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A Framework for Development of Integrated Intelligent Human Engineering Environment

[1]A. Azadeh and [1,2]I. Mohammad Fam
[1]Department of Industrial Engineering, Faculty of Engineering,
Research Institute of Energy Management and Planning, University of Tehran, Tehran, Iran
[2]Department of Environmental Management,
Graduate College of the Environment Science and Research Groups,
Islamic Azad University, Tehran, Iran

Abstract: In this study conceptual framework for development of integrated intelligent human engineering environment in complex manufacturing systems was introduced. The integrated intelligent human engineering environment is defined as integration of automated teamwork and intelligent interface design in the context of electronic data interchange technology and usability engineering. Moreover, it advocates integration of job design and organizational design in the context of re-engineering. Intelligent interface design deals with optimization between human operators and machines through usability design and engineering techniques. Its objective is to reduce confusion and increase the flexibility and precision of manufacturing systems. Teamwork must be designed with the aid of Electronic Data Interchange (EDI) technology in the context of Information Technology (IT). The integrated intelligent human engineering introduces a unique, effective and systemic mechanism, which integrates the structure of the organizational systems with information systems and technology and non-technical (people) sub-systems. It is designed to enhance productivity and tolerance of manufacturing system through the integrated framework of this study.

Key words: Integrated, intelligent, human engineering, usability, EDI, re-engineering

INTRODUCTION

Traditional human engineering techniques are concerned with improving the interface design between human operators and machines. However, without its upward integration with job of operators and organizational design of such systems, at best, it leads only to sub-optimization and, therefore, results in an inherently error- and failure-prone total system. Such a system, eventually, when faced with concatenation of certain events, would suffer from this `resident pathogen[1-3]. In fact, operators' error should be seen as the result of human variability, which is an integral element in human learning and adaptation[4-7]. Thus, human error occurrences are defined by the behavior of total human-task-organizational system. Also, this integration must be designed in context of the new information technology.

Finding the mechanisms, which optimize the teamwork between operators, machines and organization, is one of the great technological challenges of the twenty-first century[8-10]. The technological challenge is to create an intellectual interface between human operators, machines and organizational structures. In fact, organizational errors are often the root causes of human errors and man-machine failures[8-15]. Also, the interface systems must be matched with operators' capabilities. Therefore, there is a need for an integrated design between operators, machines, organization and technology. Furthermore, it has been shown that the integration of interface systems and teamwork in context of information technology and integration of job design and organizational design in the context of re-engineering will enhance the reliability and productivity of manufacturing systems[16].

RE-ENGINEERING AT WORK

The new information technology, according to Brehmer[17], constitutes a threat to the hierarchical structure of complex system's organization. It creates problems of mismatches in the response times at the different levels in the hierarchy and information overload. Indeed, structural or functional weaknesses of plant organization and management are often found to be the root cause of many system failures and plant accidents.

Corresponding Author: Ali Azadeh, Department of Industrial Engineering, Faculty of Engineering, University of Tehran, Tehran, Iran Tel: 00989121221103 Fax: 00982166461680

Moreover, there is a positive correlation between the quality of the organization and the plant safety and reliability. The fundamental causes of organizational errors in the organizations are uncertainty, time pressure and missed signals of deterioration[18]. Missed signals of deterioration can be attributed to inadequate organizational structures, deficient procedures and ignorance of warning signals. In addition, our investigation shows lack of coordination between various facets of an organization may create severe issues in manufacturing systems. This may be due to poor management, personnel's resistance and unavailability of technical experts. Furthermore, the success of any large complex system depends not only on the success of its individual engineered components or subsystems, but also on the extent of the integration of these with the human activities and organizational functions[3]. Moreover, these engineered components and human activities must be integrated with the inevitable information technology.

Since a complex system involves a variety of disciplines, the managers must be alert of critical problems falling between disciplines. Moreover, the managers of such systems must utilize an integrated method to identify the gaps at interfaces and overlooked weak points. Modern technology must be adjusted to the internal environment of manufacturing systems[19].

To facilitate this integration, the designers of complex systems must minimize the distance between the operators and the decision-makers. The greater the distance between the operators and the decision-makers, the more complex the communication and the higher the level of uncertainty and insecurity. While many American companies suffer from high levels of hierarchy (15-18), Japanese companies have either terminated it completely or reduced it considerably[20]. In fact, the Kyocera Company of Koyoto, Japan operates successfully with a zero level of hierarchy: the amoeba system. Perrow[11] and Weick[21] note that the real trick in designing highly reliable system is the ability to achieve centralization and decentralization in the organizational systems. The new emerging Information Technology (IT) could drive a complex manufacturing system toward centralization and decentralization if its capabilities are understood and adjusted with the organizational structures[22-25] and human systems.

Re-engineering is the collection of activities and mechanisms required to change from hierarchical to horizontal, flat and cross functional structures based on teamwork within an organization[26]. The main goal in such program is customer's satisfaction. To present the importance of re-engineering in context of human engineering in complex manufacturing systems, human engineering system of a newly modern built 2000 MW (Japanese made) thermal power plant was studied. Furthermore, maintenance and operation operators of the power plant were divided into two groups: operators who believe there could be a better job design and operators who believe the current system of job design are okay. The two groups were tested with respect to job pressures, which is 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. In addition, the same types of analysis were conducted in two other power plants and similar findings were obtained with respect to human engineering.

Test of hypothesis: The Kruskal-Wallis test performs an analysis that is very similar to an analysis of variance (ANOVA) on the ranks. The test is conducted when the assumptions for the parametric ANOVA cannot be made[27]. Furthermore, it assumes independence between subjects in conditions. The general format of the test is as follows:

Ho : The two groups of operators have the same performance with respect to job pressures

H_1 : Otherwise

Operators who have problems with co-workers due to inter-organizational issues report higher level of job pressures. They reported 50% higher job pressures at work (Table 1). Operators who don't have any problem with organizational procedures report lower level of job pressures (about 45% less). In addition, operators who believe that there could be a better job design (the majority of operators) reported higher level of job pressures. They reported 300% higher job pressures at work. It should be noted that two other thermal power plants were also examined and approximately similar

Table 1: The significant level of test of comparison on the job pressures

Difference in mean ranking			
Group 1	Group 2	Significant level (α)	Relative disadvantage (%)
Having problems with organizational procedures	No problem with organizational procedures	0.0009	50
Problems with co-workers due to inter-organizational issues	No problem with co-workers	0.0139	45
Believing a better job design is required	Believing current system is ok	0.0010	300

findings were echoed. This is an important finding which reveal the current system of job design is partially rather than totally optimized. This is due to lack of human engineering factors when the current system of job design was designed and implemented. This means that existing system of job design must be re-engineered in context of human engineering.

EDI AND TEAMWORK

Teamwork concepts have been shown to enhance the reliability of complex manufacturing systems[28,29]. Nowadays, the most important method of building teamwork is through automation and computer assisted work tasks. Providing automated and elaborated information to work groups may increase performance by providing the capability to detect and correct errors[28,30]. It is therefore suggested that computer-supported cooperative work offer the potential of enhanced group effectiveness. This is referred to as electronic data interchange (EDI) in the context of concurrent engineering. For the planning and construction phase of the teamwork through electronic data interchange, the following suggestions may be quite useful to consider:

- The operators and supervisors should give each other necessary feedback. In fact, feedback is seen as a contingency leading to effective and cognitive outcomes, including level of attraction to the group, pride in the group, defensive feelings and acceptance of the group problems. This finding is also echoed in studies conducted by Harmon and Rohrbaugh[31], Raudsepp[32] and Brehmer [33]. They reported that significantly greater group consensus occurred as a result of the full exchange of cognitive feedback.
- The supervisors should foster a sense of unity by convincing the employees that cooperative work serves a purpose that is superior to their independent contributions. Organizational culture plays an important role in the team construction phase. The team skill training starts with top management and continues throughout the organization.
- The group's rebuttal to every single impetus situation must be unique and atypical. The team must seek a dynamic structure and avoid the habitual routines. A habitual routine exists when a team repeatedly exhibits a functionally similar pattern of behavior in a given stimulus situation without explicitly selecting it over alternative ways of behaving[34].

Test of correlation: To present the importance of teamwork and communication and information exchange, the maintenance and operation operators of the 2000 MW thermal power plant were studied by non-parametric statistical analysis. The Cramer's Phi statistic tests the null hypothesis (H_0) of no correlation between the two variables against alternative hypothesis (H_1) of correlation between the two variables (Table 2). The test of hypothesis is in the following general format:

Table 2: Test of correlation between job pressures and selected human engineering factors

Human engineering factors	Cramer's Phi	Significant level (α)
Usefulness of informal information exchange	.43	.00017
Reward for teamwork by supervisors	.55	.00002
Supervisors' monitoring and assessment at work	.40	.00900

H_0: The selected factors are not correlated with job pressures
H_1: Otherwise

As shown there is strong evidence that usefulness of information exchange is correlated with job pressures at work. Lower job pressures are reported as the quality and usefulness of information exchange increases. Also, job pressures 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. To further our investigation and robustness of the study, two other thermal power plants were also examined and very similar findings as stated here were realized. Furthermore, there is a need for an accurate reliable modern information system which allows effective teamwork and information interchange between persons. Next section shows Electronic Data Interchange (EDI) technology is the most reliable and efficient information exchange system available today.

Electronic data interchange: EDI is being used by various production systems to order and pay for goods from suppliers, to receive orders from customers, to invoice customers and to collect payments from customers. The applications of electronic data interchange technology are discussed by several studies and to name a few the interested readers are referred to the following papers[35-40]. The concepts and applications of EDI in supply chain management are reported by other recent studies[41-49].

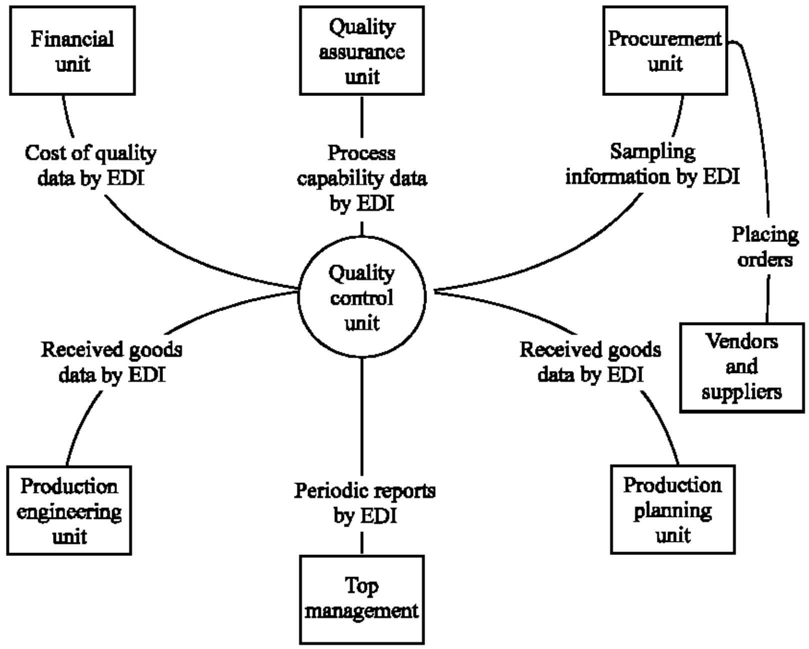

Fig. 1: An example of the role of EDI in integrated intelligent human engineering environment

Various studies discuss theories, issues, success and failure factors related to EDI implementation and interested reader is referred to the following studies[50-62]. EDI is the electronic, computer-to-computer exchange of information in a structural format between organizations or between various units within an organization[63]. It is a high-speed method of electronic communication that facilitates the exchange and processing of high volumes of information from one computer to another in particular and quality control unit and other inter-related units in general. It is therefore an integral part of an IQC. Furthermore, in an IQC, the information related to quality is exchanged between quality control unit and other inter-related units by EDI mechanism. The application of EDI involves the conversion of quality control documents into structural, machine-readable formats so that a computer in the quality control unit within a company can receive and process quality related data from other unit's computer. These quality related documents are in conjunction with orders, vendors, samplings, process capability, inventory and cost of quality.

An example of typical information exchange in context of EDI is shown in Fig. 1. EDI technology has numerous benefits discussed in various studies[63,64]. A recent paper analyses showed the benefits to be gained from the use and adoption of EDI from the point of view of administration as well as of improvement in information and relationships with business partners and concludes that once the technology has been adopted, its users become aware of the benefits and change their opinion[65]. Key success factors in implementing EDI within US market and global markets are analyzed by another study[66]. Another study developed a model and decision support tool for identifying if EDI adoption is cost effective[67]. In summary, EDI technology can bring about a production system with several advantages listed as follows[68-70]:

- The exchange time between units is greatly reduced
- Human errors are reduced
- Less paper woks as paper-based systems are replaced by a faster and more accurate electronic system
- Filing costs are minimized
- Quality of exchanged information between units are improved
- Faster response to required information

Figure 2 presents the design elements of re-engineering organizational structures as a prerequisite for development of integrated intelligent human engineering environment. It is noticed that the prescribed approach is integrated rather than conventional and requires a systemic effort throughout organization.

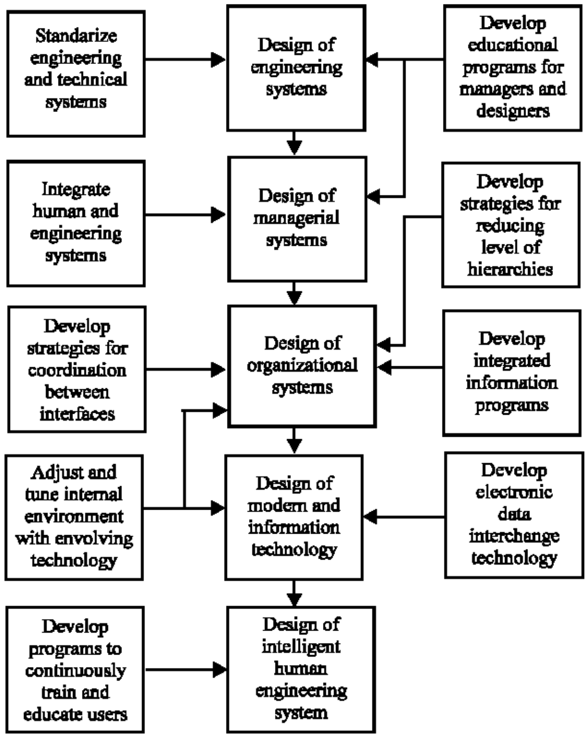

Fig. 2: Re-engineering organizational structures as a prerequisite for integrated intelligent human engineering environment

INTELLIGENT HUMAN ENGINEERING

Human factors engineering techniques strive to optimize the interaction between human operator and machine. It considers those factors of machine design and work posture that have influenced on the user interface and working conditions related to the job (task) design. In an intelligent human engineering approach, the usability and ergonomics factors in parallel to the organizational and managerial aspects of working conditions in context of a total system approach are considered. Moreover, it attempts to create equilibrium between, organization, operators, interfaces and machines through the utilization of EDI, usability design and re-engineering. It focuses on overall people-technology systems and is concerned with the impacts of technological systems on organizational, managerial and personnel sub-systems.

The present complex technological systems pose additional demands and new requirements on the human operators. The role of human operators responsible for such systems has changed from a manual, or man-in-the-loop, controller to a supervisory controller who is responsible for overseeing one or more computer controllers who perform the routine, frequently occurring control functions. In supervisory control systems, the human operator's role is primarily passive, a monitor of the change in system state[71]. The operator's passive role, however, changes to one of active involvement in cases of unexpected systems events, emergencies, alerts and/or system failures[72]. Unfortunately, the operators may suffer from isolation and remoteness from actual work. They may find their skills degraded when called upon to take over emergencies. Therefore in an intelligent human engineering environment, the interface systems must be matched with operators' capabilities. 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 the complexity of information processing in persons in an inverted-U-shape function[73]. Environmental load is defined as the sum of the effects of four basic factors: (a) information complexity (e.g., information load, time pressure), (b) noxity or negative input (e.g., threat), (c) eucity or positive input (e.g., support from others) and (d) uncertainty Each individual or group can be considered to have a unique and consistent curvilinear information pattern.

Also, there is a need to create an intelligent interface between human operators and machines. An intelligent interface system is capable of adjusting itself with evolving information technology through usability engineering and design techniques. It means that in an intelligent human engineering environment, the interface system is continuously designed and adjusted with evolving and emerging modern and information technology. Moreover, it acts as an expert system composed of a knowledge base and a learning module capable of continuously learning and improving itself. In such environment, design of interface systems must be based on simplicity, flexibility, visibility and accuracy. The recent development in this area is referred to as Error Tolerant Interface Design. The interface design should aim at making the boundaries of acceptable performance visible to operators while the effects of the committed errors are observable and reversible[74-78]. To assist the operators in coping with unforeseen situations, the interface design should provide them tools to make experiments and test hypothesis without having to carry them directly on potentially irreversible processes.

Test of correlation: To present the importance of validity design, the maintenance and operation operators of the 2000 MW thermal power plant were studied by non-parametric statistical analysis. The Cramer's Phi statistic tests the null hypothesis (H_0) of no correlation between the two variables against alternative hypothesis (H_1) of

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

correlation between the two variables (Table 3). Hence, the test of hypothesis is in the following format:

H_0: The quality and suitability of information is not correlated with job pressures
H_1: Otherwise

There is strong evidence that suitability (quality) of perceived information from co-workers and supervisors are correlated with job pressures. Lower job pressures are reported as the quality and usefulness of perceived information increases. In addition, ease of contact is positively correlated with workload. Hence, enhancing ease of contact with supervisor seems to be lowering job pressures. Furthermore, an efficient user friendly information exchange system may result in lowered workload. In summary, these findings suggest the positive impacts of user-friendly interface and well-designed information exchange systems on human performance. Also, the same study in two other thermal power plants verified and validated the above findings. Furthermore, 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. It advocates on-the-job training to operators using simulators and training classes. Educational and training programs are important and integral aspects of intelligent human engineering systems.

The supervisors should foster a sense of unity by convincing the operators that cooperative work serves a purpose that is superior to their independent contributions. Providing automated information to operators in context of information technology may increase performance by providing the capability to detect and correct errors and consequently higher productivity. Figure 3 shows the design elements for development of integrated intelligent human engineering environment in complex manufacturing systems. It should be noted that one of the major prerequisites to design and develop such environment is by integration of electronic data interchange technology and usability techniques and re-engineering organizational structures and managerial systems. Furthermore, the evolving information technology must be cautiously and systematically integrated to organizational structures and human systems.

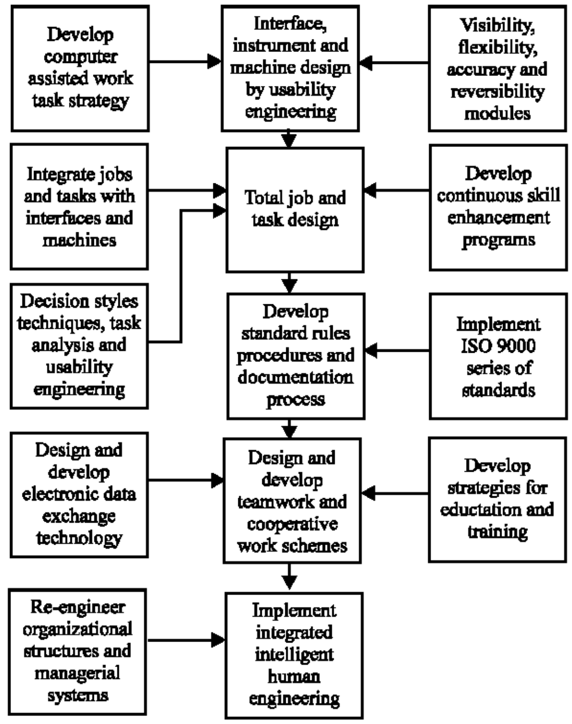

Fig. 3: The elements of integrated intelligent human engineering environment

EPILOGUE

The integrated intelligent human engineering is defined as integration of automated teamwork design, job design, intelligent interface design and organizational design (Fig. 4). It is designed to enhance productivity and tolerance of manufacturing systems. Introduction of unmatched technology (both advanced and information technology) is the major bottleneck in design and implementation of an integrated intelligent human engineering. Also, the specialization of designers and engineers of such systems adds a new magnitude of reservation. Most designers prefer to deal with absolutes than probabilities. The 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 Electronic Data Interchange (EDI) technology, interface design in context of usability design, job design and organizational design in the context of re-engineering when integrated could

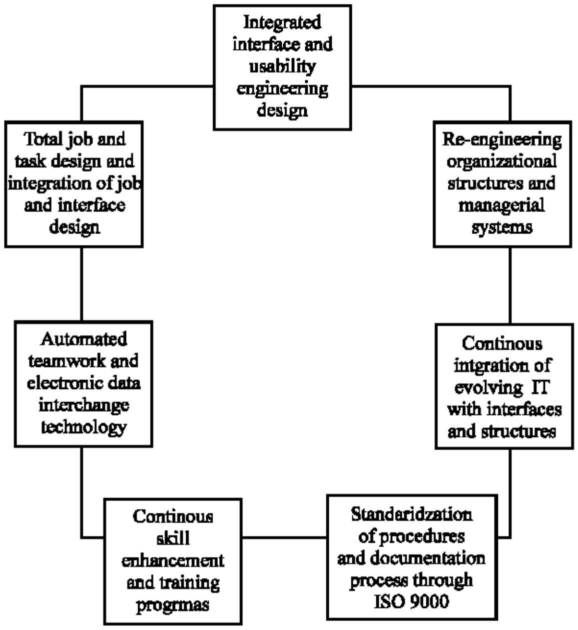

Fig. 4: Integrated intelligent human engineering environment

enhance the reliability and productivity of manufacturing systems. However, it should be noted that each system is unique and the problem solving approach of each system must be based on systems uniqueness philosophy. Furthermore, the design philosophy of an integrated intelligent human factors engineering system must based on simplicity and practicability.

Job design and organizational design in context of re-engineering requires assessment and redesign of all tasks, jobs, responsibilities, hierarchies, communication channels within the organization. We need to recreate a new organization rather than modification and/or improvement of existing organization. We need to recreate a new organization for the internal customers (personnel), external customers and organization itself by employing the concepts of macroergonomy in the context of re-engineering. The objective is not relative improvement or growth, rather a fundamental radical change in organizational thinking and attitudes. Two fundamental questions must be answered first: what should our organization do? and how it should accomplish it? Furthermore, previous experiences and activities with respect to job design and organizational design loose their importance. They must be redesigned from scratch by considering how they should interact, work and communicate in the context of re-engineering. Furthermore, integration of job design and organizational design in context of re-engineering have the following features:

- Integration of centralization and decentralization: The real trick in designing high reliable organization is the ability to achieve centralization and decentralization in organizational systems[2]. Furthermore, there are several independent units within the organization that have their existing information available to one another and the central office. This is achieved through EDI techniques. The integration of centralization and decentralization is achieved by horizontal and vertical integration.
- Teamwork: The hierarchical pyramid structure must be changed to a more flat integrated structure. Management should become a part of the work teams or process teams. A particular team leads a particular process. The particular teams are substituted for hierarchies with greater span of control. A hierarchical manager could have 6 employees under his direction whereas an integrated manager could have about 30 employees with more flexibility and control in his process team. Personnel with the same type of skills, background and knowledge are placed in work teams (or process teams) for actual group think and brainstorming. Information Technology (IT) must be used to facilitate this feature. This may be achieved through automated teamwork and EDI technology. Teamwork through EDI will introduce a new flexible organization. The new organizational structure must be capable of identifying new markets, products and customers.
- Self-organization: Traditional hierarchical procedures are replaced by natural self-organized procedures. The chains of commands are minimized as possible. Reworks as the result of chain of commands and organizational rules procedures are identified and eliminated. Rules and procedures are standardized and tailored according to the new effective organizational structure. This mechanism changes the controlled workers to self-organized workers and team workers. The workers and team workers have the authority to make judgment and decision.
- Knowledge engineering: This requires emphasis on knowledge in addition to conventional training procedures. Information technology must be used to access the required knowledge to the workers. This in turn reduces the learning curves, response times and cycle times. Also, the traditional training courses such as on-the-job-training and simulator training could be offered to the workers via information technology.
- Standardization: This critical feature requires design and implementation of standard documentation process according to the formats of the International

Organization for Standards (ISO). This would allow easier and faster communication with the vendors, suppliers, customers and other organization.

As mentioned, one of the major tools to achieve job design and organizational design in context of re-engineering is IT. IT certainly facilitates re-engineering of organizational structures. Furthermore, integration of automated teamwork in context of EDI and intelligent interface design in the context of usability design requires re-engineering and technological assessment of the organization. Teamwork's and intelligent interfaces must be designed and implemented by identifying proper EDI and usability techniques. Careful considerations must be given to the operation and maintenance of the intelligent interfaces as usability techniques are continuously progressing. The interfaces must be created by usability design and engineering techniques. The integration of intelligent interfaces and automated teamwork in context of information technology has the following features:

- Flexibility: The interfaces are flexible such that they could be altered with continuous advances of information technology.
- Automated teamwork: Personnel could communicate with each other through the intelligent interface systems. Furthermore, information and data could be interchanged between departments through intelligent interfaces. A particular department can access to the databases and knowledge base of another through interface systems. Also, the work teams or process teams can communicate and exchange information within and between departments.
- Integrated interfaces: Intelligent interfaces are not limited to particular units within the organization. They are designed and implemented by usability techniques and are integrated by the electronic data interchange technology. As noted, teamwork and intelligent interface design are achieved through EDI and usability techniques. Moreover, job design and organizational design are achieved through re-engineering. Therefore, integration of teamwork and interface design with job design and organizational design requires integration of EDI and usability techniques with re-engineering concepts. The integrated interface mechanism achieves integration between EDI and usability techniques in context of IT and re-engineering. It means proper systematic integration of IT and re-engineering is the major tool for design and implementation of the integrated intelligent human engineering environment.

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