchange systems on human performance. There is a need for user-friendly interfaces within electronic information systems, which allows easy visible information retrieval and effective communication between personnel.

Intelligent human engineering environment considers the real people involved in the processes (operators) and aims at continuously improving their performance and productivity[27]. It advocates on—job training to operators using simulators and training classes. Educational and training programs are important and integral aspects of intelligent human engineering systems. Supervisors should foster a sense of unity by convincing operators that cooperative work serves a purpose that is superior to their independent contributions. Providing automated information to operators in context of IT may increase performance by providing capability to detect and correct errors and consequently higher productivity[28]. One of the major prerequisites to design and develop is by integration of electronic data interchange technology and usability techniques and re-engineering organizational structures and managerial systems (Fig. 1). Evolving IT must be cautiously and systematically integrated to organizational structures and human systems.

Conclusions

Integrated HSEE-MS is an integration of conventional HSE-MS with ergonomics factors through electronic data interchange, teamwork and re-engineering organizational structures (Fig. 3). It enhances reliability, productivity and tolerance of manufacturing systems. Introduction of unmatched technology (both advanced and IT) is the major bottleneck in design and implementation of an integrated HSEE-MS. Also, specialization of designers and engineers of such systems adds a new magnitude of reservation. Most designers prefer to deal with absolutes than probabilities. Designers and engineers need to adopt a more holistic approach to problems of human systems. They must consider the whole and avoid the trap of dealing with specialties with which they feel comfortable. Automated teamwork in context of EDI technology, interface design in context of usability design, job design and organizational design in the context of re-engineering when integrated with conventional HSE-MS could enhance reliability and productivity of manufacturing systems. Design philosophy of an integrated intelligent human factors engineering system must base on simplicity and practicability. Job design and organizational design in context of re-engineering requires assessment and redesign of all tasks, jobs, responsibilities, hierarchies, and communication channels within the organization. There is need to create an HSEE new for the internal customers (personnel), external customers and organization itself by employing the concepts of ergonomics in the context of re-engineering.

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