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SPIRAL DYNAMICS OPTIMIZATION-BASED ALGORITHM FOR HUMAN HEALTH IMPROVEMENT

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Abstract

A study using the spiral dynamics optimization algorithm to evaluate the human health effects of using computer-aided workstations on employees. We collected data for human health risk on employees at their workplaces, analyzed the data and proposed corrective measures applying our methodology. It includes a checklist with nine human health dimensions: work organization, displays, input devices, furniture, work space, environment, software, health hazards and satisfaction. By the checklist, data on human health risk are collected. For the calculation of a human health HS risk index a neural-swarm spiral dynamics search (NSSS) optimization-based algorithm has been employed. Based on the human health risk index, I_{HS} *four groups of human health risk severity are determined: low, moderate, high and extreme HS risk. By this index HS problems are allocated and corrective measures can be applied. This approach is illustrated and validated by a case study. An important advantage of the approach is its easy use and HS index methodology speedily pointing out individual employee specific HS risk.*

Keywords*: Human health, Risk, Employee, Checklist, Neuro-Swarm, Spiral dynamics Optimization, Algorithm.*

1. INTRODUCTION

There is little empirical evidence of the influence of design and computer-aided workstation aesthetics on employees and the distance between human health and safety (HS), psychological safety, and the architectural design process can be considerable [1]. HS, an integral part of computer-aided workstation design, is related to occupational ergonomics and job satisfaction [2]. Perceived environmental attributes, neighbourhood and computer-aided workstation design characteristics are associated with well-being and job satisfaction [3]. In addition to HS and work organisation an aesthetically supportive and harmonious physical environment may influence employees´ views of their computer-aided workstations and their own health [4]. According to [5] the work chair's design, aesthetics and comfort might be as important as its HS advantages.

Aesthetic and HS, with or without psychosocial effects can be perceived to overlap [6]. In the clinical praxis HS problems are often focused on. The question arises if the comprehension of aesthetic needs only reflects the HS needs. To differentiate between those two is important in prevention of computer-aided workstation problems. Long hours of computer use are associated with HS problems [7]. It is shown by [8] that prolonged use of computers, while performing work activities in poor HS environments is one major contributing factor to increase causes of neck pain. Studies reported less discomfort when HS were improved or HS information was given [3]. The computer-aided workstation HS-related risk include hours of computer use, sustained awkward head and arm postures, poor lighting conditions, poor visual correction, and work organizational safety [9]. These risks cause problems such as, musculoskeletal disorders (e.g. sustained pain in the neck and upper extremities and regional disorders, such as wrist tendonitis, epicondylitis and trapezius muscle strain), eye discomfort and visual fatigue; and mental stress which are identified as some of the principal risks of computer task-based work. [10]

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If working tasks are carried out in inadequate conditions, workers with functional limitations may, over time, risk developing further disabilities. HS complaints have also been found to be associated with psychosocial health and safety at work [7]. There are a lot of approaches for employee HS risk assessment of computer-aided office computer-aided workstations [11], but for big sized companies with a lot of office computer-aided workstations it is difficult to study all of the employees. There is a need of an approach for systematic HS employee risk assessment of whole companies and identification of employees with extreme HS risk for immediate attention.

2. HS RISK ASSESSMENT METHOD

The integration of HS into computer-aided workplaces provides an organisational framework to ensure the systematic identification and analysis of relevant HS issues and application of appropriate tools, methods and measures to address such issues [12]. When applied and implemented, these principles will help address people and systems challenges in computer-aided engineering to achieve appropriate and identifiable benefits. A methodology for HS risk assessment and redesign of computer-aided workstations is developed (cf. Figure 1). It includes a checklist [13] and a model (cf. Figure 2) for human health and safety (HS) risk assessment. At steps 1 and 2 the checklist dimensions and items are determined. At step 3 data is gathered by interviews, observations and measurements. At step 4, HS risk is assessed and a quantitative HS risk index is determined using the data gathered. Based on risk assessment relevant corrective measures for reducing HS risk (step 5) are proposed and implemented (step 6).

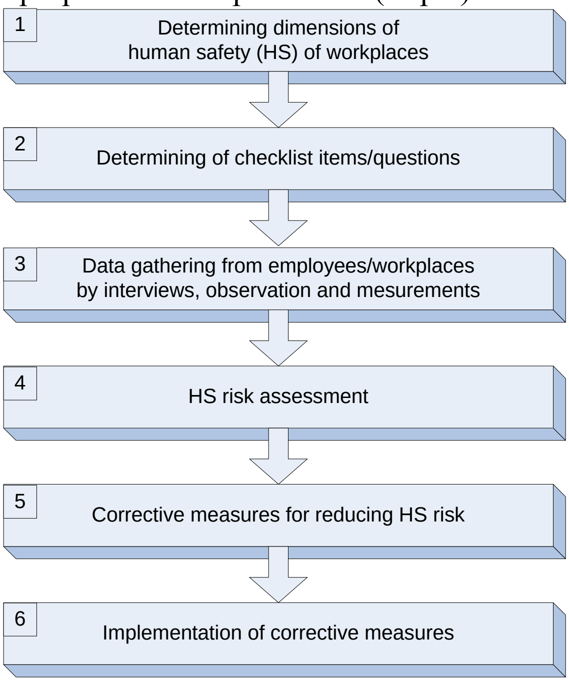

Figure 1: Methodology steps for HS risk assessment and redesign of computer-aided workstations.

HS risk assessment aims at identifying HS-related weaknesses of computer-aided workstations. The entire construct of HS can be represented by a single dependent variable: HS risk index. It is a measure of how closely the features of a computer-aided workstation match generally accepted HS guidelines. For HS risk assessment a HS index is calculated (cf. Figure 2). The HS index, I_{HS} integrates 9 HS dimensions measured by 50 checklist questions. This index is used by the algorithm for HS risk assessment and for the redesign of computer-aided workstations (cf. Figure 2).

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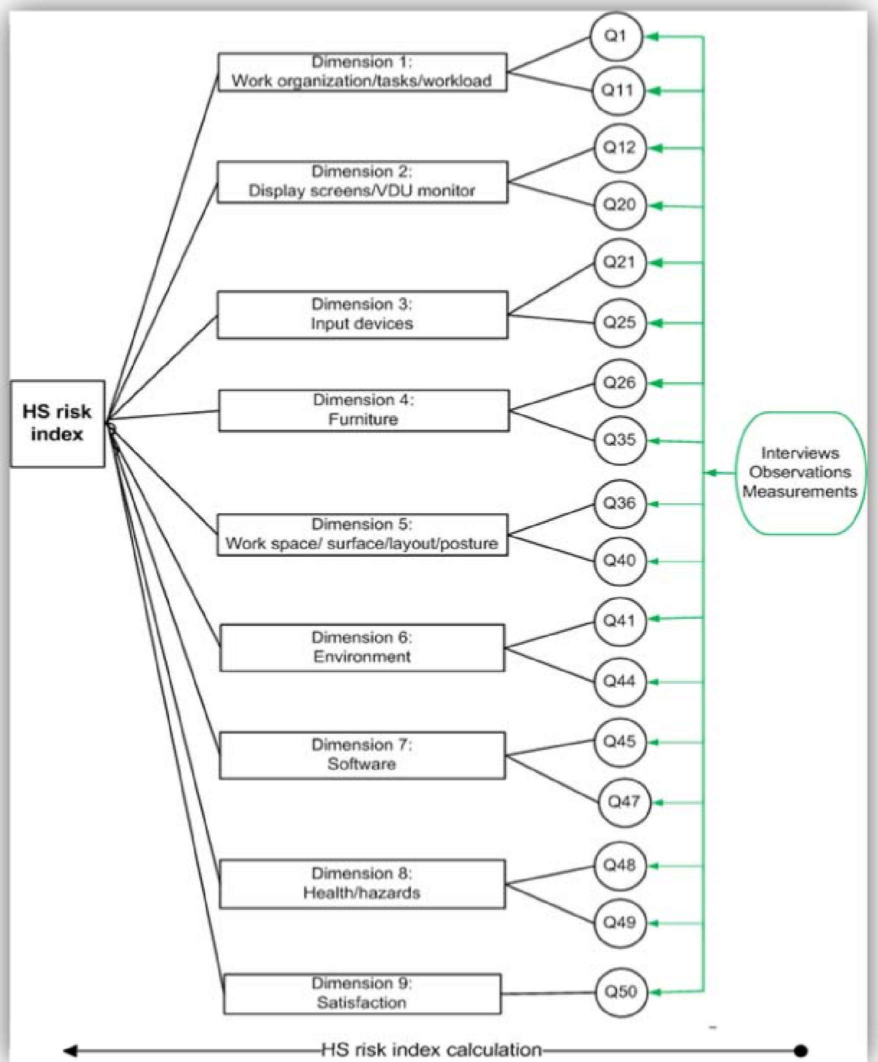

Figure 2: Computer-aided computer-aided workstations HS risk assessment model.

The severity ratings of HS risks on computer-aided workstations are defined in Table 2. The computer-aided workstation ratings for HS risk index, dimensions and items are determined by using the NSSS algorithm. HS index I_{HS} is determined using employee responses, observations and measurements. Checklist dimensions/items indicating high (yellow) and extreme (red) HS risk guide the proposal for corrective measures for reducing the HS risk at specific computer-aided workstations.

Table 2: Severity rating for HS risk

Rating	Index range [1,5]	Index range [0,100]	Color
Low	[1,2]	[0,25]	Dark Green
Moderate	(2, 3]	(25,50]	Light Green
High	(3, 4]	(50,75]	Yellow
Extreme	(4,5]	(75,100]	Red

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2.1 Neuro-swarm-based HS risk assessment model

At step 4 a HS employee risk assessment of company office computer-aided workstations by departments is carried out. HS risk assessment aims at identifying HS-related problems for employees at their computer-aided workstations. The entire construct of employee computer-aided workstation HS risk assessment can be represented by a single quantitative dependent variable: HS risk index. It is a measure of how closely the features of a computer-aided workstation match employee HS guidelines. For HS risk assessment an HS risk index is determined.

For calculation of this risk index, a spiral dynamics search-based neuro-swarm optimization algorithm is proposed. It aggregates nine computer-aided workstation ergonomic dimensions measured by 49 checklist items/questions. The checklist structure is represented as an artificial neural network. By a modification of the neuro-swarm spiral dynamics search algorithm neural network weights are trained using as a target the employee HS to computer-aided workstation satisfaction (checklist dimension D9). Using these weights the responses of computer-aided workstation users/employees are aggregated to individual risk indices. Based on risk indices, extreme employee HS risk can be found from a computer-aided workstation HS viewpoint.

2.1.1 Artificial neural network (ANN)

An ANN consists of a set of processing elements (cf. Figure 3), also known as neurons or nodes, which are interconnected with each other. Output of the ith neuron can be described by:

$$y_i = f_i\left(\sum_{j=1}^{n} w_{ij} x_j + \theta_i\right) \quad (1)$$

where y_i is the output of the node, x_j is the jth input to the node, w_{ij} is the connection weight between the node and input x_j, θ_i is the threshold (or bias) of the node, and f_i is the node transfer function.

The adaptation can be carried out by minimizing (optimizing) the network error function ε given by equation:

$$\varepsilon(w(i)) = \frac{1}{n}\sum_{j=1}^{n}\left(t_j - o_j\right)^2 \quad (2)$$

where ε(w(i)) is the error at the ith training iteration; w(i) - the weights in the connections at the ith iteration; t_j- the desired output/target (D8-user-satisfaction); o_j - the actual value of the output node; n - the number of patterns (data gathered by checklist from computer-aided workstation users). The optimization goal is to minimize the objective function by optimizing the network weights w (i).

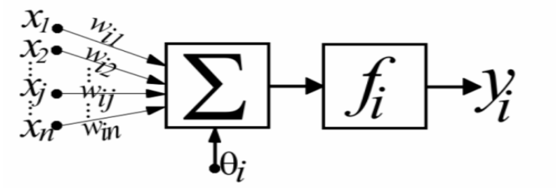

Figure 3: Processing unit of an ANN (neuron).

2.1.2 Spiral Dynamics Optimization (SDO)

Search principles of metaheuristics are often inspired from natural phenomena such as biological evolution, bird flocking or fish schooling. Motivation of these developments came from anticipations that mechanisms of the natural phenomena would contribute to solutions for optimization problems. These methods are well known as convenient and powerful methods for problems today. [15] proposed a new two-dimensional metaheuristics inspired from spiral phenomena existing in nature, which is called spiral optimization (cf. Figure 4). The focused spiral phenomena are approximated to logarithmic spirals which are frequently appeared in nature, such as a whirling current, a low pressure, a nautilus shell, arms of spiral galaxies and so on. It was shown that a common feature of logarithmic spirals that can realize an effective search strategy in

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$$x^{k+1} = A_{spiral}\, x^k - (A_{spiral} - I_2)\, x^*,\ x \in R^2 \qquad (3)$$

The interested reader is referred to [15] for more information.

2.1.3 Neural-Swarm Spiral dynamics Search (NSSS) algorithm

In the NSSS algorithm, the major idea underlying this synthesis is to interpret the weight matrices of the ANNs as solutions, weights, and to change the weights by means of an iterative spiral finding a better one. The regular dimensionality used by the dynamic spiral optimization algorithm was increased to nine (number of dimensions in the HS problem domain). Also exploitation of the algorithm was encouraged by the usage of sub-spirals within the neural network structure. This method ensured faster convergence of the neural algorithm. The maximum iteration number T_i (cf. Figure 4) was set to 2000. The parameters α, β and A (cf. Figure 4) for the algorithm after being randomly initialized were dynamically adjusted with initial automatic adjustments being made during runtime. The error, ε produced by the ANNs using these weights is the fitness measure which guides selection. This leads to a following weights training cycle (Yao, 1993) in order to get the best weights. The output is the HS risk index as indicated in Figure 2 and evaluated with a combination of concepts as discussed including the algorithm shown in Figure 4. The actual decision criterion made by the algorithm was reduced to four decision variables, low, moderate, high and extreme risk as shown in Figure 5.

Step 0 [Preparation]
Select the number of search points $m > 2$, the parameters α_i, β_i of $A_{spiral i}$ such that $\sqrt{\alpha_i^2 + \beta_i^2} < 1$, $\beta_i \neq 0$, $i = 1, 2, \ldots, m$, and the maximum iteration number T_{max}. Set $k = 0$.

Step 1 [Initialization]
Set the initial points $x_i^0 \in \mathbb{R}^2 (i = 1, 2, \ldots, m)$ in the feasibility region at random and the center x^* as
$x^* = x_{i_g}^0$, $i_g = \arg\min_i f(x_i^0)$.

Step 2 [Updating x_i]
$x_i^{k+1} = A_{spiral i} x_i^k - (A_{spiral i} - I_2) x^*$, $i = 1, 2, \ldots, m$.

Step 3 [Updating x^*]
$x^* = x_{i_g}^{k+1}$, $i_g = \arg\min_i f(x_i^{k+1})$

Step 4 [Checking Termination Criterion]
If $k = T_{max}$ then terminate. Otherwise, set $k = k + 1$, and return to Step 2.

Figure 4: Algorithm of spiral dynamics optimization

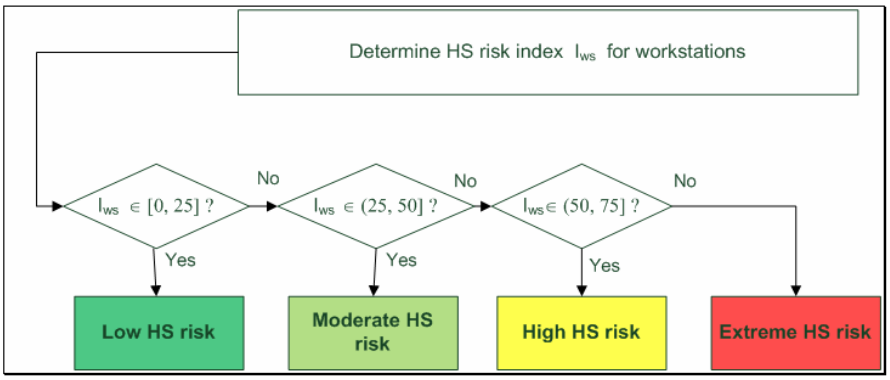

Figure 5: HS risk index determination.

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3. CASE STUDY

Within 3 months we observed the workstations in two buildings, a total of 91 workstations and interviewed 91 employees working on these workstations. The pre-test of the checklist with employees showed that the time for answering the questions took 59-60 minutes. Unclear questions were found and improved. On Table 3 are presented the summarized some results of this study. With red color are presented checklist dimensions with extreme HS risk for which relevant corrective measures for reducing HS risk to acceptable level should be proposed.

Table 3: Workstations studied and their aggregated values for different checklist dimensions and total risk assessments

Nr	Dept	Dept #	WP#	Name	height	D1	D2	D3	D4	D5	D6	D7	D8	D9	risk
1		1			168	29	53	61	49	16	0	63	90	20	67
2		1			173	15	51	66	16	11	25	6	0	10	16
3		1			168	5	7	58	30	0	19	0	0	5	10
4		1			165	5	30	64	94	100	34	0	100	35	80
5		2			163	36	65	54	58	34	48	25	100	20	76
6		3			168	46	17	70	70	70	54	31	0	60	26
7		3			170	63	26	50	61	11	31	69	90	30	66
8		4			176	65	22	93	17	23	18	25	90	10	61
9		4			173	43	51	97	49	15	0	44	68	10	58
10		4			165	10	19	58	43	23	0	0	45	11	37

For illustration and validation of this study data was collected and analysed using the NSSS algorithm. The algorithm was implemented in MATLAB. Each solution x_i, i = {1, 2, ..., n}, and d = 9 represents the checklist dimensions (network weights) w_i or solutions, that is, the number of optimization parameters. Figure 6 shows the run of the NSSS algorithm displaying the RMSE training error. The initial convergence was at first to local minima but the algorithm was able to escape these locally optimal points and converge towards the global optimum. This was achieved after roughly 1320 iterations.

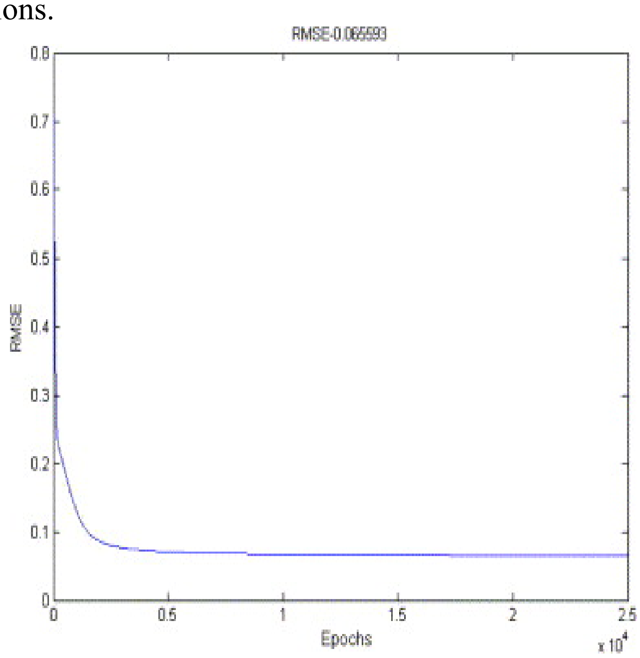

Figure 6: NSSS RMSE error per epoch.

At the beginning of each employee record a bar chart summarizing workstation related health risks for 8 dimensions is given, together with the employee dissatisfaction and total health risk is (cf. Figure 7). Further for each workstation the study results are summarized in a table. Relevant corrective measures for reducing the HS risk are proposed. In the first column are given the numbers of questions discussed. In the third column is given the HS risk in the scale [0,100] for the checklist item with highest risk value in this group.

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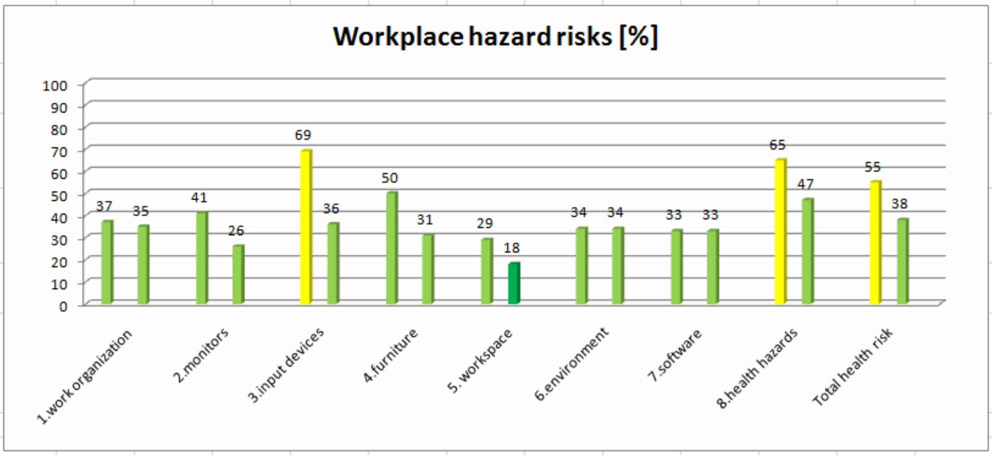

Figure 7: Sample bar chart visualizing workstation related HS risks.

For each workplace HS risks before and after implementation for 8 dimensions (cf. Figure 8), and recall that the total risk and the decrease of risk after implementation are presented in Table 3. With red color are indicated extreme risks according to Table 1. For each employee the total risk is indicated using the colors from Table 2. For example the total risk for one workplace: from 67% (yellow) after implementation of low-cost corrective measures was reduced to 50% (light green), i.e. 27% relative risk reduction. The average relative HS risk reduction after implementation of low-cost corrective measures for all 40 workplaces is 32%. For most of the workplaces where HS risk is more than 25% (yellow and light green) implementation of further corrective measures are needed. Because of high workplace rotation and employee turnover there is a need of a long-term solution for each type of workplace independent of which employee is working on it.

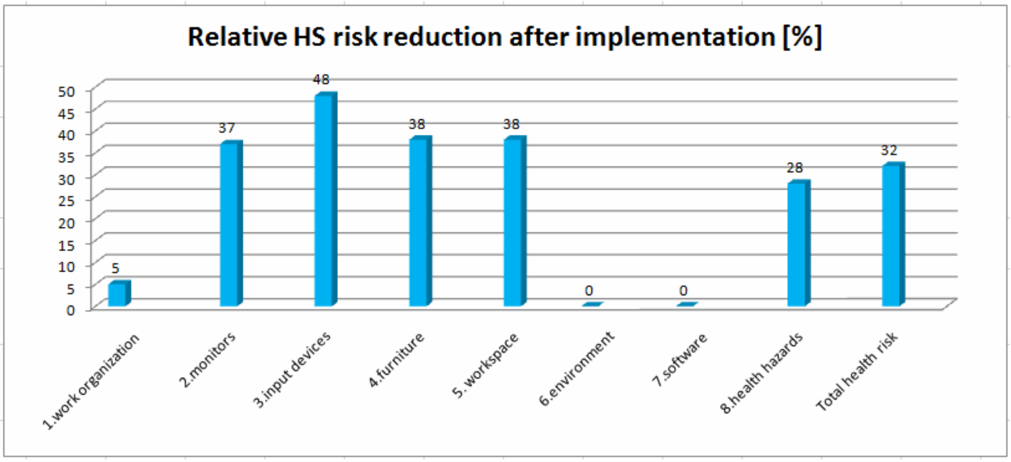

Figure 8: Relative decrease of HS risk after implementation of corrective measures

4. CONCLUSIONS

A study for human HS (health and safety) employee indicators in a company is developed. Its checklist contains 50 items. A Neural-Swarm Spiral dynamics Search algorithm trains employee checklist dimensions and questions weights. The calculation of individual employee HS risk indices I_{HSs} based of these weights enables the classification of employees into four categories: low, medium, high and extreme HS risk levels. Employees with extreme and high indices are immediately attended to by the purchasing of/ re-arrangement of equipment at their workstation. Further low-cost measures for reducing their HS risk are recommended.

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The advantages of evaluation approach are: (1) significantly reduces the time and errors for HS evaluation; (2) applies modern mathematical model the neuro-swarm spiral dynamics search algorithm for quantitative HS risk assessment; (3) reduces the load on the evaluating team when dealing with large companies having many employees by screening out employees with low and moderate I_{HS} risk; (4) makes companies precisely formulate their strategies to redesign and improve their departmental workstations for employees; (5) higher employee satisfaction resulting in increased company profit.

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