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An Integrated and Multivariate Model along with Designing Experiments Approach for Assessment of Micro- and Macro- Ergonomic Factors: The Case of a Gas Refinery

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Abstract

Background: The objectives of this paper are three folds. First, an integrated framework for designing and development of the integrated health, safety and environment (HSE) model is presented. Second, it is implemented and tested for a large gas refinery in Iran. Third, it is shown whether the total ergonomics model is superior to the conventional ergonomics approach. This study is among the first to examine total ergonomics components in a manufacturing system.

Methods: This study was conducted in Sarkhoon & Qeshm Gas refinery- Iran in 2006. To achieve the above objectives, an integrated approach based on total ergonomics factors was developed. Second, it is applied to the refinery and the advantages of total ergonomics approach are discussed. Third, the impacts of total ergonomics factors on local factors are examined through non-parametric statistical analysis.

Results: It was shown that total ergonomics model is much more beneficial than conventional approach. It should be noted that the traditional ergonomics methodology is not capable of locating the findings of total ergonomics model.

Conclusion: The distinguished aspect of this study is the employment of a total system approach based on integration of the conventional ergonomics factors with HSE factors.

Keywords: *Health, Safety, Environment, Ergonomics, Gas refinery*

Introduction

The main objective of this research was to present a comprehensive model in connection with designing and analyzing the macro and micro factors of ergonomics. Since, there are a lot of factors in ergonomic design of workplace both in micro and macro parts, it seems inevitable to consider a model which includes all related factors. Measurement methodology, analysis techniques, all factors and finally presentation of executive solutions are taken into consideration in designing this model. Because of using the statistical methods and multi analyses as strong tools of result analysis, this model is different from the previous ones. Furthermore questionnaire data, direct assessment of environmental factors, comparison of safety factors in refineries, comparison of ergonomic and macro ergonomic factors among work groups and shifts and anthropometry data are

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simultaneously used. Therefore, decision making and presenting effective solutions are easier and more precise.

Introduction of subdivisions and basic model

The ergonomic and macro ergonomic analysis model has a process approach to macro and micro ergonomic factors. The initial data is acquired by questionnaire, direct measurements and data sources, existing as four distinct inputs

Questionnaire subdivision

In this part, questions about quality of environmental indices (light, temperature, humidity, etc), musculoskeletal disorders and personal protective equipment are asked. These questionnaires should be designed according to the type of activity in investigated organizations. It is suggested to use Henrich and Nodric standard questionnaires, which are scientifically valid and standard and also widely used in many ergonomic studies (1-3).

These questionnaires must be adapted to all industrial, production and service departments; also, obtained data should be gathered in related groups, to be used in later analysis. Furthermore, accuracy of answers can be evaluated by setting common questions in questionnaire. Fig. 1 shows the first part of model's input. After acquiring data by parametric and non-parametric tests and plenty frequency diagrams, the obtained answers will be evaluated. In this part, a lot of variant data will be obtained as self reporting data. Due to personnel age, education and attitudes divergences, unreal factors may be added to the model. The final objective of this subdivision is to process and filtrate the obtained data. The questionnaires can be distributed either to all of the organization's personnel or a group of personnel who are randomly chosen. Obviously, applying the former will provide more data into the model and its results will be more precise. Taking the latter, the sample must contain all jobs; therefore each job should have one representative. When several people do the same job, they should be randomly chosen. Although the second way is less precise, it is less expensive and faster.

Environmental indices subdivision

Another subdivision of the new model was environmental indices data. In this section data would be summarized with a special form and compared to the available standards. This section's output might be consistent or non consistent with international standards. Considering environmental indices -in a way that personal attitudes such as lighting, temperature, humidity, etc are taken into account-is one of the significant point about this model (Fig. 2).

For indices which bring up no consistency, it is expected to receive more complaint about the unsuitable environmental factors. But it is essential to say that unsuitable environmental indices have sometimes indirect influences, for example insufficient light in workplace might cause accidents.

Safety subdivision

The third part of the model introduces the safety subdivision, which compare organizations with other similar organizations (peers) nationally or internationally (Fig. 3). A Multi analysis is also used in this section. Since in the previous sections ergonomic and macro ergonomic standards were taken into consideration and analyzed, in this section the organization is assessed in comparison with the other organizations. Due to work complexity, astronomical costs, increasing of final price and lack of required technology, reaching the mandatory standard level is impossible (4). Therefore real criteria can be for the indices, which are in disconformities with standard, organization assessment touchstone.

This approach is applied to the cases, which were ignored in previous studies or do not have a statistical basis. Using of Multi Analyses (PCA & Numerical Taxonomy) evaluates the organization's position among its peers and implicitly emphasizes on the improvement of factors, which merely have deviation with due attention to the world's reality (5). If we directly want to gather data and facts from

peers ,a great deal of money and time will be spent and it almost brings the economic justification of ergonomic' improvement structure under question. Therefore, in this section we have to make use of available data even though it is very limited. One of the most important domains, in which it is possible to compare the organization with other peers, is safety. Since in the most of organization such as refineries, power plants, and military sites, etc the first error is considered as last one, there is no margin of safety for safety issues; therefore it is inevitable to compare organization to the less risky ones.

Ergonomic and macro ergonomic factors' subdivision

The 4th subdivision of the model is to design the matrix of ergonomic and macro ergonomic indices between work shifts on one hand and work groups on the other hand (Fig. 4). The work groups include jobs, which are in each work shifts. Contrary to the 3rd subdivision, that compares organization to the peers, this section will compare the internal parts of organization according to the designed indices. One of the advantages of this subdivision is determining the priority of improvement process and execution of ergonomic for organization's parts or individuals, which are in unacceptable condition. (PCA & Numerical Taxonomy) is also used to rank work groups Multi Analyses.

In this main structure, outputs of A, B, C, D in addition to anthropometry's data is present together and provide executive solutions to improve the organization's work condition (Fig. 5). This executive recipe has two improvement aspects:

engineering improvement

managerial improvement Engineering improvement includes, redesigning or replacement of tools, equipment, work station, packings, etc (6). These improvements can be very effective, because they can omit or decrease the principal reasons concerning effective factors. The best time for applying engineering improvement is at the time of installations, processes designing or new design methods.

Managerial improvement contains changing working operations or organizational working methods (7). The improvement may not state the relevant reasons or other problems. Managerial improvement usually needs continuous management and employees' feedback with the intention of having confidence on policies and new operations' efficiency.

Whit respect to the fact that this model contains all ergonomic factors, no repetitive suggestion-which has later modified the ergonomic indices in the other way, will be given. Besides, by performing each suggestion, it defines all effects of executive recipes in other domains. Therefore the speed and cost of ergonomic interference performance will be decreased.

Having presented and performed executive solutions in work circumstances, the indices must be again evaluated after a specific period and this will continually go on. In this process, the internal organization's parts always improve independently in relation to each other; the organization's total procedure in comparison with the organization patterns will also be studied to get the organization's development relative rate.

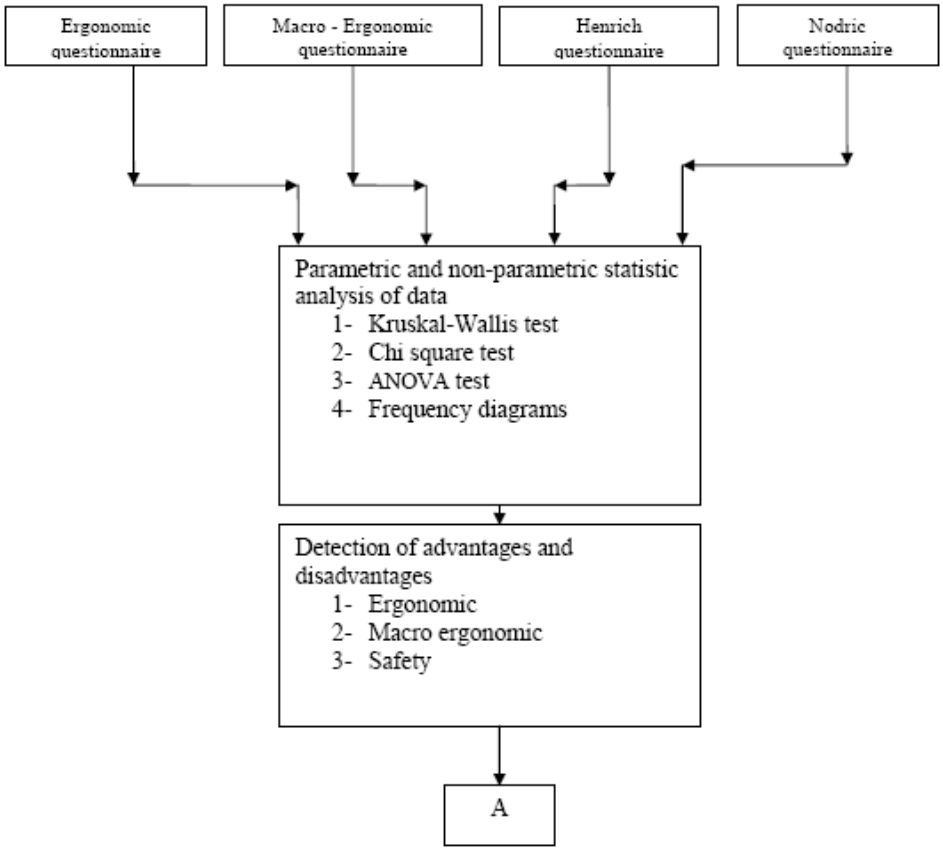

Fig. 1: Questionnaire subdivision of ergonomic and macro ergonomic factors' analysis

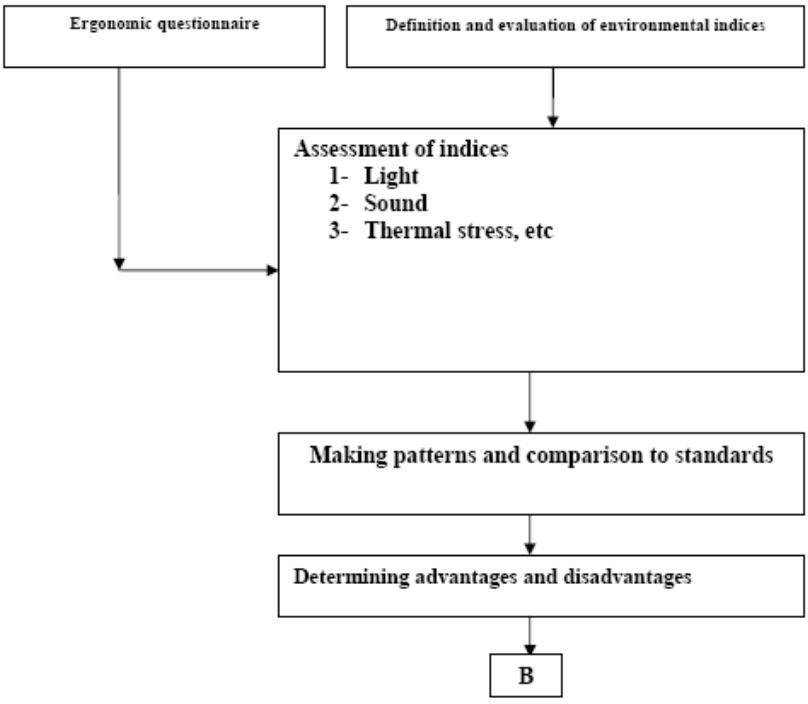

Fig. 2: Environmental subdivision of ergonomic and macro ergonomic factors' analysis model

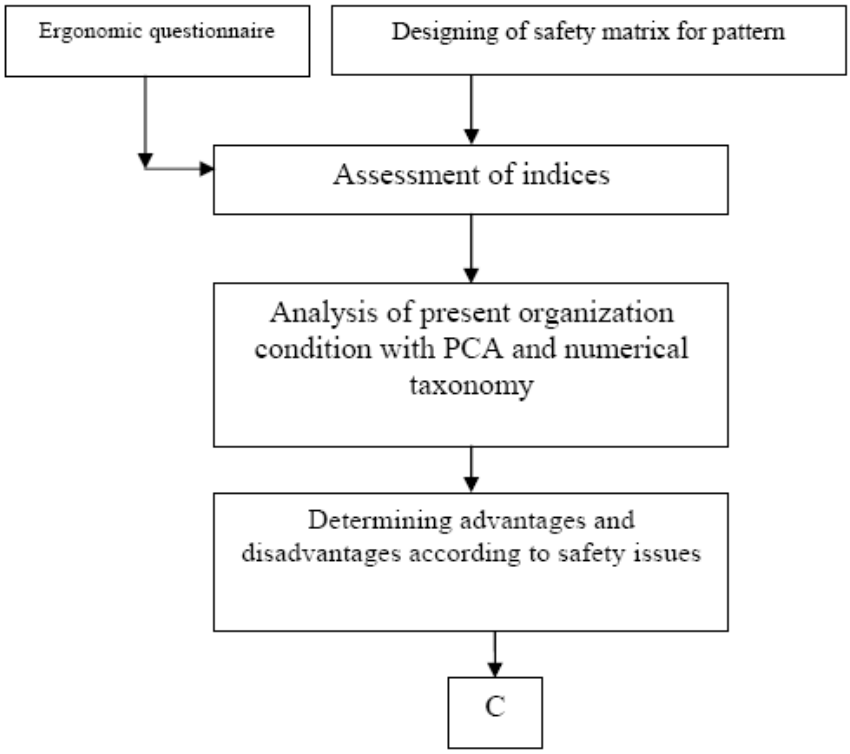

Fig.3: Safety subdivision of ergonomic and macro ergonomic factors' analysis model

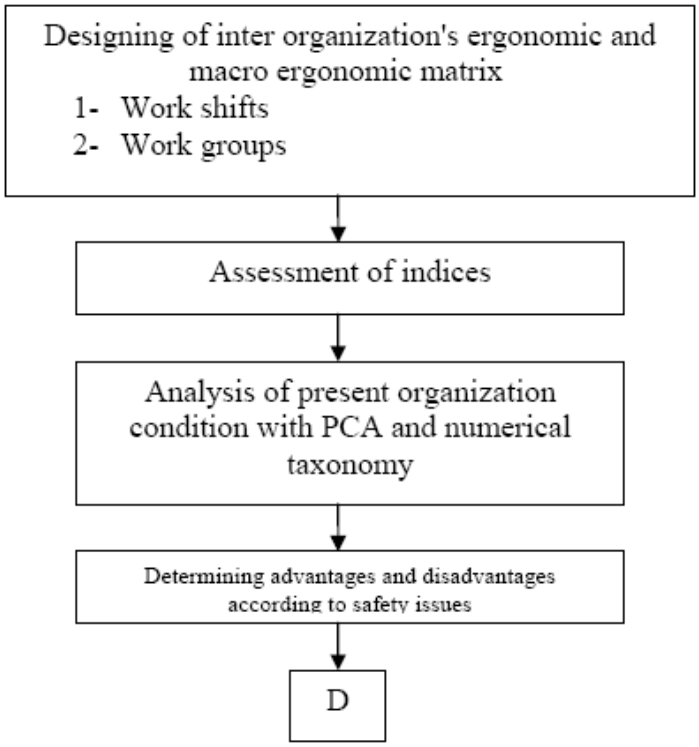

Fig. 4: Ergonomic and macro ergonomic subdivision of model

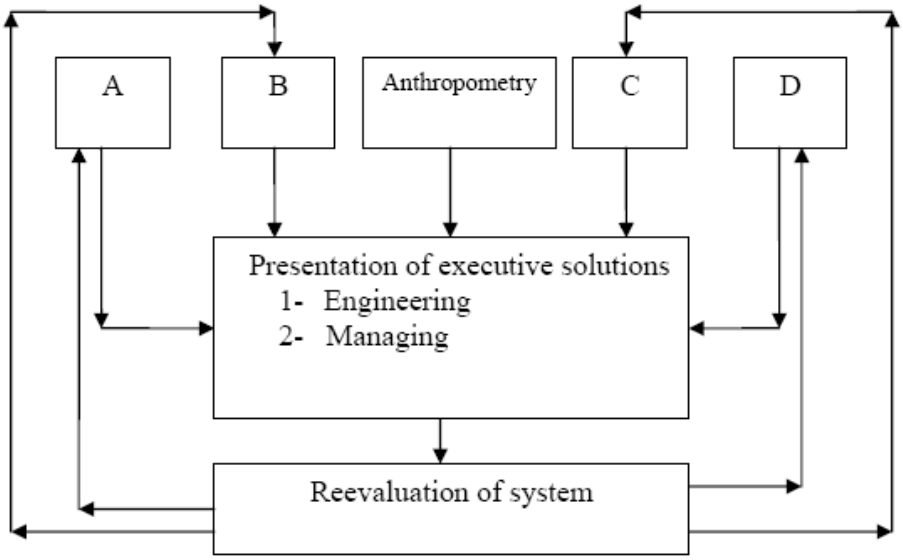

Fig. 5: Comprehensive model of ergonomic and macro ergonomic factors' analysis

Materials and Methods

This study was conducted in Sarkhoon & Qeshm Gas refinery- Iran in 2006. The integrated model was implemented in Sarkhoon & Qeshm Gas refinery. Sarkhoon & Qeshm Gas refinery was established to provide a part of country needs of energy, and consumption of natural gas as an environmental friendly energy, which is suitable for industrial and civil consumption in Hormuzgan and Kerman provinces. This refinery began to work in 1978 with producing refined natural gas and gas liquids in Sorkhoon and Gavarzin, which are located in Bandarabbas and Qeshm. This refinery has been taken into consideration as a case study for executing the integrated model. Due to a great deal of data in different parts, only a few aspects of subject have been considered.

The control room of Gheshm and Sorkhoon refinery has different panels, which are related to the special parts and all of the parts are coordinated by controllers and displayers. Generally, a refinery consists of the following units:

Separation

Sweetening

De moisten (adjustment of the dew point)

In order to apply the last subdivision's conceptual model in organizations, a system must be designed, which via model's subdivisions accesses and processes the introduced indices and factors by evaluation techniques. This system can be designed with two different approaches (8):

Traditional systems

These systems have been used since many years ago and one or several units of organization perform their task collaborate (9).

Suppose that organization X which has system analysis, ergonomic, safety and health organization's unit, want to apply the introduced model. According to this approach, the matrix of different organization's subdivisions involves on the basis of organization nature and their rolls in diverse model's subdivisions (Table 1).

At first, system analysis division gathers the required data. To do this, questionnaires are copied according to number of each subdivision questioned personnel and will be distributed among them by system analysis experts.

Table 1: Organization matrix

	Total results of model	Subdivision D	Subdivision C	Subdivision B	Subdivision A
Systems' analysis	√	√	√	√	√
Ergonomic	√	√			
Health & Safety	√		√	√	
Managers of other organization units	√				

Then, the completed questionnaires are collected, the responses of questionnaires as quantitative data are entered to a relative software by the system analysis division, and figures and diagrams are made by them to be used in later analysis. On this point the system analysis division can show a great deal of present organization's problems by designing the proper hypothesis tests and plenty frequency diagrams. After this process, the output of questionnaires subdivision is prepared to be entered into the other organization's units: ergonomic, safety and health, and each of these units in conjunction whit system analysis division in a parallel manner accomplish the related subdivisions according to the above matrix.

The ergonomic subdivision performs the process of D subdivision with the aid of system analysis division and detects the advantages and disadvantages of organization in ergonomic and macro ergonomic issues. Evaluating the work safety factors and anthropometric data are also done by safety and health experts. Finally, all data is entered into the main model, and a procedure will be planned according to each division's weakness and strength. After change exertion, aforesaid indices and factors are again evaluated and improvement quantity is studied and required changes are possibly exerted by systems, safety and health division's experts or executive managers in the case of macro ergonomic factors. Also, the safety and health subdivisions accomplish B&C subdivisions. The indices of environmental factors' subdivision can be measured by the safety and health experts of the organization. For the purpose of easier decision-making, data which are mostly: light, sound, thermal stress and environmental pollutants, are compared to the national and international values and weakness and strength points are mentioned. In this subdivision "the analysis of organization's present condition by PCA & Numerical Taxonomy" is only allocated to the system analysis organization's unit and is done by this unit. Finally with the subdivisions' fulfillment, the related results enter into the main model and executive solutions are detected with the cooperation of organization's units' common committee: systems analysis, ergonomic, safety and health and are communicated to the related unit's manager in order to accomplish. It is essential to mention that ,after gathering other required data and presentation of executive solutions in respect of organization's dynamic and changeable nature ,system re-evaluation & copying , delivering and summarization of questionnaires is inevitable. Due to expensive and long evaluation period and complexity of administrative affairs, it is very expensive, and these are counted as its disadvantages. Therefore, it is essential to use modern systems and new technologies. The disadvantages of traditional systems are:

High costs of execution
Long periods of factors evaluation
Exerting personal taste
Imprecise data and achieved results
Unreliability to data and gained results

The modern technology based systems

As it was mentioned in previous section, the application of the discussed model in organizations with traditional methods imposes

problems and costs (10). With appearance of modern technologies in present epoch such as information technologies and information systems, application of discussed general model can be executed and used with less costs and problems (11). In this section, the manner of model application in organization is given by using of information technologies and information systems. On the basis of web technology, firstly information system of questionnaire delivering and collecting web based is designed and set at the related organization. On this basis, the personnel of different organization's unit are connected to the system by username and password and the relative information system. Then, the gathered responses are saved in the information system basis. The responses are changed to quantitative data ,then A subdivision is performed in system analysis organization's unit by connecting information system to the statistical and mathematical software's such as Microsoft Excel, SPSS, SAS, etc and decision support systems and statistical-mathematical analysis. This process continues by connecting information system to the steps of B, C and D model subdivisions. Finally in order to compile executive solutions by data sources, organization tools and solutions are selected from tools and solutions, and are electrically communicated to the managers and organization units' personnel by web based information system. The electrical performance of model processes is very helpful to pursue the gained results and determine the proper decisions and actions, and these are the electrical performance advantages of model:

Fast and precise performance of subdivisions' and total models' different processes
Low price of model performance in organization
Ability of making and producing different information by complex and intelligent analyses

Results

As it was mentioned, the questionnaires are the most common way for collecting data and providing information for the model. In the first subdivision, the systematic solution of data analysis was studied. We can analyze data by the introduced indices and tools. We study all of the indices, which were in the questionnaire, by frequency diagrams. Then characteristics between shifts and work groups are shown by parametric and nonparametric statistic techniques. Finally, positive and negative points are explained.

As in the introduction of Gheshm and Sorkhoon refinery was mentioned, Sarkhoon & Qeshm gas refinery has 4 work shifts. Every shift has 8 h and shifts change periodically. Each group works continuously 3 weeks and rests 1 week. In Sarkhoon Gas refinery, each group filled the questionnaires separately; therefore, we can compare the shifts. In this part, we will exam, if there is a meaningful relation between work shifts and personnel's complaints about tiredness and work.

In Sarkhoon refinery, 60 people of the exploitation unit have been asked. Gheshm-Gavarzin refinery is physically and on the point of work shift different from Sarkhoon refinery. Gheshm-Gavarzin refinery has two 12 h work shifts and 4 persons work on average in each shift in the exploitation unit. Because the few number of the personnel, the work shifts aren't separated. The real reason of this problem is the few number of statistic population, which effects analysis results of the comparison between shifts. Each group works 2 weeks and rests for 2 weeks.

According to the personnel's answers, 67.7% of personnel are satisfied with the program of work shift. Nowadays, designing of the work shifts is one of the most important ergonomic discussions. Because the type of work shift has a great effect on the natural circle of the body such as circle of Circadian, Infra,

ultra dine. In the case of wrong design, it causes mentally and physically damaging effects.
As mentioned, the groups, which were introduced as work shifts, has been investigated in a special section. So, their answers cannot completely show the effect of shifts. In the following part, the tables of chi square test are shown separately according to the questionnaires (Table 2). Every question can show, if there is any relation between shifts and answers. Then, we can finally conclude by number of questions and cases, which show relation or lack of relation.
It is obvious, that the atmosphere frequently changes out of the control room at different work shift and this matter gives meaning to the above question. The most important changes are changes of relative moisture and radiation temperature. This matter inconveniences the personnel because of its quick and acute effects contrary to other long lasting effects.
According to the chi square test, it was concluded that shifts cannot make block. They have been chosen from a uniform population. Chi square test only considers the independence of shifts and it doesn't point the relation between the averages. Kruskal-Wallis test studies the equality of population several averages hypothesis. Kruskal-Wallis test is a non-parametric synonym for one-factor analysis of variance. The test uses the zero hypotheses of same distributive populations against the hypothesis, which expresses that some populations produce bigger observations. The method has been designed in a manner that averages' difference is sensitive to the test. It is better to take the Kruskal-Wallis test into consideration as the test of equality of different populations' averages. The results of test can prove that the shifts don't make block (Table 3).
If we accept the hypothesis that our data is normal, we can test the above question on the basis of one-factor analysis of variance. The results of the test have been presented for 2 questions of the ergonomic questionnaire (Table 4).

Analysis of environmental indices

Here, assessment of noise is evaluated as one of the environmental indices. In the control room of Gheshm and Sorkhoon gas refinery and Gourzin's installations, noise measurement by level meter of model $\frac{SL-4001}{Wtron}$ and Quest calibrator is done to provide a district map and finally compare to the permissible boundaries of noise (Fig. 6). The noise map of the refinery's control room is as follow:
Safety limit (SPL<65dBA) with S code
Precaution limit (65<SPL<85dBL) with C code
Danger limit (SPL>85dBL) with D code

	A	B	C	D	E	F
1	S	S	S	S	S	S
2	S	S	S	S	S	S
3	S	S	S	S		
4	S	S	S	S		

Fig. 6: The noise map of refinery control room

As observed, according to the national standards of Iran about permissible boundary of noise for 8 h, noise is not harmful on the point of injuries caused by noise. Nevertheless, according to the filled questionnaires, 43.3% of persons inside the control room and 81.7% of persons out of the control room know the noise harmful.

Analysis of the safety indices

As in the 3rd subdivision of the comprehensive model of ergonomic and macro ergonomic factors analysis was explained, the aim

of this part of model is to compare Sarkhoon & Qeshm Gas refinery to other gas refineries in regard to the introduced factors (Table 5). The most important Sarkhoon & Qeshm Gas refinery's indices, which are at data bank, are related to the safety indices. Because of the cost and time limitations, we content with the data of this part. Although in this manner, we compare only one special aspect of refineries to each other, other aspects can be gradually studied with the information expansion.

Indices, which are accessible, are:

Number of events

Wasted days according to the above events

Fire accident

This information is gathered in 1380 and 1381.

Refineries, which are chosen as the comparison pattern, are:

Asalooyeh gas refinery

Fadjr gas refinery

Bidboland gas refinery

Khangiran gas refinery

In addition to the comparison between refineries, gas refining companies as a set of gas national company have been compared to three sub-set companies in regard to indices (Table 6). The below comparative table shows indices and frequency rate of each index. Like the previous case, theses indices are related to 1380 and 1381.

Sarkhoon & Qeshm refinery had gained the second place among four other refineries during 1380 and 1381 by both methods of PCA and Numerical Taxonomy, which shows the high place of this refinery in the vie of national safety indices.

Table 2: Chi square test for ergonomic questionnaire

Question	Observed significance level	Acceptation or rejection of zero hypothesis at significance level of 0.05
Do you breathe out of your control room comfortably?	0.04	unaccepted

Table 3: Kruskal-Wallis test for ergonomic questionnaire

Question No.	Statistics test	Observed significance level	Acceptation or rejection of zero hypothesis at significance level of
Do you feel pain or fatigue in low back during work days?	8.638	0.035	unaccepted
Do you breathe out of your control room comfortably?	16.355	0.001	unaccepted

Table 4: one-factor ANOVA for ergonomic questionnaire

Question No.	Observed significance level	Acceptation or rejection of zero hypothesis at significance level of 0.05
Do you feel pain or fatigue in low back during work days?	0.033	unaccepted
Do you breathe out of your control room comfortably?	0.001	unaccepted

Table 5: Some of the safety indices of gas refinery

Company name	indices		
	Wasted days	**Disabling injuries**	**Partial injuries**
Gas delivering companies	12596	45	11
Gas pipeline affairs	475	28	9
Gas refining companies	6412	3	16
Head offices and stores	118	6	0

Table 6: ranking the refineries on the basis of safety indices

Company name	PCA	Taxonomy
Asalooyeh gas refinery	1	1
Fadjr gas refinery	4	4
Bidboland gas refinery	3	3
Khangiran gas refinery	5	5
Sarkhoon & Qeshm refinery	2	2

Discussion

The comparison of internal companies of gas national company shows a great difference by PCA method and Numerical Taxonomy (12). The PCA method is generally more efficient than other methods and it is taken into consideration as the basis for this section. Treatment company and gas works stand respectively in the last place and the last place but one. These results are expected due to the hazardous work type of these companies in comparison with central administration, warehouses and pipeline affairs. However, on account of these results, it is necessary to consider and lead the gas national company's investment to promote safety indices grade in refineries all over the country, and in regard to refineries' ranking results, it is vitally significant to lay stress on Khangiran, Fadjr and Bideboland refineries.

In the 4th subdivision of the comprehensive model, the ergonomic and macro- ergonomic matrix was introduced. This subdivision ranks work shifts and some of equal indices. As it was explained in the questionnaire analysis, work shifts haven't usually meaningful difference in the light of statistic, and its reason was explained in detail. But this time even though few differences were studied with a view to PCA and Numerical Taxonomy. Below, work shifts and work groups are stated as the under study sample (DMU), so evaluating indices are. Pains and some of macro-ergonomic indices are studied as samples.

For the pain's matrix scoring is on the basis of following points, which are considered for each answer. Meanwhile, Gourzin group score is multiply by 15.12 on account of difference in the statistic population in order to standardize. Following ranking is obtained for work shifts in connection with variable indices, on the basis of the main component analysis and Numerical Taxonomy.

As it is shown, morning and afternoon work shifts stand respectively in the lowest places among shifts concerning pains indices, and this is a significant factor for designing and compiling work shifts program of Govrzin and Sorkhoon gas refinery. It is essential to state that Gourzin has the best rank in these lines.

For macro ergonomic indices ,Govrzin work shift stands again in the first place, due to the smallness of the refinery and the simplicity of organization's structure (although ,it is one part of Sorkhoon refinery) simple relation between managers and operators ,this work shift has the highest point. Though in the case of the most critical work shifts ,two

work shifts are different in the light of vocation satisfaction ,it is clear that one of the daily work shifts (morning or afternoon) suffers from vocation dissatisfaction ,and because of managers presence in these work shifts in the refinery, it is vague.
This problem should be realized and studied, and after exerting the executive solutions, these indices should be again evaluated. The distinguished aspect of this study is the employment of a total system approach based on integration of the conventional ergonomics factors with HSE factors.

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The authors declare that they have no conflict of interests.

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