ORIENTAL JOURNAL OF
COMPUTER SCIENCE & TECHNOLOGY
An International Open Free Access, Peer Reviewed Research Journal
Published By: **Oriental Scientific Publishing Co., India.**
www.computerscijournal.org

ISSN: 0974-6471
December 2012,
Vol. 5, No. (2):
Pgs. 303-313

Intelligent Fuzzy Analytic Hierarchy Processing Decision Support System - An aid in Expert Analysis of Shoulder and Neck Pain Occupational Risk Factors

T. PADMA and S. P. SHANTHARAJAH

Department of Computer Applications, Sona College of Technology, Salem - 636 005, India.

(Received: October 13, 2012; Accepted: October 30, 2012)

ABSTRACT

This research develops a fuzzy decision support system (FDSS) to evaluate and prioritize the relative importance of the imprecise, uncertain and vague nature of risk factors causing shoulder and neck pain (SNP), an important musculoskeletal disorder and most ubiquitous pain complaint in an occupational environment. The objective involves derivation of mechanical-, physical- and psychosocial-related risk categories using knowledge acquisition implemented by identifying the risk factors through literature analysis, conventional and concept mapping interviews with expert neurologist, orthopaedict, psychologist and physiotherapist. Fuzzy analytic hierarchy process (FAHP) is applied as an evaluation tool to measure the significance of the risk factors. The results indicate that the proposed system supplements SNP diagnosis experts with more precise key decision support information.

Key words: Fuzzy analytic hierarchy process, Decision support system, Musculoskeletal disorder, Domain expert, Risk factors.

INTRODUCTION

A musculoskeletal disorder refers to conditions that involve the nerves, muscles and supporting structures of the body. The association between long term and short term exposure to different work environment plays a vital role in the incidence of musculoskeletal disorders. Now the increase in use of visual display terminal (VDT) work, work above shoulder level, inclusive opportunities to acquire new knowledge and an increased amount of seated work have become common issues in any work environment. These leads to an important musculoskeletal disorder called SNP[1]. SNP is the most common disease in the population acquired from an occupational environment. Inability to work, loss of productivity, occupational illness and inability to carry out household activities are the sufferings due to SNP and can be a considerable burden to the patient as well as to society[2, 3]. SNP remains one of the primary occupational hazard classifications in the world with associated costs in the hundreds of billions of dollars per year[4]. SNP have a strong, negative effect on quality of life, and cause considerable personal suffering. In many countries every year worker's SNP problems lead to time away from jobs and reduce the nation's economic productivity. Risk factors that have been associated with occupational related SNP are numerous. These risk factors may be work-, and psychological-related or individual aspects. These risk factors are very likely not independent and some researchers have attempted to develop theories that describe their interactions[5, 6]. SNP occurs due to individual or combination of risk factors related to the fields such as orthopaedic, neurology and psychology etc. and it involves diagnosis of medical practitioners from all those fields. There is a disparity in the occurrence of SNP for workers with similar backgrounds and work activities. The risk factors sourcing SNP are uncertain and vague among the people in the same working environment. Hence it is difficult to find the set of risk factors and the level of significance of the risk factors that creates SNP.

This will make the diagnosis process as complicated as possible. Identifying the risk factors causing SNP from the single or combination of many of the specialized medical fields has become a tedious procedure. Now a day practitioners are interested in identifying accurate methods for evaluating the risk factors of SNP in an occupational setup. It is highly important to acquire knowledge about the management of SNP and how musculoskeletal health can be maintained. Consequently SNP is one of the most important problems threatening the occupational society; it is essential to find a system that is capable of handling the knowledge of domain experts from all of these medical fields causing SNP and evaluate the risk level of SNP. Such an outsized problem faced by a physician and medical community motivates this research. It is an effort to develop a FDSS that can be used by medical practitioners to review the likelihood of degree of severity of the SNP risk level caused by various risk factors in an occupational environment.

Statement of the problem

SNP is multi-facet. Several studies illustrate the work related exposures for SNP are categorized into mechanical-, physical- and psychosocial-related factors[7, 8, 9, 10]. Many workers are simultaneously exposed to several, especially combination of risk factors creating SNP. A set of risk factors generating SNP in each category is diagnosed by an individual medical expert. Different categories simultaneously grounds for SNP, moreover the risk factors vary among individuals though they have similar occupational backgrounds. Therefore diagnoses by medical experts in different categories are required. But there is no such system in practice that gives a common diagnosis including all the experts due to one or other reason. That is, there is no one universal structure that entirely characterizes qualitatively or quantitatively the status of the occupational risk associated with SNP of person at any point of time. This is due to the great dimensionality of the parameters involved. On the other hand, the available data is featured with imprecision, and subjective, which render very tedious and problematical task to assess the SNP risk level through single index. This research is an attempt to formulate such single comprehensive measure for the set of risk factors and the level of risks associated with SNP. FAHP model has been used to determine relative measures of significance and priority weights for different risk categories of SNP. FAHP is effective in obtaining domain knowledge from numerous experts and representing them in knowledge guided index. The intent is that this model will be applied eventually in an occupational setting and the model development is to focus on a method that provides a usable interface to medical practitioners during diagnosis phase.

Fuzzy analytic hierarchy processing (FAHP) method

Numerous multi criteria decision making (MCDM) techniques had been developed to date. One of the most common MCDM techniques is analytic hierarchy process (AHP)[11-15]. Saaty defines AHP as a decision method that decomposes a complex multi-criteria decision problem into a hierarchy. The use of AHP will keep increasing because of the AHP's advantages such as ease of use, great flexibility, and wide applicability[11]. AHP will not provide solution when uncertainty in data of problems is observed[16]. To address such uncertainties[17] proposed and used Fuzzy Set Theory (FST). FST emphasized on humans' thoughts, inference, and cognitions of surroundings. In FST the concept of membership function is used to describe the solutions to uncertain and vague problems. FST can be used as a modeling tool for uncertain and complex systems that are difficult to accurately define. Thus FST is introduced into the pair-wise comparison to deal with the deficiency in the traditional AHP. This is referred to as FAHP.

The linguistic assessment of human feelings and judgments are vague and it is not reasonable to represent it in terms of precise numbers. Giving interval judgments is more confident for decision makers than fixed value judgments. So, triangular fuzzy numbers (TFN) are used to decide the priority of one decision variable over other in FAHP[18]. FAHP is an efficient tool to handle the fuzziness of the data involved in deciding the preferences of different decision variables. The comparisons produced by the expert are represented in the form of TFN to construct fuzzy pair-wise comparison matrices[19]. By using the extent analysis method, the synthetic extent value of the pair-wise comparison is calculated. This approach decides and normalizes the weight vectors and determines normalized weight vectors. As a result, based on the different weights of criteria and attributes the final priority weights of the alternative risk factors are decided that will provide information to the medical practitioners the priority of risk factors that is useful for diagnosis.

FAHP applications in literature

Numerous authors have presented different ranking methods to rank alternatives under fuzzy environment during the last two decades[20]. Fuzzy logic had used to deal with vagueness of human thought and FAHP to make a selection the most suitable dyad supplier/ purchased item[20, 21]. FAHP method had proposed to evaluate e-logistics-based strategic alliance partners[8]. Two-phase model based on artificial neural networks and FAHP to select a third-party reverse logistics provider had proposed by[22]. FAHP had proposed for management maintenance processes where only linguistic information was available[23]. For selecting the suitable bridge construction method FAHP is used by[24]. FAHP is used for market positioning and developing strategy in order to improve service quality in department stores[25]. FAHP for measuring the non-profit organizational performance had proposed by[26]. FAHP had applied to represent subjective expert judgments in government-sponsored R&D project selection by[27]. FAHP had constructed to evaluate performance of IT department in the manufacturing industry in Taiwan[28]. FAHP is used to evaluate and control silicon wafer slicing quality by[29, 30]. FAHP for behavior based safety management was developed by[31]. Fuzzy AHP was applied to identify problem features for injection mold development by[32]. FAHP was used for machine-tool selection by[33]. Various aspects of river basins to find the most efficient use of water system using FAHP had been proposed by[34]. Measuring intellectual capital using FAHP is given in[35]. A significant finding from all the researchers is they used triangular fuzzy number (TFN) to represent vague data or linguistic information.

Fuzzy sets and fuzzy numbers

A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function that operates over the range of real numbers [0, 1].

The main characteristic of fuzziness is the grouping of individuals into classes that do not have sharply defined boundaries. The uncertain comparison judgment can be represented by the fuzzy number. The TFN used as the membership function is illustrated in Fig. 1. A TFN is the special class of fuzzy number whose membership function is defined by the triplet (l, m, u) defined as in (1). TFN help the decision maker to make easier decisions.

$$U(x) = \begin{cases} (x-l)/(m-l) & l \le x \le m \\ (u-x)/u-m) & m \le x \le u \\ 0 & otherwise \quad u < x > l \end{cases} \quad ...(1)$$

The calculation of fuzzy numbers can be done according to the extension principle of TFN. If there are two TFN $A = (l_1, m_1, u_1)$ and $B = (l_2, m_2, u_2)$, the basic calculation principles are listed in Table 1. Here A and B are positive.

A fuzzy number can always be given by its corresponding left and right representation of each degree of membership:

$$\tilde{M} = (f_\alpha(l), f_\alpha(u)) = ((m-l)\alpha + l, u-(u-m)\alpha),$$

$$y \in [0,1], \quad \text{... (2)}$$

where $f_\alpha(l)$ and $f_\alpha(u)$ denote the left side representation and the right side representation of a fuzzy number, respectively.

Table 1: Fuzzy Arithmetical Operations Using Two TFN

Operators	Formula	Results
Summation	A + B	$(l_1 + l_2, m_1 + m_2, u_1 + u_2)$
Subtraction	A - B	$(l_1 - l_2, m_1 - m_2, u_1 - u_2)$
Multiplication	A * B	$(l_1 * l_2, m_1 * m_2, u_1 * u_2)$
Division	A / B	$(l_1 / l_2, m_1 / m_2, u_1 / u_2)$

Table 2: The fuzzy evaluation matrix with respect to the goal

	B_1	B_2	B_3
B_1	(1,1,1)	(5/2,3,7/2)	(2/3,1,3/2)
B_2	(2/7,1/3,2/5)	(1,1,1)	(3/2,2,5/2)
B_3	(2/3,1,3/2)	(2/5,1/2,2/3)	(1,1,1)

Table 3: Evaluation of sub-attributes with respect to mechanical-related factors

	C_{11}	C_{12}	C_{13}	C_{14}
C_{11}	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	(2/3,1,3/2)
C_{12}	(2/3,1,3/2)	(1,1,1)	(3/2,2,5/2)	(2/3,1,3/2)
C_{13}	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)
C_{14}	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)	(1,1,1)

Table 4: Evaluation of the sub-attributes with respect to physical-related factors

	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}
C_{21}	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(2/3,1,3/2)	(2/5,1/2,2/3)
C_{22}	(2/5,1/2,2/3)	(1,1,1)	(2/3,1,3/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)
C_{23}	(2/5,1/2,2/3)	(2/3,1,3/2)	(1,1,1)	(2/5,1/2,2/3)	(2/7,1/3,2/5)
C_{24}	(2/3,1,3/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(2/3,1,3/2)
C_{25}	(3/2,2,5/2)	(3/2,2,5/2)	(5/2,3,7/2)	(2/3,1,3/2)	(1,1,1)

The weight vector from Table 4 is calculated as

FAHP algorithm

In this study the FAHP is utilized, which was originally introduced by[36]. This section outlines the extent analysis method on FAHP and this method is applied to know the priority weights of different main and sub categories of SNP risk factors.

Let $X = \{x_1, x_2, \ldots, x_n\}$ be an object set, and $U = \{u_1, u_2, \cdots u_m\}$ be a goal set. According to the method of Chang's extent analysis, each obiect is taken and extent analysis for each goal g_i, is performed, respectively.

Table 5: Evaluation of the psychosocial-related sub-attribute factors

	C_{31}	C_{32}	C_{33}	C_{34}
C_{31}	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	(2/3,1,3/2)
C_{32}	(2/3,1,3/2)	(1,1,1)	(3/2,2,5/2)	(2/3,1,3/2)
C_{33}	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)
C_{34}	(2/3,1,3/2)	(2/3,1,3/2)	(3/2,2,5/2)	(1,1,1)

The weight vector from Table 5 is calculated as $W_{B_3} = (0.31, 0.31, 0.08, 0.31)^T$

Table 6: Summary of priority weight of major and sub-category of risk factors

Item assessment hierarchy		Factor assessment hierarchy		Synthesized weight	Score	SNPRC
Symbol	Weight	Symbol	Weight	$(b_i C_{ij})$	P_i	$(b_i C_{ij})(P_i)$
B_1	0.65	C_{11}	0.32	0.21	88.91	18.67
		C_{12}	0.32	0.21	92.43	19.41
		C_{13}	0.11	0.07	53.74	03.76
		C_{14}	0.25	0.16	68.02	10.88
B_2	0.27	C_{21}	0.27	0.07	70.42	04.93
		C_{22}	0.00	0.00	50.61	00.00
		C_{23}	0.00	0.00	62.74	00.00
		C_{24}	0.31	0.08	80.15	06.41
		C_{25}	0.42	0.11	90.01	09.90
B_3	0.08	C_{31}	0.31	0.03	86.00	02.58
		C_{32}	0.31	0.03	80.02	02.40
		C_{33}	0.08	0.01	73.69	00.74
		C_{34}	0.31	0.03	78.95	02.37

Table 7: Score standard of each option

	Extremely promising	Very promising	Promising	Common	Unpromising
Grade	5	4	3	2	1
Score	100	80	60	30	0

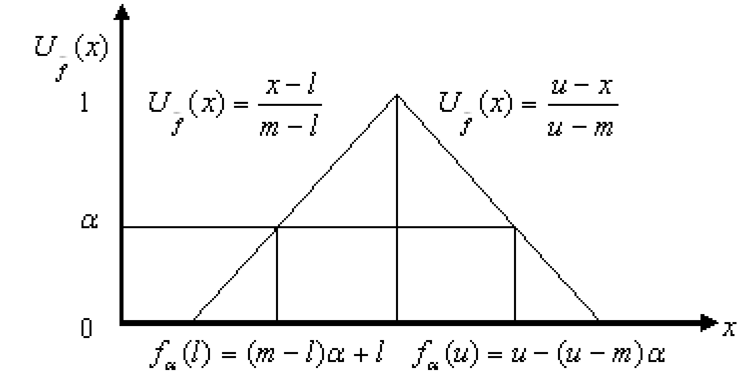

Fig. 1: Left and Right representation of TEN, f_α

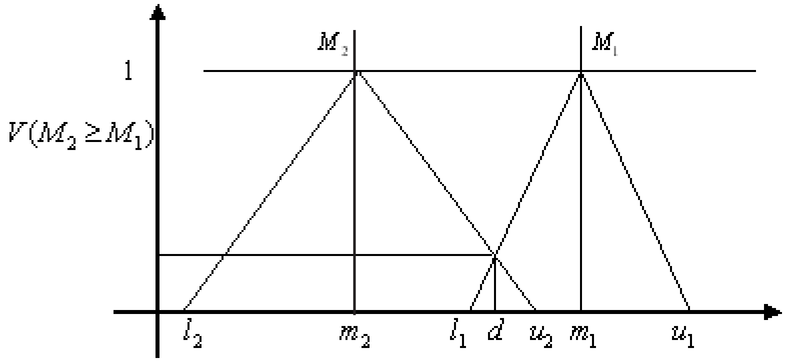

Fig. 2: The intersection between M_1 and M_2

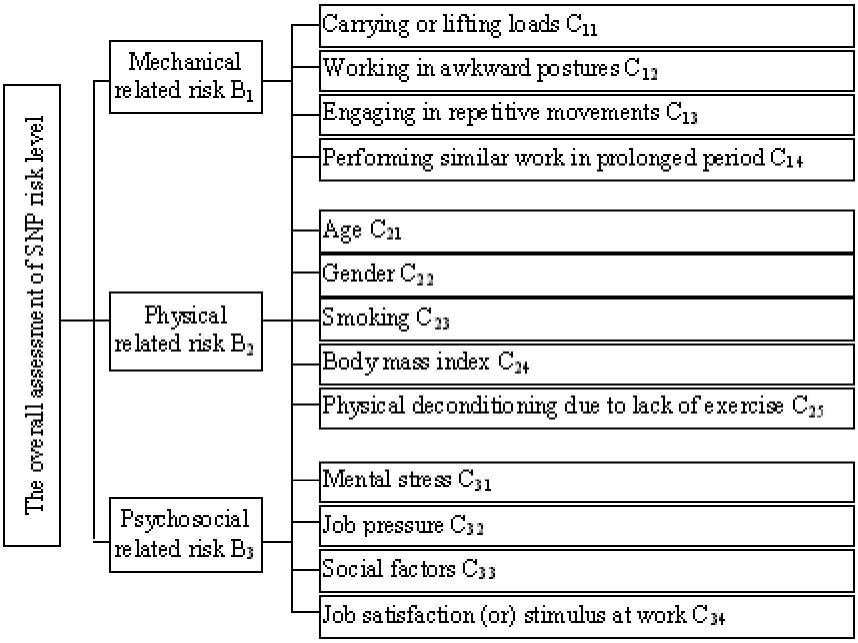

Fig. 3: The hierarchy of the problem

Therefore m extent analysis values for each object can be obtained, with the following signs:

$$M_{g_i}^1, M_{g_i}^2, \cdots, M_{g_i}^m, i = 1, 2, \cdots, n, \quad ...(3)$$

Where all the $M_{g_i}^j (j = 1, 2, \cdots, m)$ are TFNs.

The steps of Chang's extent analysis can be given as in the following:

Step 1: The value of fuzzy synthetic extent with respect to the i^{th} object is defined as

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1} \quad ...(4)$$

To obtain $\sum_{j=1}^{m} M_{g_i}^j$, perform the fuzzy addition operation of extent analysis values for a particular matrix such that

$$\sum_{j=i}^{m} M_{g_i}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \quad ...(5)$$

And to obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1}$ perform the fuzzy addition operation of $M_{g_i}^j \ (j = 1, 2, \cdots, m)$ values such that

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \quad ...(6)$$

and then compute the inverse of the vector in Eq. (6) such that

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right). \quad ...(7)$$

Step 2

The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as

$$V(M_2 \geq M_1) = \sup_{y \geq x} \left[\min(\mu_{M_1}(x), \mu_{M_2}(y)) \right] \quad ...(8)$$

And can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d)$$

$$= \begin{cases} 1, & if\ m_2 \geq m_1, \\ 0, & if\ l_1 \geq u_2, \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise, \end{cases} \quad ...(9)$$

Where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2} (Fig. 2). To compare M_1 and M_2, both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$ are needed.

Step 3: The possibility degree for a convex fuzzy number to be greater than k convex fuzzy numbers $M_i (i = 1, 2, \cdots, k)$ can be defined by

$$V(M \geq M_1, M_2, \cdots, M_k)$$
$$= V[(M \geq M_1)\ and\ (M \geq M_2)\ and \cdots and\ V(M \geq M_k)\ ]$$
$$= \min\ V(M \geq M_i),\ i = 1, 2, 3, \cdots, k. \quad ...(10)$$

Assume that

$$d'(A_i) = \min(S_i \geq S_k). \quad ...(11)$$

For $k = 1, 2, \cdots, n;\ k \neq i$. Then the weight vector is given by

$$W' = (d'(A_1), d'(A_2), \cdots, d'(A_n))^T, \quad ...(12)$$

Here $A_i (i = 1, 2, \cdots, n)$ are n elements.

Step 4

Via normalization, the normalized weight vectors are

$$W = (d(A_1), d(A_2), \cdots, d(A_n))^T, \quad ...(13)$$

Where is a non-fuzzy number.

Assessment model and process of SNP risk level estimation

Knowledge acquisition process and hierarchy establishment

The significance of knowledge acquisition process (KAP) in this research is to identify all possible risk factors for the prevalence of SNP for different occupational groups and finding their importance. To simplify this activity and better organize the domain model, the process of finding the SNP risk factors has been divided into major most important modules of risk factors according to the literature as well as domain expert's guidance.

KAP consists of a hybrid of knowledge acquisition methodologies and the most important methods used include prelude analysis, literature analysis, domain expert's knowledge engineering analysis and concept mapping interviews. These aspects of knowledge acquisition are performed sequentially to build a framework for the classification of the knowledge.

The data obtained have been used to identify the dominant categories of SNP determinant factors. The hierarchical model should be able to break the existing complex decision problem into manageable components of different layers/levels. Different layers of the hierarchical structure of the risk factors of SNP for different type of occupation are depicted in Fig. 3.

Evaluation of SNP risk factors

The fuzzy comparison judgments with respect to the main goal are shown in Table 2.

From Table 2 $S_{B_1} = (4.17, 5, 6) \otimes (1/13.07, 1/10.83, 1/9.03) = (0.32, 0.46, 0.66)$, $S_{B_2} = (2.79, 3.33, 3.90) \otimes (1/13.07, 1/10.83, 1/9.03) = (0.21, 0.31, 0.43)$, $S_{B_3} = (2.07, 2.50, 3.17) \otimes (1/13.07, 1/10.83, 1/9.03) = (0.16, 0.23, 0.35)$ are obtained. Using these vectors, $V(S_{B_1} \geq S_{B_2}) = 1.00$, $V(S_{B_1} \geq S_{B_3}) = 1.00$, $V(S_{B_2} \geq S_{B_1}) = 0.42$, $V(S_{B_2} \geq S_{B_3}) = 1.00$, $V(S_{B_3} \geq S_{B_1}) = 0.12$, and $V(S_{B_3} \geq S_{B_2}) = 0.64$ are obtained. Thus the weight vector from Table 2 is calculated as $W_G = (0.65, 0.27, 0.08)^T$

Then, the decision-maker compares the sub-attributes with respect to main-attributes. Table 3 gives the fuzzy comparison data of the sub-attributes of mechanical-related risk factor.

From Table 3 $S_{C_{11}} = (0.18, 0.29, 0.47)$, $S_{C_{12}} = (0.18, 0.29, 0.47)$, $S_{C_{13}} = (0.13, 0.18, 0.24)$ $S_{C_{14}} = (0.16, 0.24, 0.36)$ are obtained. Using these vectors $V(S_{C_{11}} \geq S_{C_{12}}) = 1.00$ $V(S_{C_{11}} \geq S_{C_{13}}) = 1.00$ $V(S_{C_{11}} \geq S_{C_{14}}) = 1.00$ $V(S_{C_{12}} \geq S_{C_{11}}) = 1.00$ $V(S_{C_{12}} \geq S_{C_{13}}) = 1.00$ $V(S_{C_{12}} \geq S_{C_{14}}) = 1.00$ $V(S_{C_{13}} \geq S_{C_{11}}) = 0.35$ $V(S_{C_{13}} \geq S_{C_{12}}) = 0.35$ $V(S_{C_{13}} \geq S_{C_{14}}) = 0.57$ $V(S_{C_{14}} \geq S_{C_{11}}) = 0.78$, $V(S_{C_{14}} \geq S_{C_{12}}) = 0.78$ and $V(S_{C_{14}} \geq S_{C_{13}}) = 1.00$ are obtained. The weight vector from Table 3 is calculated as $W_{B_1} = (0.32, 0.32, 0.11, 0.25)^T$

The other matrices of pair-wise comparisons of personal- and psychosocial-related risk factors and the weight vector of each matrix are given in Tables 4 and 5.

The relevant results of the priority weights of attributes and sub-attributes are presented in Table 6.

RESULTS

Based on the results obtained in the FAHP analysis, the following statements can be made:

- Mechanical related risk is more important than physical related risk.
- Physical related risk is more important than psychosocial related risk.
- Psychosocial related risk is less important than mechanical- and physical-related risk.

The synthesized weight of each factor has been given in Table 6.

The fuzzy score index system and the final grade standard for SNP risk level are constructed by reference to five point Likert-type rating scale, with responses ranging from 1 = disagree very much to 5 = agree very much. This scale has been found to be simple to understand, thorough, and applicable to the medical and service industry[37]. 55 patients with SNP at high risk are concerned to give scores to the identified factors. The final factor values, showed in Table 6, are the average of scores obtained from all the respondents. Based on the Fishbein Rosenberg Model, the final score called SNP risk level coefficient ($SNPRC$) for the SNP risk is calculated as in the following formula.

$$SNPRC = \sum_{i=1}^{n} P_i W_i$$

$$= 88.91 \times 0.21 + 92.43 \times 0.21 + \cdots + 73.69 \times 0.01 + 78.95 \times 0.03$$

$$= 82.05$$

Where *n* is the number of assessment factors; P_i is the score for the i^{th} factor, and W_i is the weight of the i^{th} factor.

According to the grade standard results presented in Table 7, the final score of SNP risk level of the group of patients is more than the "very promising" grade (82.05) and nearing to "extremely promising grade", indicating that the SNP risk of the selected group of patients is relatively very high.

CONCLUSION

Decision making is a cumbersome process in any increasingly complex environments. SNP is one such problem where the knowledge of domain experts in various medical fields is necessary and a stringent system network is required for making effective decisions. This research formulates SNP problem as a multiple criteria decision making problem under uncertainty and the FAHP based analysis results in accurate local and global priorities of all the identified risk factors through various KAP processes. The results obtained are validated and the output reveals the patients considered for the evaluation process have high risk of SNP, this goes in accordance with the actual condition of the patients as diagnosed by Domain Experts. The derived results of this research confirm FAHP is an efficient approach to arrive at decisions in diagnosis phase of SNP.

REFERENCES

1. Sillanpää, J., Huikko, S., Nyberg, M., Kivi, P., Laippala, P., Uitti, J. Effect of work with visual display units on musculo-skeletal disorders in the office environment. *Occupational Medicine,* **53**(7): 443-451 (2003).
2. Van der Windt, D.A.W.M., Thomas, E., Pope, D.P., De Winter, A.F., Macfarlane, G.J., Bouter, L.M., Silman, A.J. Occupational risk factors for shoulder pain: a systematic review. *Occupational and Environmental Medicine*, **57**: 433-442 (2000).
3. Pope, P., Silman, A.J., Cherry, N.M., Pritchard, C., Macfarlane, G.J. Association of occupational physical demands and psychosocial working environment with disabling shoulder pain. *Ann Rheum Dis.,* **60**: 852-858 (2001).
4. Office ergonomics, Neck/Shoulder area hazards, Safe Work, Bulletin No. 234 (2010).
5. Kumar, S. Theories of musculoskeletal injury causation. *Ergonomics,* **44**(1): 17-47 (2001).
6. Marras, W.S. Occupational low back disorder causation and control. *Ergonomics,* **43**(7): 880-902 (2000).
7. McCauley, B.P., Lesia, C. A fuzzy linguistic model for the prediction of carpal tunnel syndrome risks in an occupational environment. *IBM J. Res. Develop.,* **44**(5): 759-769 (2000).

8. Buyukozkan, G., Feyzioglu, O., Nebol, E. Selection of the strategic alliance partner in logistics value chain. *Int. J. Production Economics*, **113**: 48-158 (2008.
9. Bongers P.M. The cost of shoulder pain at work. BMJ, **322**: 64-65 (2001).
10. Borghouts, J.A., Koes, B.W., Bouter, L.M. The clinical course and prognostic factors of nonspecific neck pain: a systematic review. Pain, **77**(1): 1-13 (1998).
11. Ho, W. Integrated Analytic Hierarchy Process and Its Applications – A literature review. *European Journal of Operational Research*, **186** (1): 211-228 (2008).
12. Hajkowicz, S., Collins, K. A review of multiple criteria analysis for water resource planning and management. *Water Resources Management,* **21**(9): 1553-1566 (2007).
13. Balteiro-Diaz, L., Romero, C. Making forestry decisions with multiple criteria: A review and an assessment. *Forest Ecology and Management*, **255**: 3222–3241 (2008).
14. Steuer, R. E., Na, P. Multiple criteria decision making combined with finance: A categorized bibliographic study. *European Journal of Operational Research,* **150**(3): 496-515 (2003).
15. Vadya, O.S., Kumar, S. Analytic hierarchy process: An Overview of applications. *European Journal of Operational Research*, **169** (1): 1-29 (2006).
16. Ayað, Z. A fuzzy AHP-based simulation approach to concept evaluation in a NPD environment. IIE Transactions, **37**: 827-842 (2005).
17. Zadeh, L.A. Fuzzy Logic. Computer, **21**(4): 83 (1998).
18. Chan, F., Kumar, N. Global supplier development considering risk factors using fuzzy Extended AHP-based approach. *Omega,* **35**(4): 417-431 (2007.
19. Ghodsypour, S.H., O'Brien, C. A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming. *International Journal of Production Economics,* **56**(57): 199-212 (1998).
20. Ashari, M., Zaiton, S., Supiah, M.H. AI Applications in MCDM: A Review. Post Graduate Research Seminar., Universiti Teknologi. Malaysia (2008).
21. Bottani, E., Rizzi, A. An adapted multi-criteria approach to suppliers and products selection-An application oriented to lead-time reduction. Int. *J. Production Economics,* **111**: 763-781 (2008).
22. Efendigil, T., Onut, S., Kongar, E. A holistic approach for selecting a third party reverse logistics provider in the presence of vagueness. *Computers & Industrial Engineering,* **54**: 269-287 (2008).
23. Cascales, M. S. G., Lamata, M. T. Fuzzy Analytical Hierarchy Process in Maintenance Problem. IEA/AIE, LNAI **5027**: 815-824 (2008).
24. Pan, N.F. Fuzzy AHP approach for selecting the suitable bridge construction method. *Automation in Construction,* **17**: 958-965 (2008).
25. Tsai, M.T., Wu, H.L., Liang, W.K. Fuzzy Decision Making for Market Positioning and Developing Strategy for Improving Service Quality in Department Stores. *Quality & Quantity*, **42**: 303-319 (2008).
26. Wu, C.R., Lin, C.T., Chen, H.C. Integrated environmental assessment of the location selection with fuzzy analytical network process. Quality and Quantity, **43**(3): 351-380 (2009).
27. Huang, C.C., Chu, P.Y., Chiang, Y.H. A fuzzy AHP application in government-sponsored R&D project selection. *Omega*, **36**(6): 1038(15) (2008).
28. Lee, D., Lee, C. Pietrucha, M.T. Evaluation of driver satisfaction of travel information on variable message signs using fuzzy aggregation. *Journal of Advanced Transportation,* **42**(1): 5(18) (2008).
29. Chang, C.W., Wu, C.R., Chen, H.C. Using Expert Technology to Select Unstable Slicing Machine to Control Wafer Slicing Quality via Fuzzy AHP. *Expert Systems with Applications,* **34**(3): 2210-2220 (2008).
30. Chang, C.W., Wu, C.R., Lin, C.T., Chen, H.C. Evaluating and controlling silicon wafer slicing quality using fuzzy analytical hierarchy and sensitivity analysis. *Int J Adv Manuf Technol.*, **36**: 322–333 (2008).
31. Dagdeviren, M., Yuksel, I. Developing a Fuzzy Analytic Hierarchy Process (AHP)

Model for Behavior-based Safety Management. *Information Sciences,* **178**(6): 1717-1733 (2008).

32. Nagahanumaiah, K., Subburaj, B., Ravi, Computer Aided Rapid Tooling Process Selection and Manufacturability Evaluation for Injection Mold Development. *Computers in Industry,* **59**(2) (3): 262-276 (2008).
33. Duran, O., Aguilo, J. Computer-aided Machine-tool Selection Based on A Fuzzy-AHP Approach. Expert Systems with Applications, **34**(3): 1787-1794 (2008).
34. Mohamad, A.A., Siti, Z.M.H., Supiah, S. Using Fuzzy Analytic Hierarchy Process for Southern Johor River Ranking. *Int. J. Advance. Soft Comput. Appl.,* **1**(1): 62-76 (2009).
35. Chen, H.H. Measuring intellectual capital using fuzzy analytic hierarchy process. *International Journal of Innovation and Learning*, **6**(1): 51-61 (2009).
36. Chang, D.Y. Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research,* **95**: 649–655 (1996).
37. Vyskocil-Czajkowski, T.L. Gilmore, S.A. Job satisfaction of selected Institutional foodservice supervisors. Journal of Foodservice Systems, 7: 29-42 (1992).