Studies on Product Design using Ergonomic Considerations

A THESIS SUBMITTED IN FULFILLMENT OF

THE REQUIREMENT FOR THE AWARD OF THE DEGREE

OF

DOCTOR OF PHILOSOPHY

IN

DEPARTMENT OF INDUSTRIAL DESIGN

BY

PRAGYAN PARAMITA MOHANTY

(ROLL NO.511ID102)

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA - 769008, INDIA

NOVEMBER – 2014

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008, ODISHA, INDIA

CERTIFICATE OF APPROVAL

This is to certify that the thesis entitled **STUDIES ON PRODUCT DESIGN USING ERGONOMIC CONSIDERATIONS** submitted by **Pragyan Paramita Mohanty** has been carried out under my supervision in fulfillment of the requirement for the award of the degree of ***Doctor of Philosophy*** in ***Industrial Design*** at **National Institute of Technology Rourkela** and this work has not been submitted to any university/institute before for any academic degree/diploma.

Prof. Siba Sankar Mahapatra
Professor

Department of Industrial Design
National Institute of Technology, **Rourkela-769008**, **INDIA**

This thesis is dedicated to lord Gayatri, my son Abhigyan and all who have inspired me.

ACKNOWLEDGEMENT

While bringing out this thesis to its final form, I came across a great number of individuals whose selfless dedication and contribution in various ways that helped me to execute this research work and therefore, they deserve special thanks. I am greatly indebted to them.

First and foremost, I would like to express my deep sense of gratitude and indebtedness to my supervisor ***Prof. Siba Sankar Mahapatra****, Professor, Department of Mechanical Engineering, National Institute of Technology Rourkela, for his esteemed guidance, invaluable encouragement, moral support, free to act on my ideas and scholarly inputs from early stage of research work that instill confidence in me during the research work. Above all, his priceless and meticulous supervision at each and every phase of work has been the cradle of illumination for me. This thesis could not have been completed without his accordant suggestions, motivation, constant encouragement and crucial contribution, which have enriched value of my thesis. He had always been there to route me through all pros and cons.*

Besides my supervisor, I would like to thank the rest of my doctoral scrutiny committee (DSC) members: Chairman (DSC Member), ***Prof. B. B. Biswal****, Head, Department of Industrial Design,* ***Prof. B. D. Subudhi****, Professor, Department of Electrical Engineering,* ***Prof. S. Datta****, Assistant Professor, Department of Mechanical Engineering and* ***Prof. H. B. Sahu****, Associate Professor, Department of Mining Engineering for their encouragement and insightful comments.*

I am highly grateful to ***Prof. S. K. Sarangi****, Director, National Institute of Technology (NIT), Rourkela and* ***Prof. B. B. Biswal****, Head, Department of Industrial Design,* ***Prof. B. Majhi****, Dean (Academic Affairs), National Institute of Technology, Rourkela for the academic support and the facilities provided to carry out the research work at the Institute.*

I also express my thankfulness to the faculty and staff members of the Department of Mechanical Engineering, Department of Industrial Design for their continuous encouragement and suggestions. Among them, ***Sri P. K. Pal, Sri J. K. Sahu,*** *deserves special thanks for their kind cooperation in non-academic matters during the research work. Besides this I will certainly carry the fond memories of the company of Research Scholars at NIT Rourkela for exchange of ideas and supports.*

I am obliged to ***Sanjita Jaipuria, Bijaya Bijeta Nayak, Swagatika Mishra, Mr. Swayam Bikash Mishra, Mr. Panchanan Jha, Mr. Chinmay Prasad Mohanty, Mr.Suman Chatterjee, Mr. Kumar Abhishek and Mr. Chitrasen Samantra*** *for their* *support and co-operation that is difficult to express in words. The time spent with them will remain in my memory for years to come.*

I owe a lot to my parent, ***Mrs. Bimla Mohanty*** *(Mother), who encouraged and helped me at every stage of my personal and academic life, and longed to see this achievement come true. I deeply miss my father* ***Late Prof. Nirmal Chandra Mohanty****, who is not with me to share this joy.*

I am very much indebted to my husband ***Mr. Abhay Sanatan Satpathy*** *and son* ***Abhigyan*** *for their understanding, patience, co-operation and support throughout the course of my doctoral dissertation and I am highly thankful to them for bearing the inconvenience of stay away from me.*

I also feel pleased to strongly acknowledge the support received from my brother ***Asit Mohanty*** *and sister* ***Sthitapragyan Mohanty*** *in every possible way to see the completion of this doctoral work.*

Above all, I owe it to Almighty ***Lord Gayatri*** *for granting me the wisdom, health and strength to undertake this research task and enabling me to its completion.*

PRAGYAN PARAMITA MOHANTY

ABSTRACT

Embedding ergonomic consideration into product/machine/equipment/component design as well as work environment taking into account both psychological and physical needs of user helps to enhance user efficiency, satisfaction and productivity. It is vital to find best design elements to visualize the product which possesses the characteristics not only to satisfy the users but also reduces fatigue and injury during prolonged use. Although subjective and objective product characteristics are important during product design, user comfort becomes a vital factor that can be quantified by the analysis on continuous physical interaction between product and user. Beside above influential factors, ergonomic design of product also considers cognitive and behavioral information during the design stage with a view to improve the comfort level of the user and aesthetic look of the product.

To address above issues, an integrated approach using statistical and artificial intelligence techniques has been proposed in this thesis to effectively handle subjective and objectives characteristics during design phase. The statistical method is used to assess various user requirements and their significance whereas artificial intelligence method determines the relationship between user requirements and product characteristics. Since most of the psychological needs of users are difficult to express quantitatively, combined approach of statistical and artificial intelligence method can handle the subjectivity and uncertainty in an effective manner. The approach has been demonstrated with the help of design of office chair. Keeping view with the physical interaction between human soft tissue and product as a measuring factor of comfort sensation in an office environment, a numerical analysis of human soft tissue-chair seat model has been introduced into current work. In order to evaluate superior ergonomically designed product (office chair), suitable multi-attribute decision making (MADM) approach based on few important features has been chosen to address the usability of product improving satisfaction level of customer. The study also analyses a kinematic model of human upper arm extremity to diagnose comfort arm posture that allows the operator to have a comfort work zone within which possible postures can be accepted.

The integrated approach of statistical and artificial intelligence techniques produces an office chair that satisfies most of comparable design elements of Bureau of Indian Standard (BIS). Finite element (FE) model of the human soft tissue (buttock)-seat predicts maximum stress in human soft tissue (at ischial tuberocity) on prolonged sitting in an office environment. By the help of a detailed and realistic two dimensional geometric description, the analysis provides insight into the problem and finds the ways to reduce the stress on bony prominence causing cell death of muscle tissue and avoids suffering from pressure sore. The analysis also shows the effect of postural changes on maximum stress beneath ischial tuberocity. However, a large number of products are available in the market place possessing a wide range of features to address the ergonomic considerations. In this regard, several multi-attribute decision making (MADM) methods have been attempted considering both subjective and objective weights for qualitative and quantitative design attributes for selecting a suitable alternate (chair). In order to synergize the capability of an operator within workstation, a comfort work zone has been generated with a kinematic model of human arm. The model predicts an isocomfort posture of human upper extremity to enhance the operator performance within a workplace. Model efficiency has been predicted by using two artificial intelligence techniques such as adaptive neuro-fuzzy inference system (ANFIS) and least square support vector machine (LSSVM).

The methodology adopted in this study is quite general and can be extended to design of hand tools, machinery, vehicles and furniture used in various work environments. The numerical approach considered in this work may be extended to dynamic analysis where vibrational effect can be analyzed in a moving vehicle. Contouring of the seat can be considered to study its influence on pressure distribution at ischial tuberosity. Kinematic model proposed in this study can be extended to model the whole human body with more number of degrees of freedom.

Keywords: Ergonomic design; Subjective and objective design characteristics; Comfort level; Artificial intelligence techniques; Bureau of Indian Standard; Numerical model; Finite element model; Ischial tuberocity; Multi-attribute decision making (MADM) approach; Kinematic model; Neuro-fuzzy inference system (ANFIS); Least square support vector machine (LSSVM).

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

BACKGROUND AND MOTIVATION

1.1 Introduction

It is imperative to focus on design and performance of work system for ensuring a healthy and safe work environment that leads to improve productivity. Although technological advancement leads to improve productivity, the risk factors emerging from complex interaction of employees and elements of work system needs to be sufficiently dealt in involving ergonomic concepts in order to enhance human performance (Peterson,1997).Therefore, ergonomic design of a product/equipment/machine becomes highly desirable because interaction between user and product/machine leads to enhance user satisfaction, comfort and performance of users minimizing health risks. Ergonomic typically solves the physical problem associated with work environment by reducing mismatch between user anthropometric and biomechanical parameters with physical dimension of work place, equipment, furniture (Bridger, 1995; Jeong and Park, 1990). The physical problems resulting due to anthropometric and biomechanical aspects are excess muscle loads, posture change, working with awkward posture, exposure to constant static and vibration force, repetition and duration of body movements. Such problems lead to fatigue and musculoskeletal disorder and physical injuries in low back area, upper extremities and blood circular system (Nunes, 2009). World Health Organization (WHO) has recognized work related musculoskeletal disorder (WMSD) as a major part of health problem that directly affects the behavior of employees and become an influential factor for occupational accidents (Hilton and Whiteford, 2010; Sobeih et al., 2009). It has been observed that repetitive work in the same posture can lead to antagonistic of muscle tendon resulting in degradation of joint function (Bridger, 1995; Marras and Schoenmarklin, 1993).

Consideration of ergonomic principles and methodologies not only involves anthropometric and biomechanical aspects at design phase to improve the physical capability of employees but also touches psychological needs of user to enhance user satisfaction (Kuoppala et al., 2008; Morag, 2007; Moreau, 2003; Fredriksson et al., 2001; Neumann et al., 2006; Vink et al., 2006; Kazmierczak et al., 2007; Erdinc and Vayvay, 2008; Falck et al., 2010; Axelsson, 2000). User satisfaction associated with psychological aspect and functional requirement of the product/machine invariably improves the performance of the users and considered as an important issue in designing a consumer/industrial product (Dandavate et al., 1996; Yang et al., 1999; Park and Han, 2004). Improving functional requirements not necessarily satisfy the user thoroughly especially in case of consumer products such as compact disc (CD) players, mobiles, personal data assistant (PDA) etc. In such cases, subjective performance of the product also matters to improve the user satisfaction. Usability of a product comes through both functional requirement as well as subjective performance of the product. Usability is defined as the degree of ease of use (subjective performance) and effectiveness of use (objective performance or functional requirement) within a specified users, tools and work environments (Bennet, 1984; Shackel, 1984; Veryzer, 1995). Objective performance explains how to interpret the product, how fast the users use/control the product and how well the product functions. Subjective performance measures user perception of image and impression regarding the product that explains the appearance of product as well as the attitude or judgmental feelings about the product (Han et al., 2000).

1.2 Application of Ergonomic design

Ergonomics concern with human performance considering human physiology and psychology for the improvement of work system consisting of person, jobs, tools, equipment and workspace. Three general applications of ergonomics are observed in practice as discussed below.

Ergonomics in industry

In manufacturing and service sectors, ergonomics reduce risk of work related injuries and fatigue by designing the tools and equipment within user physical capability so that the operator becomes flexible with work environment. Ergonomics emphasize on design of the tools, equipment and work processes to improve work productivity and efficiency providing safety (Lucas, 1984). Ergonomics usually emphasize physical work load and productivity issues alongside safety and health (Schmidtke, 1989; Luczak and Volpert, 1987).

Ergonomics in equipment design

Inadequate equipment operation leads to awkward/inaccurate posture and body vibration giving rise to musculoskeletal disorder, unhealthy and unsafe work place (Santos et al., 2011).The application of ergonomics can reduce the complex operation on operator so that the task demand can be compatible with human capabilities. Operator work schedule/habits should be considered during design of the equipment to make the way of operation easy. The design of equipment is always a compromise between the operator's biological needs and physical requirements of the equipment (Das and Grady, 1983; Das and Sengupta, 1996).

Ergonomics in product design

As the demand of a consumer product mostly depends upon the needs of end user and producer cannot control the skill level of user, it is difficult for the part of manufacturer to control over the end use of product. The ease of use of product is associated with ergonomics (Weiman, 1982). Although product design based on functionality, quality and cost as important factors, ergonomics emphasizes other design elements such as comfort, safety (Vink et al., 2006), image/impression (Jordan,1998), emotion and attractiveness (Nagamachi, 2002; Park and Han, 2004). Ergonomic provides an opportunity to use the products easily and safely. For example Volvo, Mercedes provides maximum comfort with their ergonomic design of seat and layout. Also during the design of key board, mouse, electronics product and furniture, ergonomic has a value to use the product easily.

1.3 Need for research

In spite of several applications of ergonomics design, a number of key barriers still exist in many design processes. It becomes difficult to conceptualize the relationship between subjective feelings and design characteristics. Since user requirements are product and situation specific, it is difficult to predict the change in subjective feelings. In addition to the issues related to user satisfaction, ergonomics also concern with health related issues. Health injuries in work environment are caused due to poor/awkward work posture, repetitive and continuous work for prolonged time duration, incompatibility between user and tools/equipment. Health risk factors when combined with poor machine structure, equipment, tools and workspace create a physical and mental stress and fatigue on human body. As muscle fatigue induces musculoskeletal disorder, it is important to quantify fatigue and maximum limit of tolerable muscle loads (Burderf, 1992; Chaffin et al., 1999; Armsstrong et al., 1990). In order to address to a large number of users satisfying their necessity and preference, many products are available in the market. In such a market environment, selection of a particular product becomes a difficult task. With such ideas in mind, an effective method can be opted in the presence of multiple, usually conflicting criteria to find out a suitable product with all important design features. In addition to the issues related user comfort and satisfaction, ergonomics also concern with design of workplace, layout and work facilities to balance the interaction between human beings and tasks for providing safe and enabling workplace environment (Schnauber,1986; Resnik and Zanotti,1997; Burri and Helander,1991; Shikdar and Das,1995; Das and Sengupta,1996).

These problems offer new opportunities for ergonomic design as follows:

- Concept of user satisfaction should be emphasized from both subjective and objective design requirements to evaluate a product’s usability (Nagamachi, 1995; Han et al., 2000).
- As it becomes a complex task to design a product/equipment/machine relating design characteristics of product and user requirements, an appropriate customer driven approach must be adopted.

- It is also necessary to develop a relationship between product characteristics and user comfort level using an appropriate method due to non-linearity of the relationship.
- It is necessary to investigate various physical exposures of muscles and predict muscle fatigue in the work environment using as simple and efficient tool.
- The physical discomfort is usually associated with biomechanical aspects (Anderson et al., 1979). Hence, biomechanical analysis using analytical or numerical models can help to quantify the damage on soft tissues of the users, fatigue on human limbs and musculoskeletal disorders occurring through interaction of product/machine and human body (Tewari, and Prasad, 2000; Thakurta et al., 1995).
- Although a product can be designed considering subjective and objective design requirements and health related risk factors, it is often difficult to choose a particular product in a market place with selected functions satisfying large number of users. Therefore, a suitable selection approach in a well-structured manner must be developed to provide a feasible alternative in the presence of multiple and conflicting criteria.
- Always poor working posture, unnatural postures and irregular motions have been considered as major cause of musculoskeletal disorders (Haslegrave, 1994). Therefore, it is important to design a comfort work zone for users to assume good working posture for task performance minimizing stress and discomfort. Improved comfort work zone enables the operators to use the hands correctly and safely reducing unhealthy and lengthy reaches.

1.4 Research objectives

Based on discussion in previous sections, this section of thesis addresses the issues and problems related to system design. Present work focuses a framework providing the guidelines and principles to the designer and decision makers to improve the quality, usability of product (office chair) in order to increase the comfort level, reduce the stress and injury due to prolong sitting in office work environment. The objective of the research is to develop the models by extracting the guidelines in order to reduce the risk of musculoskeletal disorder in office environment and increase customer satisfaction and hence productivity.

Based on this guiding principle, the objective of present work are as follows:

- To develop an integrated approach to handle objective and subjective user requirements while designing office furniture with a view to enhance customer satisfaction.
- To develop stress-time relationship on human muscle tissue through numerical analysis and ascertain the cause of pressure ulcer so that cell death can be minimized.
- To propose a multi-attribute decision making approach for selecting a suitable ergonomically designed product under uncertain decision making environment.
- To predict the comfort work zone considering comfort posture within which materials and controls existing in the work place are easily accessible.

1.5 Thesis outline

To meet the above the objectives, the thesis can be organized into seven chapters including introduction. A brief outline of each chapter is given as follows:

Chapter 2: Literature review

The chapter deals with review of related literatures that provide background information on the issues and problems to be considered in the thesis and hence focus the relevance of the present study. It identifies the problems associated with work system design with relevance to technical and psychological aspects, health and safety issues, comfort and productivity. The chapter proposed different approaches to identify various aspects in work system design. Present research summarizes on various system design issues considering ergonomics guidelines

Chapter3: An integrated approach for designing office furniture with ergonomic considerations

Since it is difficult to manage subjective requirements in the design process, this chapter proposes an integrated approach to deal with subjective and objective design criteria for a product with ergonomic consideration. The procedure is demonstrated with the help of design of an office chair. A questionnaire survey was conducted including information on user requirements regarding office chair, anthropometric sitting and standing dimensions and design parameters of office chair. The survey was conducted through different modes over a period of four months. The respondents are advised to provide ratings in a five point Likert type scale (1 for strongly agree and 5 for strongly disagree) on forty different items. The user requirements and design criteria are suitable to the users having average anthropometric dimension. A total of one hundred fifty responses are collected. Sixty percent of the respondents belong to officers and staffs of different banks and twenty percent respondents belong to technical institutes. Rest data are collected from different government/private offices. After screening, 100 data with useful responses are considered for further analysis. Data reduction technique like factor analysis has been applied to survey data in order to eliminate redundancy. Thirteen different models of office chairs from standard manufacturers are displayed to the respondents to finalize the tangible and intangible design parameters of the office chair. Total of forty different adjectives indicating user requirements were identified. Twenty two user requirements were loaded on three factors having factor loading score more than 0.7.The reduced user requirements are translated into design characteristics using quality function deployment (QFD). The nonlinear relationship between design characteristics and user satisfaction is developed through adaptive neuro-fuzzy inference system (ANFIS). Finally, a large number of design scenarios are generated using design of experiment (DOE) approach and the best design parameters are chosen that maximizes user satisfaction. A prototype model is developed by using optimal design parameters. The design parameters are compared with measurements by Bureau of Indian Standards (BIS). The comparison indicates that some of the design parameters of the proposed model are out of range suggesting that the variation is due to localization of sample data. The standard needs to be reviewed regularly to enhance comfort level of the users.

Chapter 4: Study on human-product interaction by means of a stress analysis to minimize risk of injuries

Once the prototype with proper design parameters satisfying user satisfaction has been developed, the numerical model is developed to analyze the effect on human tissues due to prolonged use. The model includes a soft human tissue, ischial tuberosity (a bony part) and the seat cushion/rigid seat. Soft tissue (buttock)-seat model is assumed to be two dimensional axisymmetric finite element model with an upright posture. The nonlinear soft tissue-seat model is developed using ANSYS 10.0. A volunteer weighing fifty five kilogram is contacted to obtain image of the soft tissue (buttock). The seat cushion has been modeled by a rectangular flat surface having thickness of 80 mm and area of 450×450 mm^2. Two different models comprising of human soft tissue-rigid seat (model I) and human soft tissue-soft polyurethane foam cushion (model II) are considered. The simulation is conducted over a period of three hours to study the effect of time of loading on soft tissue. The stress distribution throughout meshed model is studied by varying the material properties of seat cushion, angle of loading (sitting posture) and cushion thickness. It is observed that the maximum stress affected area is less in case of soft cushion having elastic modulus of E=20kPa and density ρ =40 kg/m^3 than the cushion having elastic modulus of E=200kPa and density ρ =60kg/m^3. The model predicts a maximum stress of 20324Pa at ischial tuberosity after a continuous sitting duration of half an hour on a soft cushion having elastic modulus of E=20kPa and density ρ =40 kg/m^3 and comparable with experimental value (nearly 19500Pa) (Verver et al., 2004). The morphological changes at ischial tuberosity has been noticed as a result of von Mises stress in soft muscle tissues for three different cushion types with continuous sitting for 1800sec. It has been seen that the size of damage area decreases from rigid seat to soft cushion. It is minimum for the cushion having elastic modulus 20kPa and density 40 kg/m^3. The trend of increasing stress with increase in time of sitting at ischial tuberosity is nearly similar for all seat types. The analysis also been done by changing the posture from 0° to 30° to investigate the effect of loading direction and time of loading on change in stress and damage area at ischial tuberocity.

Chapter 5: A novel multi-attribute decision making approach for product selection conforming ergonomic considerations

In the market place, a large number products are available with various design features (design attributes) with ergonomic considerations. However, it is difficult to choose a particular one suiting to user's needs. Multi attribute decision making (MADM) approach provides a structured approach in selecting a feasible alternative in the presence of multiple and conflicting criteria. Generally, MADM approach carries objective weight for design attributes to find a feasible alternative. But the weights need not be necessarily expressed objectively. In many situations, the weights are expresses objectively and subjectively. In this chapter, a novel decision making approach has been explored to consider both subjective and objective weights of design attributes so that the decision maker facilitates with the objective information regarding the product as well as the uncertainty of human judgement. The approach is explained with an example having six alternatives based on ten attributes of different design features (attributes).

The structure of the present work is as follows. Section 1 concerns with finding the design characteristics (attribute) with respect to alternatives (office chair). Section 2 considers both objective subjective weights of various attributes. On the basis of statistical variance method, the objective weights of the attributes are computed. Analytic Hierarchy Process (AHP) is used to calculate subjective weights of attributes. The integrated weights of attributes are obtained considering the different weightings proportion of the objective and subjective weights. Four decision makers are involved to assign the fuzzy rating values to alternatives under each attribute using a five-point fuzzy scale with triangular membership functions. In order to assess the rating of alternative under each attribute, the fuzzy numbers are aggregated. The aggregated fuzzy rating values are converted into crisp values to simplify the calculations using left and right score (Chen, 1985). The aggregate crisp values are then normalized. The normalization is based upon beneficial and non beneficial attribute. For beneficial attributes higher values are desired (maximization) whereas lower values (minimization) are preferred for non-beneficial attributes. In Section 3, three different MADM methodologies such as TOPSIS (Techniques for Order Preference by Similarity to Ideal Solution), VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenjea) and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) are utilized to find out the best possible way to choose the suitable office chair. In order to check the stability of the ranking, a sensitivity analysis has been carried out considering different proportion of attribute weights (subjective and objective).

Chapter 6: Kinematic analysis of human upper extremity based on comfort joint posture reducing unhealthy and awkward posture.

In this chapter, a kinematic model of human upper extremity is analyzed allowing the movements of all axes of kinematic chain within a comfort zone so that fatigue on human limb can be reduced. The diagnosis of posture analysis of the upper extremities within the comfort operating zone allows the operator to have a comfort work range within which possible posture can be accepted. With the help of comfort joint angle range from literature (Diffrient et al., 1985) as comfort posture and different segment measurements of upper arm (link length) (Kaur et al., 2011;Singh et al., 2013), forward kinematic equations are developed to achieve the hand reach position and consequently three dimensional comfort work zone. The parameters used in the link segment are extracted from the model of Murray (Murray, and Johnson, 2004). Human body carries a number of links with offset joints and adapts some specific postures to formulate specific task. Therefore, it is important to get a right posture within comfort work zone. Due to the presence of non-linearity, complexity and singularity issues in solving inverse kinematic problem, two artificial intelligence techniques such as adaptive neuro-fuzzy inference system (ANFIS) and least square support vector machine (LSSVM) are used to predict upper arm posture (comfort joint angles). It has been seen that LSSVM shows a better performance with less error (0.1173428) in comparison to ANFIS (0.506631) for predicting the posture.

Chapter 7: Executive summary and conclusion

This chapter presents the summery of the results, suggestions and scope for future work in the direction of ergonomic design. With specific contribution and limitations, the chapter concludes the work enclosed in the thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Demand for improved performance of product and comfort for the operator/user have led to an increasing emphasis on ergonomic design. Development of a comfortable product bridges the gap between the subjective feeling of comfort and the prediction of comfort level of new designs through practical use. Various customer-driven approaches allow the needs of the customer to be communicated through the various stages of product planning, design, engineering and manufacturing into a final product to improve the performance of product/machine and user satisfaction. Sometimes, simulation of computer models to test the design process for highest degree of comfort allows manufacturers to speed up the design process by reducing cost and minimizing health hazards. Due to advanced technology, convenient functions are added to a product. However, providing more functions usually results in a more complex user interface which sometimes neither offer user satisfaction as a part of usability nor provide physical comfort. Customer demand for product with improved performance is as important as the demand for products with improved comfort level. Therefore, the manufacturers consider user satisfaction, comfort and biomechanical issues as the most important factors that distinguish each product/tool/equipment from each other product/tool/equipment. Ergonomics not only concern with health related issues (Kuoppala et al., 2008) and psychological aspects (Fredriksson et al., 2001) but also associated with system performance aspects like productivity (Kazmierczak et al., 2007) and quality (Falck et al., 2010) by integrating various features in the product t design stage.

In this direction, the present chapter highlights various concepts and approaches through a broad-based literature survey. Current literature survey deals with ninety articles published after 1992 with attention paid to last twenty two years. Sixteen articles referred here are published before 2000 and rest published after 2000. The majority of the citations are found from peer reviewed journal publications (90%). The other citations are taken from conference articles and book chapters. Two journals namely International Journal of Industrial Ergonomics and Applied Ergonomics together account for 35% of total citations in journals. Table 2.1 provides the source and number of citations from each source. The literature review provides enough information regarding existing problem to identify gap in the existing work and provides advancement in solving the problem and minimizing the gap so that the relevance of the present work can be emphasized.

Table 2.1 Summary of publications referred

Name of Journals	**Citation**
International Journal of Industrial Ergonomics	24
Applied Ergonomics	15
Journal of Occupational and Environmental Medicine	1
The Ergonomics Open Journal	1
International Journal of Industrial Engineering Computations	1
Expert System with Applications	3
Applied Soft Computing	1
Mathematical and Computer Modeling	1
Journal of Human Ecology	1
International Journal of Services and Operation Management	1
Journal of Convergence Information Technology	1
Computers and Industrial Engineering	1
Materials and Design	1
Journal of Biomechanics	4
Journal of Engineering	1
Computer Methods in Biomechanics and Biomedical Engineering	1
International Journal of Solids and Structures	1
Cellular Polymers	1
Journal of Rehabilitation Research and Development	3
Journal of Electromyography and Kinesiology	1
International Journals of Simulation Modeling	1
Journal of Biomechanical Engineering	3
Archives of Physical Medicine and Rehabilitation	1
Computers in Industry	2
Journal of Mechanical Design	1
Journal of Operation Management	1
Human Factors and Ergonomics in Manufacturing and Service Industries	3
Ergonomics	2
Journal of the Chinese Institute of Industrial Engineers	1
Computer Standards and Interfaces	1
Scandinavian Journal of Work, Environment and Health	1
International Review of Social Sciences and Humanities	1
Journal of Electronic Commerce Research	1
The Journal of Visualization and Computer Animation	1
Conferences	6
Books	1
Total	**91**

The referred literature is broadly classified into four categories such as (1) Ergonomic consideration improving user satisfaction, (2) Biomechanical analysis in ergonomic design, (3) Ergonomic consideration in product selection and (4) Layout design for improving work environment as illustrated. Each classification refers work system design issue with ergonomic consideration and associated with specific problem. Figure 2.1illustrates percentage of papers surveyed under each classification category. The next sections provide a brief discussion on these issues.

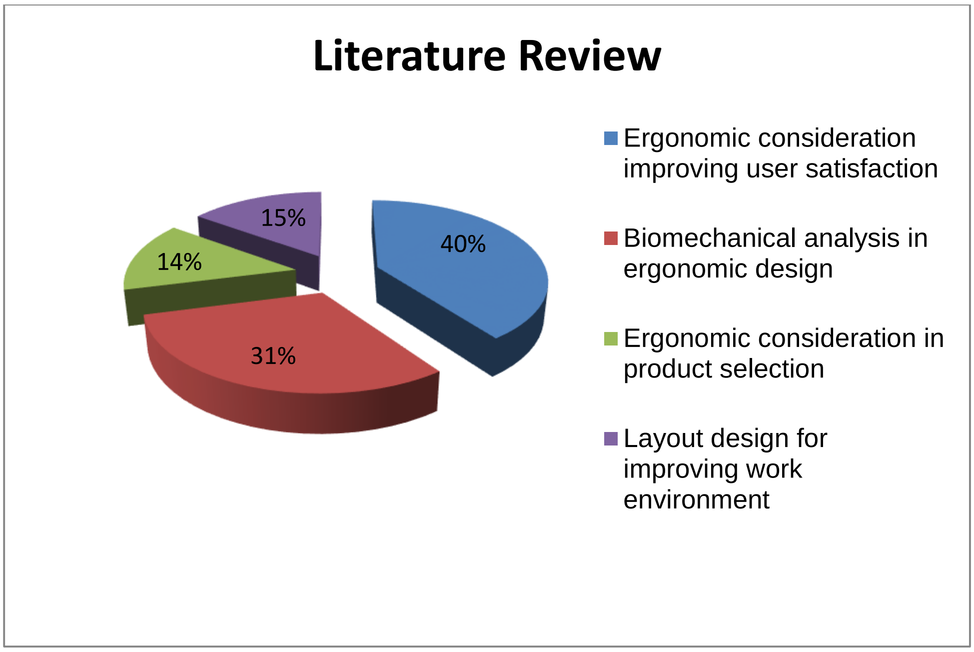


Figure 2.1 Percentage of papers under each classification category

2.2 Ergonomic consideration for improving user satisfaction

User satisfaction generally depends on perceived image/impression, functionality and physical comfort during user-product interaction. To relate user satisfaction with product's design features, various research studies focus on embedding affective human factors into product design. Usually, mismatch between product and user anthropometric data can lead to an uncomfortable and awkward body posture making adverse impact on working condition. Keeping in view with user comfort, attempts have been made to embed customers' views in product design through interviews and well-structured questionnaire survey in order to design the product to accommodate anthropometric variability. Reitenbach et al. (2009) have proposed an office chair design to support the postures of Chinese female office workers in a comfortable way by means of interviews, questionnaire survey and focus group discussions. Focusing on the comfort level of user and usability of office chair, the study conducts a comparative analysis on Hong Kong office workers and Chinese factory workers. Mokdad and Ansari (2009) have conducted a survey on Bahraini school students and suggested variability in design of furniture for them by comparing the anthropometric dimensions of boys and girls (6-12 years).Goonetilleke and Feizhou (2001) have proposed integration of subjective and objective measurement to evaluate the useful seat depth for a target population. Objective evaluation revealed that a seat depth of 31-33 cm is adequate for South China region population whereas seat depth of 38-43cm is adequate for US population. Considering anthropometric data as a major parameters for product design, many countries have been making great efforts in establishing an anthropometric database for different population groups such as civilians, military personnel, students and workers (Bolstad et al., 2001; Wang et al., 2002).Thariq et al. (2010)have evaluated design parameters (dimensions) for fixed type side mounted desktop chair to improve comfort level by developing relation between the chair dimensions and the desk dimensions with anthropometric dimension of university students of Sri Lanka. Musa (2011) has made a comparison between students of different age groups by their anthropometric dimensions and concluded that the design of furniture for 12-year students does not match with that of 17-year students. The analysis emphasized in selecting different design criteria for different age groups so that there is less chance of mismatch between school furniture and students' anthropometric dimension. Jindo and Hirasago (1997) have described the style and design specification of passenger car interiors by subjective evaluation and proposed empirical relationship using multiple regression method. Gauvali and Boudolos (2006) have utilized theoretical and practical ergonomic principles to provide a relation between furniture dimensions and anthropometric measures for choosing unique furniture dimension for unique anthropometric measurement. Castellucci (2010) has made a comparison of various furniture sizes of different schools based on anthropometric data of Chilean students in Valparaiso region. It is found that mismatch exists between furniture dimension (seat height and seat to desk height) and students' anthropometry. Jung (2005) has designed a new structure with minimum controls, cost and maximum flexibility of a prototype of adjustable table and chair. The prototype design is validated considering students' physical dimensions through subjective trials and the dimensions provided by International Standards data. Lin and Kang (2000) present an anthropometric database for designing high school and primary school desks and chairs keeping in view with subjective comfort level and anthropometric data. Ray et al. (1995) have presented a statistical analysis of anthropometric data of Indian school students to facilitate the furniture and toys that reduce biomechanical and visual problems.

Several studies focus on various customer driven approaches into product development process in order to translate design features into user needs aimed at maximizing user satisfaction. Han et al. (2000) have emphasized the importance of objective performance and subjective impression during design phase to explain the usability of product and identified the relationship between design variables of electronics product and usability using multiple linear regression techniques. Menendez et al. (2011) have studied ergonomic aspects of a highly adjustable office chair and its impact on employees through statistical analysis. Shimizu and Jindo

(1995) have proposed a method for analyzing sensitivity evaluation using a fuzzy regression method which takes into account the non-linearity of human sensation in designing vehicle interiors. Khanam et al. (2006) have explored the type of furniture used by the graduate students in the classroom environment keeping in view with relationship between physical design, physical structure and biomechanics of human body. Chen and Ko (2008) have proposed a fuzzy quality function deployment (QFD) approach for designing new product that maximize the customer satisfaction. The proposed model is illustrated with a case study from semiconductor packing industry. Jindo et al. (1995) have focused on design support system for design of office chairs and conducted a subjective evaluation using semantic differential method in order to find out a relation between design elements and user perception. Nagamachi (1995) in Kansei engineering approach has proposed an elegant methodology for translating customer requirements expressed in subjective manner into objective design attributes using statistical method. Solomani and Zhong sheng (2006) have prioritized the design characteristics using QFD.

Vergara and Page (2000) have studied the relation between lumbar and pelvic posture with the backrest of a chair through extensive experimentation. Park et al. (2000) have proposed new design of a chair to reduce muscle fatigue and discomfort as compared to conventional computer chair. Vos et al. (2006) have investigated experimentally the impact of postural and chair design on seat pan interface pressure. It is concluded that the chair design has greater impact on seat pan interface pressure than postural change. Ellegast et al. (2012) have evaluated the effect of task performed during sitting on a chair on human muscle. Groenesteijn et al. (2009) have investigated the influence of chair parameters on comfort and seat interface pressure when prolonged work is being done using office chair. Lili et al. (2010) have provided guidelines on design of office chair using ergonomics to improve the comfort level of the users.

In order to quantify vague nature of expression on comfort by the users, several studies have used fuzzy models to build the relationship between design characteristics and user requirements. Dursun Kaya et al. (2003) and Kwong et al. (2009) have adopted adaptive neuro-fuzzy inference system (ANFIS) to develop relationship between user satisfaction and design parameters of school chair and desk. The design parameters are established through six anthropometric dimensions of boys and girls. Wang (2011) has developed an approach based on rough set theory, ANFIS and Kansei engineering to convert customers' preferences into product form elements. The investigation has considered some adjectives to describe the consumers' psychological feeling on a product. Park and Han (2004) have used a fuzzy rule-based approach to build the relationship between design variables of products and user satisfaction. Three different chair dimensions such as luxuriousness, balance and attractiveness with a number of continuous and discontinuous variables are considered to build the model. To verify the model performance, traditional regression model is compared with proposed fuzzy model. Jiang et al. (2012) have attempted to model the relationship between user satisfaction and design attributes of products using swarm optimization in conjunction with ANFIS. In order to find the effectiveness of the proposed approach, modeling results are compared with fuzzy regression and genetic algorithm based ANFIS approach. Chan et al. (2011) have used genetic programming (GP) based QFD to develop relationship between engineering characteristics and customer requirement for a digital camera. The method is compared with linear regression and fuzzy regression approach.

2.3 Bio-mechanical analysis in ergonomic design

Human psychological conditions (comfort or discomfort) are always associated with body's biomechanical and physiological perspective. Feelings of discomfort and uneasiness are associated with tiredness and pain whereas comfort is associated with relaxation (Helander and Zhang, 1997).Biomechanical problems caused by the product due to lack of capabilities to perform the tasks need to be identified to prescribe preventive measures in injury-prone situations. As muscle fatigue leads to cumulative trauma disorder (CTDS), it is important to quantify fatigue and identify maximum muscle load that a human body can tolerate (Chaffin et al., 1999). Buckle and Devereux (2002) have defined musculoskeletal disorder (MSD) in terms of injuries at muscles, joints, ligaments and cartilage caused due to repetitive task. Factors such as awkward posture, prolonged contact stress, forceful exertions, vibration and environmental conditions cause MSD. With time, it converts from mild symptoms to severe chronic conditions. Visual discomfort and musculoskeletal discomfort in neck and shoulders are most common occupational health concerns for people who work with computers continuously for a prolonged period of time (Berggvist and Knave, 1994; Hunting et al., 1981).

Ma et al. (2008) have proposed a seat-buttock model to find out the contact pressure at seat-buttock interface and stress at bony prominence. Gru-jicis et al. (2009) have examined stress distribution over the seated-human/seat interface through a realistic model of car seat. Siefert et al. (2008) have proposed a human model interacted with car seat to estimate seat pressure distribution using finite element analysis. Fok and Chou (2009) have proposed a human finger model in order to predict the internal loading pattern at tendons and joint surfaces during dynamic motion under different flexion-extension joint angles. Tang et al. (2010) have considered a two-dimensional human buttock-thigh model to investigate the effect of varying vertical vibration frequencies on seat-interface contact pressure during sitting on three different seat cushions using a finite element model.

Considering pressure distribution as an objective measure of discomfort, various researchers have proposed relations between chair seat pressure distribution and comfort level of the user. Verver et al. (2004) have proposed a finite element (FE) model of the human buttocks to predict the pressure distribution between human and seating surface with detailed and realistic geometric description. A parametric study indicates that a pressure distribution at human-seat interface strongly depends on variations in human flesh and seat cushion properties. Wang and Lakes (2002) have analytically investigated the contact problems between two homogeneous and isotropic soft bodies to simulate the contact of human buttocks and seat cushions allowing Poisson's ratio of seat cushion to be negative. Analysis by both the Hertz model and a finite thickness 3D elasticity model shows that cushions with negative Poisson's ratio can reduce the contact pressure and prevent pressure-induced discomfort and pressure sores/ulcers in sick people. Lowe and Lakes (2000) have reached a similar conclusion using a FE model. Moes and Horvath (2002) have proposed a FE approach for shape optimization of seats considering interactive force between seat and body. Hobson (1992) has studied the effect of seated posture and body orientation on pressure distribution and shear force acting at body seat interface within and between two study groups made up of subjects with spinal cord injuries and nondisabled subjects. Silver-Thorn and Childress (2003) have investigated the effect of parameter variations on the prosthetic interface stresses for persons with trans-tibial amputation using FE approach.

As most of the manual work is still done with hand tools, badly designed tools can induce upper extremity musculoskeletal disorder like hand-arm vibration syndrome and carpel tunnel syndrome (Punnett and wegman, 2004).Harih and Dolsak (2013) have developed hand tool handles which can avoid deformation in soft tissue due to higher contact area and anatomical shape of handles. Vignais and Marin (2014) have proposed a biomechanical analysis of upper arm extremity during cylinder grasping based on inverse kinematics. In an effort to reduce the incidence of decubitus ulcers among wheelchair users, Todd and Thacker (1994) have emphasized on cushion design to minimize the pressure at the buttock-cushion interface using finite element analysis. Linder-Ganz et al. (2006) have used FE approach for estimating tissue deformation over critical time durations causing pressure injuries using muscle tissue of albino (Sprague–Dawley) rats exposed to pressures. Ceelen et al. (2008) have conducted experiments using magnetic resonance (MR) and T2-weighted MR imaging to measure the tissue deformation and damage. A finite element model is proposed to calculate the strain in damage experiment. A correlation analysis revealed a linear correlation between experimental and numerical strains. Gefan et al. (2008) have indicated through specialized experiments on planar tissues that there is 95% likelihood that cells could tolerate engineering strains below 65% for one hour whereas the cells could endure strains below 40% over a 285 min trial period. The decrease in endurance of the cells to compressive strains occurs between one-three hour post-loadings. In another paper, Gefan et al. (2005) have proved that stiffening occurs in-vivo in muscular tissue which undergoes widespread cell death produced by applied bone compression. The local cell-death related stiffening affects the distribution of mechanical stresses and deformations in adjacent (not yet damaged) muscular tissue promoting deep pressure sore. Linder-Ganz and Gefen (2009) have pointed out that the efficacy of wheelchair cushions should be evaluated not only based on their performance in redistributing interface pressures but also according to their effects on stress concentrations in deep tissues, particularly muscles to minimize deep tissue injury. Ragan et al. (2002) have analyzed the effect of cushion thickness on subcutaneous pressure during seating using finite element modeling approach. Fathallah (2010) have focused on MSD in agricultural workers considering psychosocial and socio-cultural aspect of the work environment.

2.4 Ergonomic consideration in product selection

In order to compete in the market-place, functions are being added to the product based on assumption that more functions would enhance the product performance. However, addition of more functions to a product usually results in complex user-product interface making it difficult to use. Hence, it is vital to prioritize the important features possessing the ability to fulfill use requirements during product design stage (Besharati et al., 2006). Han et al. (2004), Chuang et al. (2001) and Han (2003) have investigated the relationship between user satisfaction and design features of different mobile phones. Park and Kim (1998) have used modified House of Quality (HOQ) for selecting a set of design requirements of indoor building in order to improve the quality of air. Park et al. (2011) have proposed a combination of three approaches such as general usability principle, user interface component and guideline properties to choose a suitable mobile. Lin et al. (2008) have proposed a framework of analytic hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS) to choose a suitable personal data assistant. Lin et al. (2007) have presented a grey relational analysis approach for determining the best combination of features in a mobile phone. Recently, Hua et al. (2014) have proposed a hybrid multi-criteria decision making (MCDM) model like VIKOR (Visekriterijums kokompromisno rangiranje) to select a smart phone. Isıklar and Buyukozkan (2007) have proposed a MCDM approach to evaluate mobile phone in accordance to user preferences. Liu et al. (2012) have focused on customer utility generation, an optimum design selection approach based on fuzzy set decision-making to identify design attributes from customer preferences using an analytical hierarchy process. A multi-attribute analysis is developed to investigate the preference of each attribute from the expert's group decision. Conjoint analysis is used in the product customization to find the effectiveness of model. Mokhlis and Yaakop (2012) have focused on importance of different choice criteria (innovative features, image, price, personal recommendation, durability, portable aspects, media influence and post-sales service) in mobile phone selection among Malaysian consumers. Guan and Lin (2001) have proposed a neural network approach to select mobile phones.

2.5 Layout design for improving work environment

Layout design in a workplace enables the operator to use their hands and legs safely and properly preventing unhealthy and awkward movements of body parts. There may be possibility to apply maximum effort or may require extended reach to achieve a specific task. Layout design needs understanding of human posture as well as movements during work activities with maximum capabilities to obtain a safe, healthy and comfortable work environment. Cimino et al. (2009) have proposed a methodology based on 3-D simulation to evaluate the impact of workstation parameters on multiple performance measures (force level to lift the objects, stress level related to working posture, energy expenditure and process time). Hu et al. (2010) have presented an experimental analysis on drilling task to estimate three objectives performances such as maximum elbow angle extension, maximum muscle force capacity reduction and task completion time and two subjective feelings like discomfort in body parts and perceived exertion.

Kumar et al. (2009) have explored a tractor control layout (steering, foot clutch, foot break and foot accelerators in the workspace envelop) for Indian people considering anthropometric dimensions. Margarities and Marmaras (2006) have suggested ergonomic requirements for individual work stations in an office environment considering office equipment, environmental conditions, work performance and usability related issues.

With the help of a CAD model, Rajan et al. (1999) have developed an integrated virtual-reality based environment to analyze the assembly of product and jig design in order to meet the required tolerance in aircraft industry. Dewangan et al. (2010) have developed a statistical approach considering factor analysis to design agricultural hand tools and equipment for workers in the hilly region of North East India.

Although layout design facilitates the task of the operator by positioning the equipments/tools around, human posture prediction is also one of the most important issues to determine a healthy work environment. Lindegard et al. (2005) have developed a relation between VDU-user's comfort rating and observed working posture Comfort rating can be obtained through a questionnaire and the working posture can be observed by an ergonomist. In order to simulate human posture (set of joint angles) from a defined work zone (position of human limbs), researchers have attempted to solve inverse kinematic solution through algebraic (Zhao and Badler, 1994), iterative (Jung et al., 1995) and analytical method (Hingtgen et al., 2004). Wang and Verriest (1998 a) have proposed a geometric method for four degree of freedom arm model to predict reach posture. They have investigated motion analysis based on analytical inverse kinematic solution which is task oriented. Wang (1999) have determined motion prediction for two activities such as serving water from a jar and picking up a bottle.

2.6 Conclusions

Critical analysis of articles published in last few years in the broad spectrum of ergonomics reveal that systematic framework is needed in design confirming to ease human in human and products/machines/equipment/components interaction. The interactions are sometimes expressed in both subjective and objective manner. The objective characteristics relates to usability aspects whereas subjective characteristics aims at enhancing satisfaction of the users. A broad framework is vital to improve the comfort level of the users and subsequently productivity of the organization. In addition to design framework, simulation of user-product model using analytical and numerical analysis helps the designer to predict comfort level in terms of stresses and fatigue being developed on human soft tissues/muscles during the interaction process. Although empirical models and artificial intelligence techniques are capable of developing relationship between important design variables and user comfort level, simulation models referring to biomechanical analysis can be employed to understand the physical underpinnings of interactions. The design analysis leads to develop a user-friendly product. However, selection of best product out of a large number of alternatives available in a specific situation needs managerial decision making approach. Literature suggests that a large number of articles focus in this direction. However, human judgement in a uncertain situation needs careful application of various approaches available in the literature. During the use of a product, estimation of comfort work zone is an important issue as evident from the literature.

CHAPTER 3

AN INTEGRATED APPROACH FOR DESIGNING OFFICE FURNITURE WITH ERGONOMIC CONSIDERATION

3.1 Introduction

Ergonomically designed industrial or office work environment consider both psychological and physical needs of employees during design phase for increasing the job satisfaction and prevent the injuries in workplace (Braun et al., 1996). Since the employees spend most of the time at the workplace, ergonomically designed furniture plays an important role in decreasing fatigue and injury level even if an employee continues prolonged work. This is vital for enhancing employees' efficiency and productivity in workspace. Nowadays, employees in office environment not only engaged in studying and signing files but also work in computers, present business plans, and discuss with colleagues. As a result, the employees sustain muscular disorder and spine stiffness problems due to constant pressure at back, shoulder and neck muscles (Kingma and Dieen, 2009). Groenesteijn et al. (2012) have evaluated effect of office tasks on the posture and movements in different office environments. In order to prevent muscular disorder, movement of muscle and spine should be increased during sitting posture (Andreas et al., 2007). Since human-product interaction focuses on subjective satisfaction as well as on objective performance, studies have been carried out in the past to establish the relationship between user sensitivities and design elements of office chair (Jindo et al., 1995). In the process of enhancing customer satisfaction, more functions are added to the product to ensure satisfaction in terms of convenience and ease of use, the structure of the product becomes complex one. Therefore, human-product interaction is viewed as vital element for product design. Usability of the product is concerned with the process of use (i.e., how the user complete the tasks using system functions) measured in terms of efficiency, effectiveness and satisfaction (Han et al., 2000). Kansei engineering approach proposes an elegant methodology for translating customer requirements of a product expressed in subjective manner into objective design attributes using statistical method (Nagamachi, 1995; Horiguchi and Suetomi, 1995). In many situations, multiple regression techniques are used to establish the relationship between usability and design elements (Han et al., 2000). Optimization techniques have also been used to find out best values of design parameters that maximize customer satisfaction (Hong et al., 2002). In many cases, a functional model is needed to describe the relationship between subjective customer requirement and design elements.

Since it is difficult to manage subjective requirements in the design process, present work proposes an integrated approach to deal with subjective and objective design criteria for product development with ergonomic consideration. The procedure is demonstrated with the help of design of office chair. Customers' expectation from the product is extracted through a questionnaire survey. Data reduction technique like factor analysis has been applied to survey data to eliminate redundancy. The reduced customer requirements are translated into design characteristics using quality function deployment (QFD). The relationship between design characteristics and customer satisfaction is developed through adaptive neuro-fuzzy inference system (ANFIS). Finally, a large number of design scenarios are generated using design of experiment (DOE) approach and best design parameters are chosen that maximizes customer satisfaction. A prototype model is developed using the optimal parameters and compared with Bureau of Indian Standards (BIS). The verification result suggests that the proposed model parameters are within the prescribed ranges of BIS.

3.2 Methodology

The complete methodology for designing an office chair with ergonomic considerations can be explained with the help of following six steps. A well-structured questionnaire is prepared to extract data on customer attributes, design characteristics and anthropometric dimensions of users through cross-sectional survey study. Factor analysis is carried out on customer attributes to reduce the number of variables removing redundancy. QFD is employed to transform the customer requirements into important design attributes. Since it is difficult to establish relationship between design requirements and customer satisfaction due to involvement of subjectivity, a black-box type predictive approach such as ANFIS is used to map design requirements with customer satisfaction. Once ANFIS model is well trained, good number of scenarios are generated using DOE approach and the best design is recommended which maximizes the customer satisfaction value. Finally, the design is verified by comparing with standard data or developing prototypes. To design a suitable product (office chair) ergonomically, followings steps are considered.

3.2.1 Data collection

Data collection consists of two different types of survey in the eastern parts of India. First, complaints regarding the product (office chair) were collected through formal and informal interviews. In second survey, the respondents need to answer the questionnaire consisting of a set of variables, anthropometric sitting and standing dimensions and a set of design attributes. The study was conducted on different age group (from 21 to 60 years) of officers and managers working in government and non-government agencies and they used the chairs for a prolonged period every day. Data are mainly collected from staff of various offices like technical institutions (private and public), banks (private and public), hospitals (private and public) and government organization. A cross-sectional survey with random sampling procedure was conducted. One hundred twenty five responses are obtained. 60% data are collected from banks, 20% data are collected from technical institutions, and rest of the data is collected from hospitals and other sources.

Table 3.1 Customer requirements

Sl. No	Items					
1	The chair is made for active sitting	1	2	3	4	5
2	The chair is retro looking (designating the style of an earlier time)	1	2	3	4	5
3	The chair gives pleasant sensation	1	2	3	4	5
4	The chair is immortal (lasting forever)	1	2	3	4	5
5	The chair is chic (stylish and fashionable)	1	2	3	4	5
6	The chair is gaudy one (excessive showy)	1	2	3	4	5
7	The chair is flashy one (too bright intended to get attraction)	1	2	3	4	5
8	The chair is made for active sitting	1	2	3	4	5
9	The chair is very feminine (womanliness)	1	2	3	4	5
10	The chair is very casual one (convenient)	1	2	3	4	5
11	The chair is cute one	1	2	3	4	5
12	The chair is enjoyable	1	2	3	4	5
13	The chair is so cozy (friendly, comfortable)	1	2	3	4	5
14	The chair is untroubled (free from disturbance)	1	2	3	4	5
15	The chair is so cheap	1	2	3	4	5
16	The chair is voluminous	1	2	3	4	5
17	The chair is soft enough	1	2	3	4	5
18	The chair is sturdy enough (strong, solid and thick, unlikely to break)	1	2	3	4	5
19	The chair is well balanced	1	2	3	4	5
20	The chair is masculine (pertaining to the characteristic of a man)	1	2	3	4	5
21	The chair is so cool	1	2	3	4	5
22	The chair is most luxurious one	1	2	3	4	5
23	The chair is stylish one	1	2	3	4	5
24	The chair design is contemporary (old but modern feelings)	1	2	3	4	5
25	The chair has a personal recognition	1	2	3	4	5
26	The chair is elegant for you (attractive appearance and behaviour)	1	2	3	4	5
27	The chair is having distinct features	1	2	3	4	5
28	The chair is simple	1	2	3	4	5
29	The surface of chair is plain	1	2	3	4	5
30	The chair is comfortable	1	2	3	4	5
31	It is an ordinary chair	1	2	3	4	5
32	The chair is flexible	1	2	3	4	5
33	The chair provides headrest	1	2	3	4	5
34	The chair provides spinal curvature support	1	2	3	4	5

35	The chair provides footrest	1	2	3	4	5
36	Your leg is comfortable with the chair	1	2	3	4	5
37	The chair is having backrest contour	1	2	3	4	5
38	The armrest is large enough to support your arm	1	2	3	4	5
39	The chair is having a base with wheel	1	2	3	4	5
40	The chair is having lower back support	1	2	3	4	5

Table 3.2 Tangible design attributes

Sl. No	Backrest	Seat pan	Arm rest	Whole body	Others
1	Tilt of Backrest(maximum angle of the backrest in relation to the seat pan)	Length of seat pan	Length of arm rest	Ratio of seat pan and backrest	Use of decoration
2	Width of Backrest	Width of seat pan	Width of armrest	Width-height ratio of whole body	Use of pattern
3	Height of Backrest	Thickness of seat pan	Height of armrest	Height of whole body	Use of cushion
4	Thickness of Backrest	Width and length ratio of seat pan	Width-height ratio of armrest	Size of whole body	Use of curved lines
5	Width-Height ratio of Backrest	Height adjustment of seat pan		Number of controls used	Number of colors used

Table 3.3 Intangible design attributes

Sl. No	Categorical design variables
1	Shape of backrest
2	Material of backrest
3	Colour of backrest
4	Shape of seat pan
5	Material of seat pan
6	Colour of seat pan
7	wheels
8	Low back support
9	Headrest
10	Shape of armrest
11	Material of armrest
12	Colour of armrest
13	Shape of base

Table 3.4 Anthropometric standing dimension (mm)

Sl. No	Anthropometric dimension	Average
1	Stature(without shoes)	1643.8
2	Eye height	1498.8
3	Cervical height	1425.3
4	Wrist height	810
5	Elbow height	990
6	Waist height	1064
7	Ductylion height	640
8	Ankle height	97
9	Crotch height	876.5
10	Gluteal furrow height	740

Table 3.5 Anthropometric sitting dimension (mm)

Sl. No	Anthropometric dimension	Average
1	Sitting height	806.2
2	Eye height	696.4
3	Cervical height	606.6
4	Upper lumbar height	276.2
5	Elbow rest height	221
6	Popliteal height	459.4
7	Buttock height	455
8	Buttock popliteal length	439
9	body depth	190
10	Shoulder breadth	446
11	Hip breadth seated	361.5
12	Popliteal depth	344.6

Based on existing literature (Han, 2000; Jindo and Hirasago, 1995), informal discussion with office chair manufacturer and interview with users, a list of adjectives is used to represent customer's requirements towards the product as shown in Table 3.1. A total of forty different adjectives indicating customer requirements were identified. Thirteen different models of office chairs from standard manufacturers are displayed to the respondents to finalize the tangible and intangible design attributes of the office chair as listed in Table 3.2 and 3.3 respectively. In fact, the design of office chairs involves consideration of many tangible and intangible criteria for reducing fatigue to the users and improving user satisfaction. Ten standing and twelve sitting anthropometric dimensions of office employees were collected as shown in Table 3.4 and 3.5 respectively. The customer requirements and design criteria are suitable to the users having average anthropometric dimension shown in Tables 3.4 and 3.5. A respondent views the customer requirements taking into consideration of anthropometric dimensions. The respondent needs to answer in terms of Likert-type scale from 1 to 5 (1 for strongly disagree and 5 for strongly agree).

3.2.2 Factor Analysis

The responses obtained through the data collection were tested to examine the validity and reliability of variable to obtain a statically proven identification of customer requirements. The validity was tested through factor analysis method using principal component method following varimax rotation to extract the important dimensions for model analysis which removes the redundancy and duplication from a set of correlated variables (Noruzy et al., 2011; Hair et al., 2010).

3.2.3 Quality function deployment (QFD)

The reduced customer requirements identified in step 2 must be expressed in terms of design requirements to provide guidelines for design and manufacturing engineers while manufacturing the product. QFD plays an important role in this respect for transforming customer requirements into design characteristics. The main objective of QFD is to transform customers' voice (requirement) into design parameters. House of quality (HOQ) starts with customer requirements, i.e., variables defined by the customers. These variables are the inputs to the HOQ. Customer ratings for customer needs are determined by left correlation matrix using equation 3.1. The individual rating of each design requirement is obtained from the central matrix by using equation 3.2.

$$\text{Customer rating} = Z_i + \left[\frac{1}{n-1}\right] \times \sum_{j\neq 1}^{n} B_{ij} Z_j \tag{3.1}$$

$$\text{Design requirements} = \left(\frac{1}{n}\right) \times \left[\sum_{j}^{n} A_{ij} X_j\right] \tag{3.2}$$

Where, B_{ij}, denotes the relationship between customer needs, Z_i, is the initial customer rating, A_{ij}, denote the relative importance of i^{th} characteristic with respect to j^{th} customer's needs in the relationship matrix, X_j represents the importance of j^{th} customer needs and n, is the number of customer needs. The refined rating of each design requirement in the top matrix can be calculated in a similar way as in case of left matrix. The final ratings of design requirement are normalized by dividing each rating with the maximum ratings.

3.2.4 Adaptive Neuro Fuzzy Inference System (ANFIS):

Once the design characteristics have been identified in step 3, it is important to relate the design attributes with customer satisfaction so that best design can be reached. Since it is not possible to mathematically define the relationship among design attributes and customer satisfaction due to inherent imprecise nature of variables, ANFIS can be used to map non-linear relationship for prediction of result (Jang, 1991, 1993). ANFIS is a combination of two different methodology, i.e., neural network and fuzzy logic. A neural network can learn from both the data and feedback without understanding the pattern involved in the data. But, the fuzzy logic models are easy to comprehend the pattern because they use linguistic terms in the form of IF-THEN rules. A neural network with their learning capabilities can be used to learn the fuzzy decision rules; thus creating a hybrid intelligent system. The fuzzy system provides expert knowledge to be used by the neural network. A fuzzy inference system consists of three components. These are:

(a) rule base, contains a selection of fuzzy rules.

(b) data base, defines the membership functions used in the rules

(c) reasoning mechanism, to carry out the inference procedure on the rules and given facts.

This combination merges the advantages of fuzzy system and a neural network. Jang (1991) proposed a combination of a neural network and fuzzy logic popularly known as called an ANFIS. ANFIS is a fuzzy inference system implemented in the framework of neural networks. The combination of both artificial neural network and fuzzy inference system thus improves system performance without interference of operators. A typical adaptive network shown in Figure 3.1 is a network structure consisting of a number of nodes connected through directional links. Each node is characterized by a node function with fixed or adjustable parameters. Learning or training phase of a neural network is a process to determine parameter values to sufficiently fit the training data. The basic learning rule method is the back propagation method, which seeks to minimize some error, usually sum of squared differences between network's outputs and desired outputs. Generally, the model performance is checked by the means of distinct test data, and relatively good fitting is expected in the testing phase. Considering a first order (Takagi and Sugeno, 1985; Sugeno and Kang, 1988) fuzzy interface system, a fuzzy model consists of two rules.

Rule 1 : If x is A_1 and y is B_1 then $f_1 = p_1x + q_1y + r_1$

Rule 2 : If x is A_2 and y is B_2 then $f_2 = p_2x + q_2y + r_2$

If f_1 and f_2 are constants instead of linear equations, we have zero order TSK fuzzy-model. Node functions in the same layer are of the same function family as described below. It is to be noted that O_i^j denotes the output of the i^{th}node in layer j.

Layer 1: Each node in this layer generates a membership grade of a linguistic label. For instance, the node function of the i^{th} node might be

$$O_i^j = \mu A(x) = \frac{1}{1 + \left[\left(\frac{x - c_i}{a_i} \right)^2 \right]^{b_i}} \qquad (3.3)$$

where, x is the input to the node 1 and A_i is the linguistic label (small, large) associated with this node; and {a_i, b_i, c_i } is the parameter set that changes the shapes of the membership function. Parameters in this layer are referred to as the "Premise Parameters".

Layer 2: Each node in this layer calculates the firing strength of each rule via multiplication

$$O_i^2 = w_i = \mu A_i(x) \times \mu B_i(y), i = 1, 2 \qquad (3.4)$$

Layer 3: The i^{th} node of this layer calculates the ratio of the i^{th} rule's firing strength to the sum of all rule's firing strengths:

$$O_i^3 = \overline{w_i} = \frac{w_i}{w_1 + w_2}, i = 1, 2 \qquad (3.5)$$

For convenience outputs of this layer will be called normalized firing strengths.

Layer 4: Every node i in this layer is a squared node with a node function

$$O_i^4 = \overline{w_i} f_i = \overline{w_i}(p_i + q_i y + r_i) \qquad (3.6)$$

Where, $\overline{w_i}$ is the output of layer 3, and is the parameter set. Parameters in this layer will be referred as "Consequent Parameters ".

Layer 5: The single circle node computes the overall output as the summation of all incoming signals i.e.

$$O_i^5 = \text{Overall output} = \sum_i^n \overline{w_i} f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \qquad (3.7)$$

Thus, an adaptive network is presented in Figure 3.1 is functionally equivalent to a fuzzy interface system. The basic learning rule of ANFIS is the back propagation gradient decent which calculates error signals (defined as the derivative of the squared error with respect to each nodes output) recursively from the output layer backward to the input nodes. This learning rule is exactly the same as the beck-propagation learning rule used in the common feed-forward neural networks by Jang (1993). From ANFIS architecture (Figure 3.1), it is observed that the given values of the of premise parameters, the overall output can be expressed as a linear combination of the consequent parameters. Based on this observation, a hybrid learning rule is employed here, which combines a gradient decent and the least squares method to find a feasible of antecedent and consequent parameters. The details of the hybrid rule are given by Jang (1993) where it is also claimed to be significantly faster than the classical back propagation method. From the ANFIS architecture shown in Figure 3.1, we observe that when the values of the premise parameters are fixed and the overall output can be expressed as a linear combination. The output f can be rewritten as:

$$f = \frac{w_1}{w_1 + w_2} f_1 + \frac{w_1}{w_1 + w_2} f_2$$

$$= \overline{w} f_1 + \overline{w} f_2$$

$$= (\overline{w} x) p_1 + (\overline{w} y) q_1 + (\overline{w}_1) r_1 + (\overline{w}_2 x) p_2 + (\overline{w}_2 y) q_2 + (w_2) r_2 \quad (3.8)$$

which is linear in the consequent parameters p_1, q_1, r_1, p_2, q_2, r_2. Therefore, the hybrid learning algorithm developed can be applied directly. More specifically, in the forward pass of the hybrid learning algorithm, node outputs go forward until layer 4 and the consequent parameters are identified by the least squares method. In the backward pass, the error signal propagates backward and the premise parameters are updated by gradient descent. As mentioned the consequent parameters thus identified are optimal under the condition that the premise parameters are fixed. Accordingly, the hybrid approach converges much faster since it reduces the dimension of the search space of the original back-propagation method. For this network created fixes the membership functions and adapt only the consequent part; then ANFIS can be viewed as a functional-linked network where the enhanced representation, which take advantage of human knowledge and express more insight. By fine-tuning the membership functions, we actually make this enhanced representation.

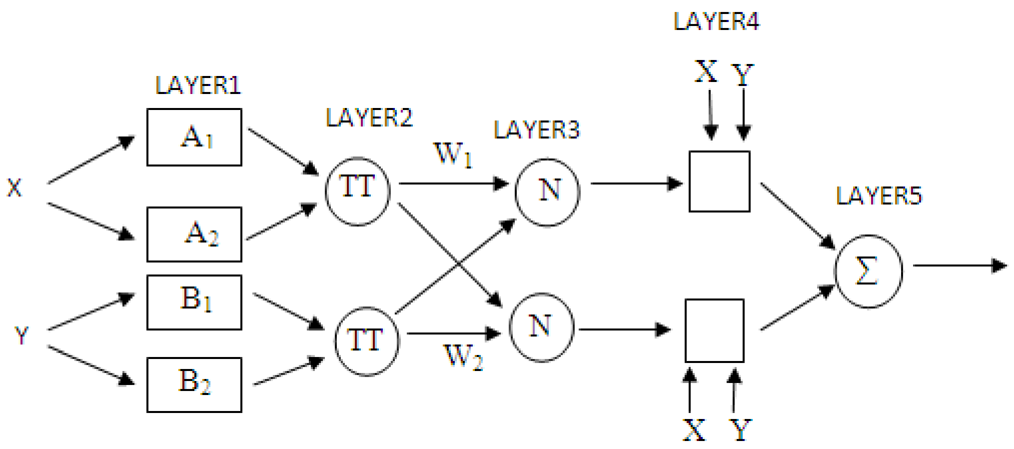


Figure 3.1 A typical architecture of ANFIS structure

The data collected on office chairs through QFD model analysis are normalized. The selected normalized design elements are considered as inputs for ANFIS system and the overall customer satisfaction for chair is considered as output. Total experimental data set is divided into training and testing data set. A total of 80 datasets are used in ANFIS model. Sixty datasets are considered as training and twenty datasets are considered under testing. During training, a five layered ANFIS structure is constructed with one input, three hidden and one output. The Gaussian type of membership function (gaussmf) is used for input and linear type function is used for output. The number of correct outputs is noted till the error is minimized.

3.2.5 Design of Experiment:

DOE is a cost effective statistical method used to optimize the response of a process under the influence of multiple factors. The information on factor and interaction effects on response can be estimated with less number of experimental runs. In fact, it involves multiple factors during experimentation to find out optimum treatments for best performance. The factors with different levels (high and low) are the input parameters which affect the output performance. The best combination is selected out of a number of combinations of different levels of different factors. DOE extensively uses full factorial and fractional factorial experiments to optimize process parameters. Since fractional factorial experiments requires less number of experiments compared to full factorial design, Taguchi proposes simplification and standardization of fractional factorial designs to estimate main effect at different levels of factors and optimize the parameters (Wu and Hamada, 2000).

3.3 Results and discussions

One hundred twenty five data are collected from respondents through cross-sectional survey on 40 items as shown in Table 3.1 to consolidate the customer requirement on office chair. The survey data are subjected to factor analysis to eliminate redundancy of data. Factor analysis has been carried out SPSS 14.0. Twenty two customer requirements were loaded on three factors showing factor loading score more than 0.7.The items exhibiting factor loading score of 0.7 (threshold value) are not considered further. Total variance explained by three factors was found to be 78.5% which is acceptable value for principal component with varimax rotated factor loading procedure. Ten items were loaded under factor 1, five items under factor 2 and seven items under factor 3 (Table 3.6). Factors extracted from analysis are named as comfortness (factor 1), balance (factor 2) and luxuriousness (Factor 3). Cronbach's alpha (α) has been used to assess the internal consistency of the scale. The value of alpha for all dimensions is 0.702, which is just the acceptable value of 0.70 for demonstrating internal consistency of the established scale. The values of α obtained are 0.878, 0.933, and 0.939 for factors 1, 2, and 3 respectively. The Kaiser-Meyer-Olkin (KMO > 0.6) and Bartlett's test of sphericity ($p < 0.05$) statistics are used to test empirically whether the data were likely to factor well. The value of KMO was found to be 0.665; hence, it can be concluded that the matrix did not suffer from multi collinearity or singularity. The result of Bartlett's test of sphericity shows that it is highly significant (sig. = 0.000) which indicates that the factor analysis is correct and suitable for testing multidimensionality.

Table 3.6 Factor Analysis for all items (0.702)

Dimensions	Variables	Factor Loadings
Comfortness(0.878)	1.Active sitting	0.729
	2.Cute	0.833
	3.Enjoyable	0.850
	4.Friendly	0.820
	5.Untroubled and free from disturbance	0.719
	6.Masculine	0.719
	7.Having plain surface	0.825
	8.Comfortable	0.882
	9.Flexible	0.816
	10.Having lower back support	0.778
Balance(0.933)	1.Lasting forever	0.885
	2.Soft enough	0.865
	3.Sturdy enough	0.875
	4.Well Balanced	0.843
	5.Having Footrest	0.782
Luxuriousness(0.939)	1.Excess showy	0.715
	2.Too bright, intended to get attraction	0.753
	3.Refind one	0.720
	4.Luxurious one	0.775
	5.Stylish one	0.742
	6.Having personal recognition	0.744
	7.Elegant for you	0.808

The customer requirements are classified into three factors such as comfortness, balance and luxuriousness. The items under each factor are expressed by the customers in a vague sense. To provide guidelines for the manufacturing, the vague items under each factor needs to be converted into design attributes. QFD being a suitable method of converting vague customer requirements into tangible design attributes, it is used for establishing the relationship among customer requirement and design attributes through experts' opinion and brainstorming sessions. Three different QFD models named as QFD model 1 (comfortness), QFD model 2 (balance) and QFD model 3 (luxuriousness) are used for correlating customer requirement with design attributes. Ten, five and seven items (customer requirements) are considered under QFD models 1, 2 and 3 respectively (Table 3.6). The design attributes extracted from the experts for three models are shown in Table 3.7. The design attributes considered are nine, seven and nine for models 1, 2, and 3 respectively.

Table 3.7 Design attributes for three different QFD models

QFD model 1(comfortness)	QFD model 2(balance)	QFD model3(luxuriousness)
Tilt of backrest	Width-height ratio of backrest	Seat adjustment range
Number of controls	Base material	Use of pattern
Width of backrest	Size of base wheel	Use of curved line
Depth of seat pan	Width-height ratio of seat pan	Use of cushion
Height of armrest from the floor	Width-height ratio of whole body	Use of colour
Overall height	Thickness of seat pan	Shape of backrest
Overall width	Width-height ratio of armrest	Use of decoration
Low back support		Shape of seat pan
Width of seat pan		Backrest height

Initial rating of customer requirements for each model is derived using a 1 to 10 scale as shown for the case of model 1, 2, 3 in Figure 3.2, 3.3 and 3.4. The customer ratings for each customer requirement were obtained from left correlation matrix using equation (1) and initial design requirements is obtained from central matrix using equation (2). The correlation of customer requirements (left matrix), design requirements (top matrix) and customer requirements with design attributes (central matrix) are extracted from the experts using scale of 0.8, 0.6, 0.4 and 0.2 for designating relationship 'strong', 'moderate', 'weak', and 'very weak' respectively. Finally, initial design requirements and with correlation values shown in top matrix are used in equation (1) to obtain final design ratings. The normalized refined rating of design attributes are obtained by dividing each rating with the maximum available design requirement rating. In Figure 3.2, the QFD model 1 (comfortness) is shown. From the normalized refined rating for design attributes, 'Tilt of backrest' has the most prioritized followed by 'Number of controls' (Table 3.8). Finally, four design attributes such as tilt of back rest, number of controls, overall width and overall height are considered out of nine design attributes having normalized refined rating value of 0.85 (threshold). Similarly, other two models have been developed. For QFD model 2 (balance), four design attributes such as width-height ratio of backrest, width-height ratio of seat pan, width-height ratio of whole body, and width-height ratio of armrest(Table 3.9) exhibiting normalized refined rating value of 0.80 (threshold) and above have been considered. Similarly, five design attributes such as seat adjustment range, use of pattern, use of cushion, use of decoration, and backrest height showing (Table 3.10) normalized refined rating value of 0.90 (threshold) and above have been considered for QFD model 3 (luxuriousness).

Table 3.8 Ranking of Design attributes for model-1(comfortness)

No	Design requirement	Initial Design requirement Rating	Revised Design requirement Rating	Normalized refined rating	Rank
1	Tilt of Back rest	5.994	8.642	1.000	1
2	Overall height	4.778	7.153	0.856	4
3	Overall Width	5.136	8.045	0.931	3
4	Height of armrest	4.510	7.400	0.828	5
5	Low back support	3.484	5.425	0.628	9
6	Length of seat pan	3.479	6.149	0.711	8
7	Size of base wheel	3.824	6.244	0.722	7
8	Number of controls	5.659	8.341	0.965	2
9	Height of backrest	4.005	6.946	0.804	6

Table 3.9 Ranking of Design attributes for model-2(balance)

No	QFD model 2(balance)	Initial Design requirement Rating	Revised Design requirement Rating	Normalized refined rating	Rank
1	Width-height ratio of backrest	6.624	10.450	0.962	3
2	Base material	3.662	5.830	0.537	7
3	Width-height ratio of seat pan	7.486	10.861	1.000	1
4	Thickness of seat pan	3.642	7.433	0.684	6
5	Width-height ratio of whole body	6.840	10.515	0.968	2
6	Width-height ratio of armrest	6.440	10.040	0.924	4
7	Size of base wheel	4.488	7.957	0.733	5

Table 3.10 Ranking of Design attributes for model-3(luxuriousness)

No	Design requirement	Initial Design requirement Rating	Revised Design requirement Rating	Normalized refined rating	Rank
1	Seat adjustment range	6.516	10.016	0.975	3
2	Use of pattern	6.909	10.258	0.998	2
3	Use of cushion	5.383	8.255	0.803	5
4	Use of curved line	4.396	7.284	0.709	6
5	Use of colour	4.480	7.127	0.694	7
6	Shape of backrest	3.966	6.318	0.615	9
7	Use of decoration	6.356	9.971	0.970	4
8	Backrest height	6.816	10.276	1.000	1
9	Shape of seat pan	4.482	6.696	0.652	8

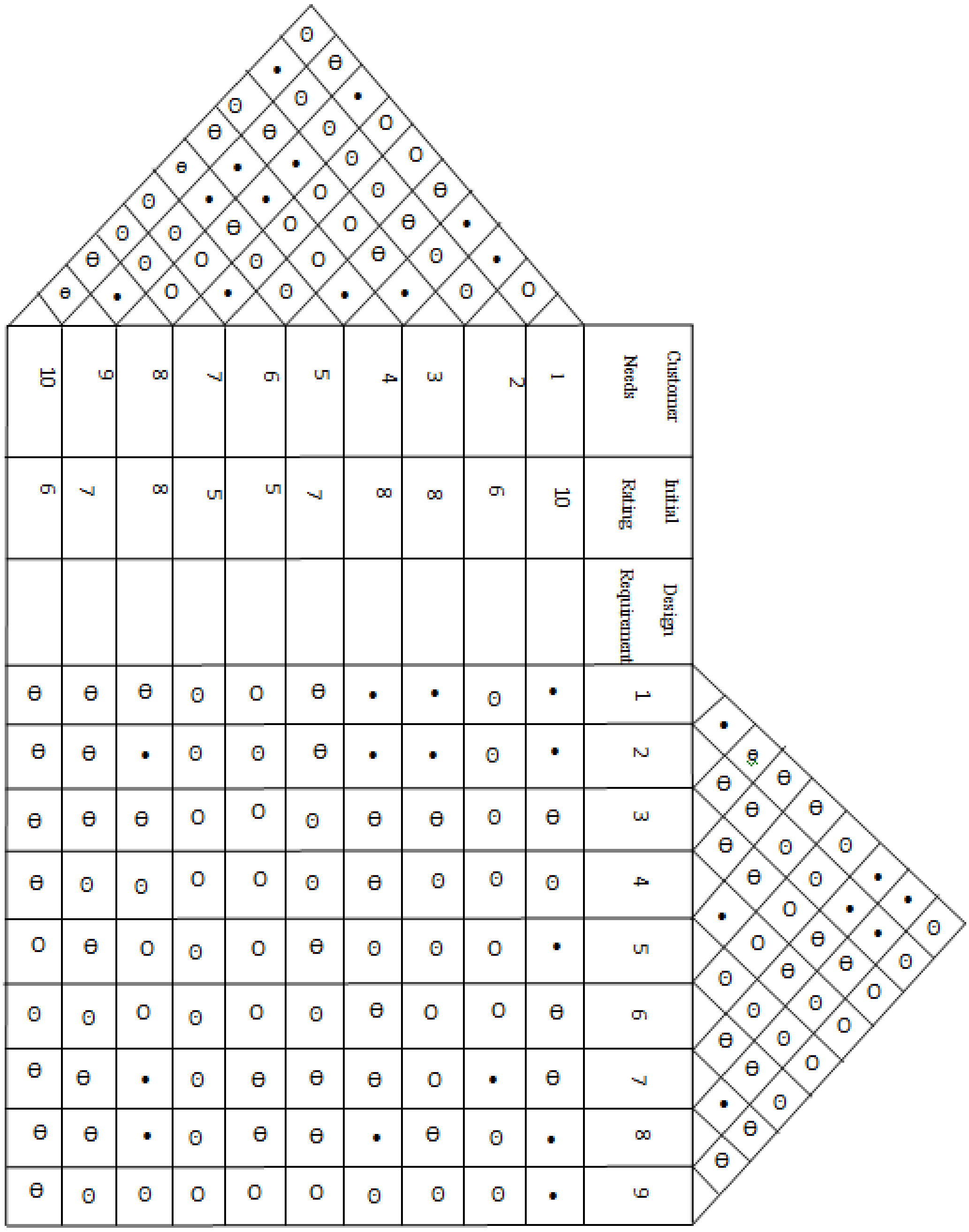


Figure 3.2 QFD model for comfortness

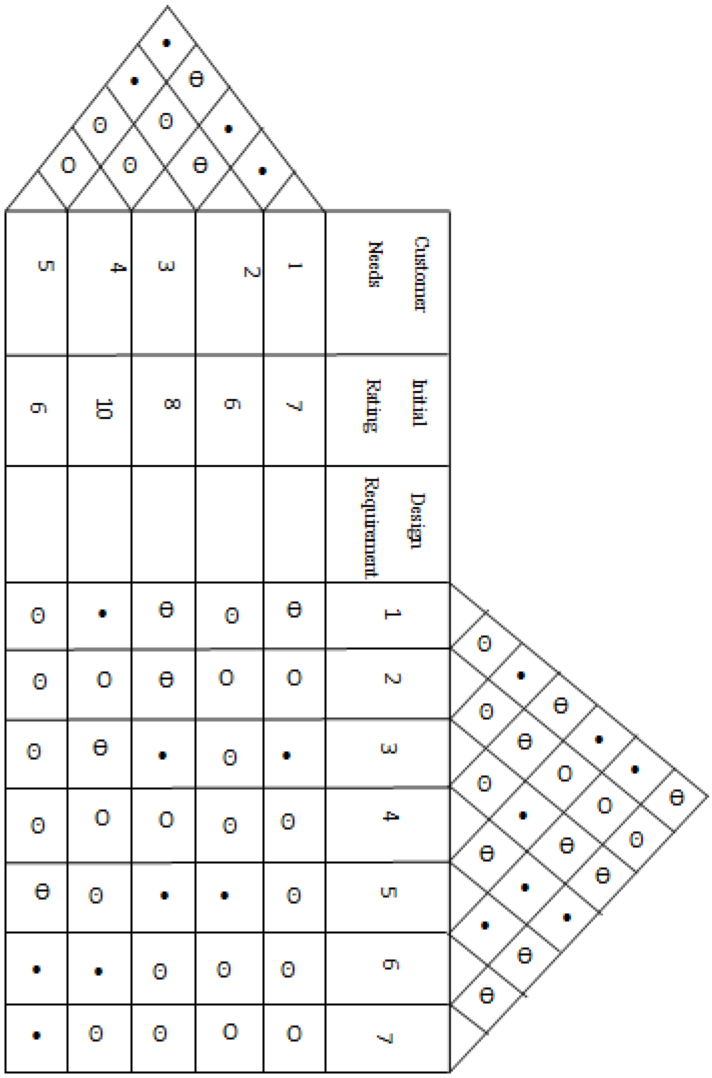


Figure 3.3 QFD model for balance

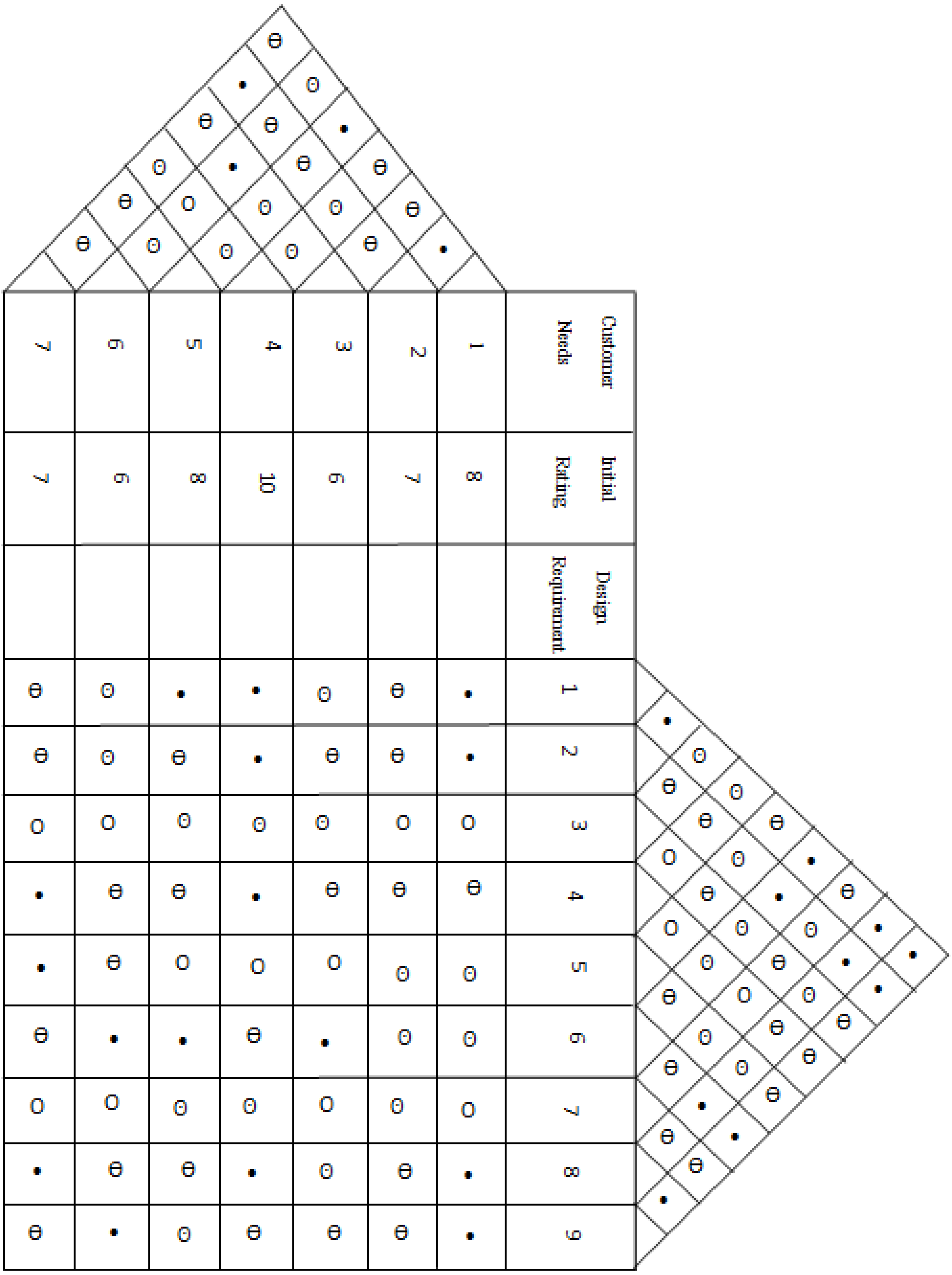
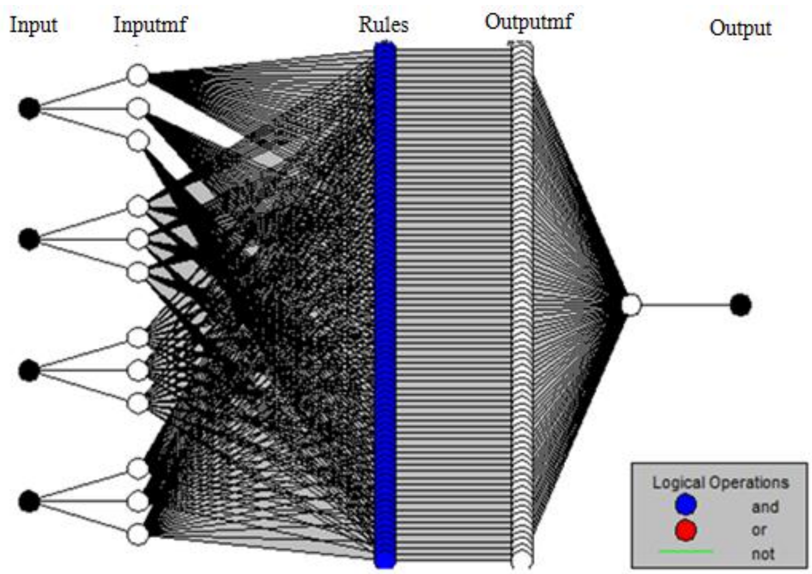
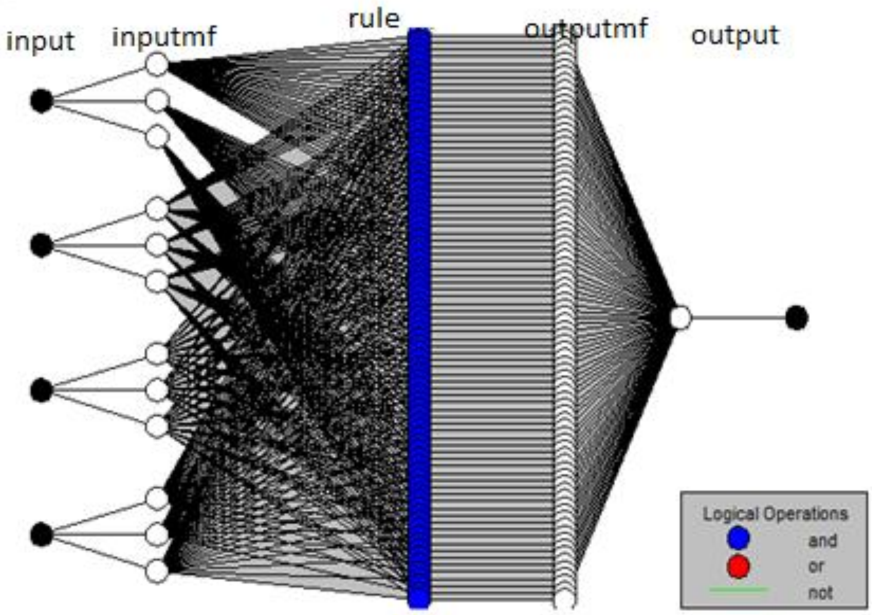


Figure 3.4 QFD model for luxuriousness

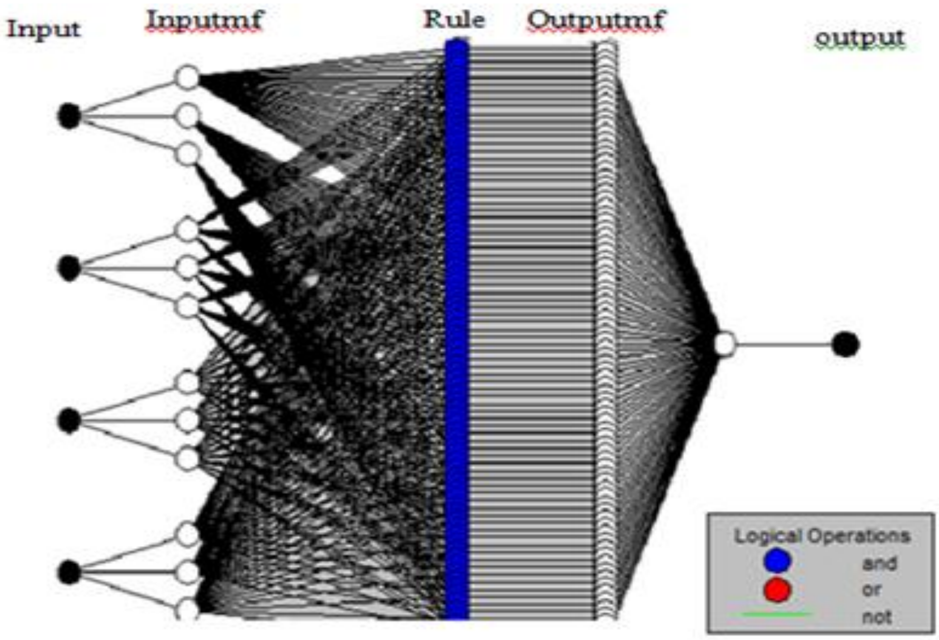
One hundred twenty five survey data collected from the respondents over 13 types of chairs regarding satisfaction level of the users are used in the ANFIS model to develop the relationship between design attributes and customer satisfaction. Three ANFIS models have been developed to relate QFD model 1 (comfortness), QFD model 2 (balance) and QFD model 3 (luxuriousness). The inputs to each ANFIS model is the design attributes related to the type of QFD model obtained over 13 types of chairs during survey (basically these are chair dimensions or tangible design attributes shown in Table 3.2). The output of each model is nothing but the sum of the customer requirements. For example, ANFIS model for QFD model 1 (comfortness) treats four design attributes such as tilt of back rest, number of controls, overall width and overall height as inputs and sum of response value of ten customer requirements such as active sitting, cute, enjoyable, friendly, untroubled and free from disturbance, masculine, having plain surface, comfortable, flexible, and having lower back support as outputs. In each model, 94 data (75%) are used for training and 31 data (25%) used for testing. The data in each model is normalized by diving corresponding maximum value. The ANFIS architecture for three QFD models: (a) comfortness, (b) balance, (c) luxuriousness is shown in Figure 3.5. Input membership function is described with Gaussian membership function. Hybrid learning algorithm is used and ANFIS model is run till the error is minimized. Error is minimized in three epochs during training. Then, testing of data is carried out. The pattern of variation of actual and predicted response is shown for training and testing dataset for QFD model 1 (comfortness). Figures 3.6 and 3.7 shows that actual (blue dot) and predicted (red dot) values for three models which are uniformly distributed respectively for training and testing data.



(a) comfortness

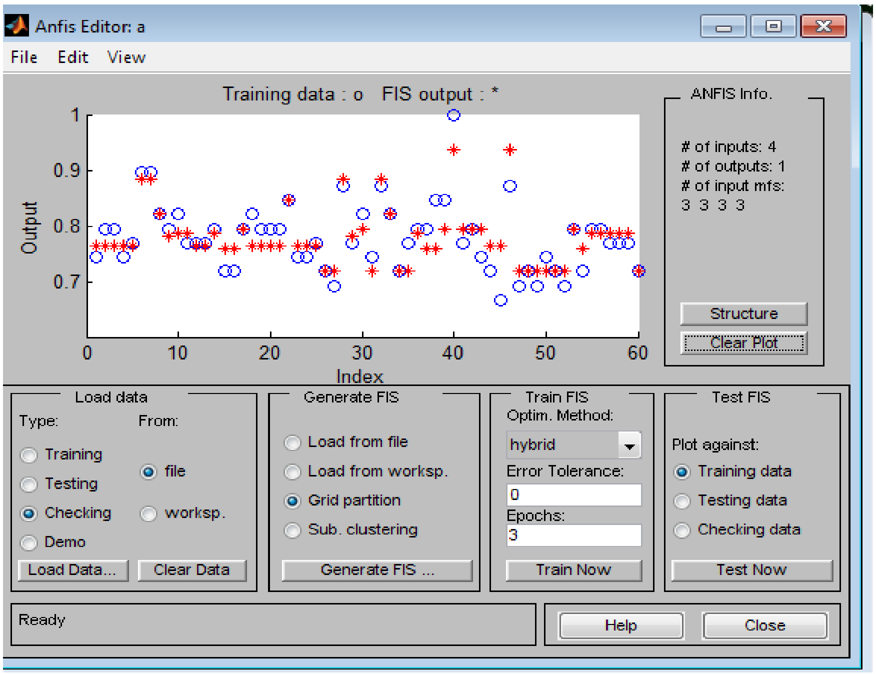


(b) balance

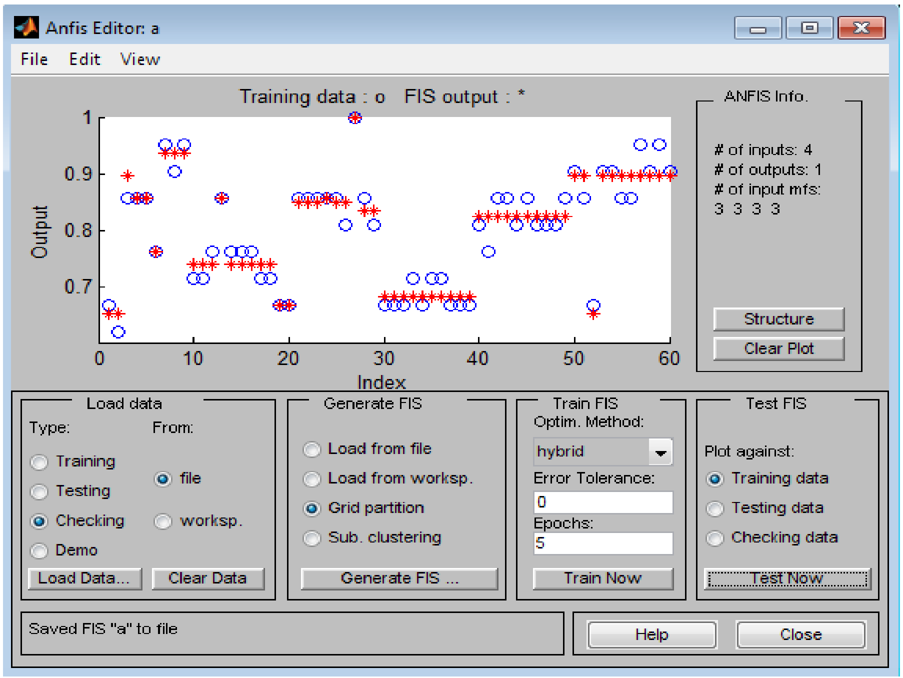


(c) luxuriousness

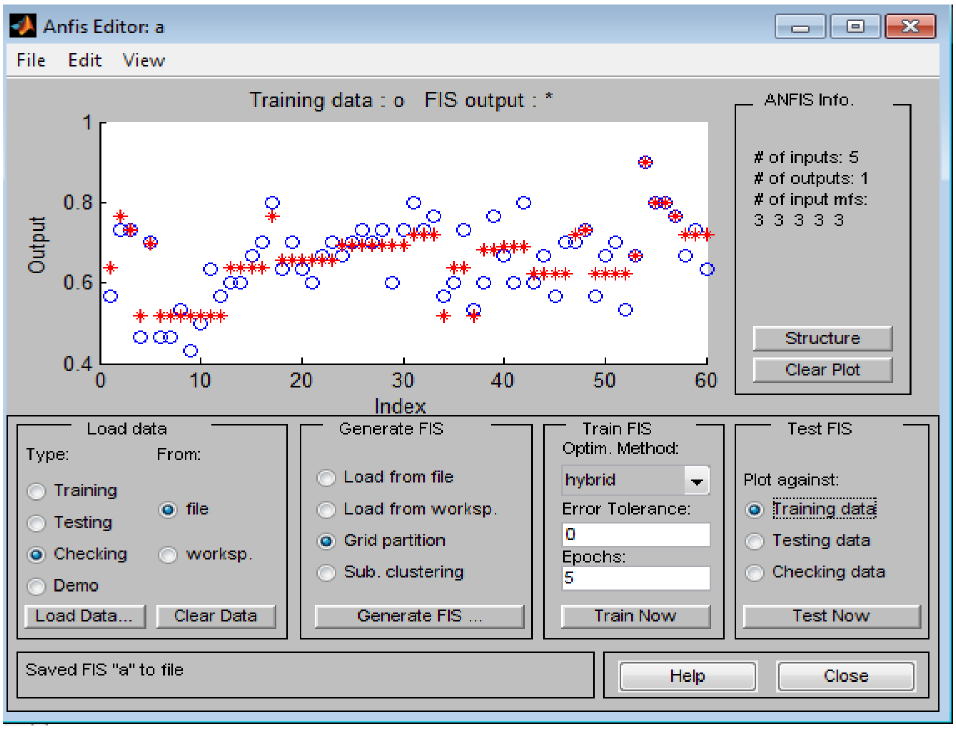
Figure 3.5 ANFIS model structure: (a) comfortness, (b) balance, (c) luxuriousness


Anfis Editor: a
File Edit View
Training data : o FIS output : *
Output
Index
ANFIS Info.
# of inputs: 4
# of outputs: 1
# of input mfs:
3 3 3 3
Structure
Clear Plot
Load data
Type:
From:
Training
Testing
Checking
Demo
file
worksp.
Load Data...
Clear Data
Generate FIS
Load from file
Load from worksp.
Grid partition
Sub. clustering
Generate FIS ...
Train FIS
Optim. Method:
hybrid
Error Tolerance:
0
Epochs:
3
Train Now
Test FIS
Plot against:
Training data
Testing data
Checking data
Test Now
Ready
Help
Close

(a)

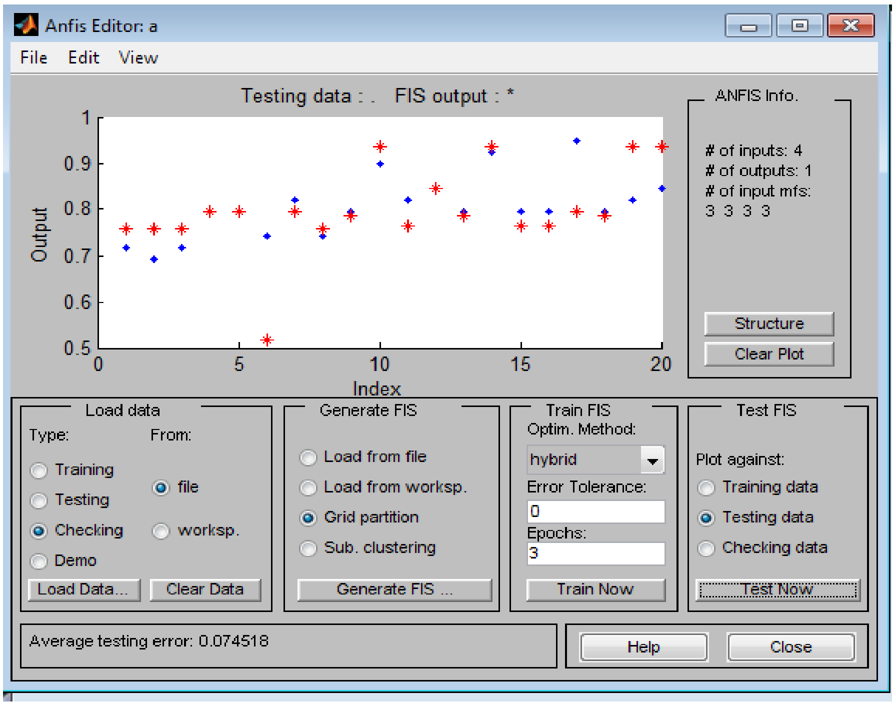

Anfis Editor: a
File Edit View
Training data : o FIS output : *
Output
Index
ANFIS Info.
# of inputs: 4
# of outputs: 1
# of input mfs:
3 3 3 3
Structure
Clear Plot
Load data
Type:
From:
Training
Testing
Checking
Demo
file
worksp.
Load Data...
Clear Data
Generate FIS
Load from file
Load from worksp.
Grid partition
Sub. clustering
Generate FIS ...
Train FIS
Optim. Method:
hybrid
Error Tolerance:
0
Epochs:
5
Train Now
Test FIS
Plot against:
Training data
Testing data
Checking data
Test Now
Saved FIS "a" to file
Help
Close

(b)

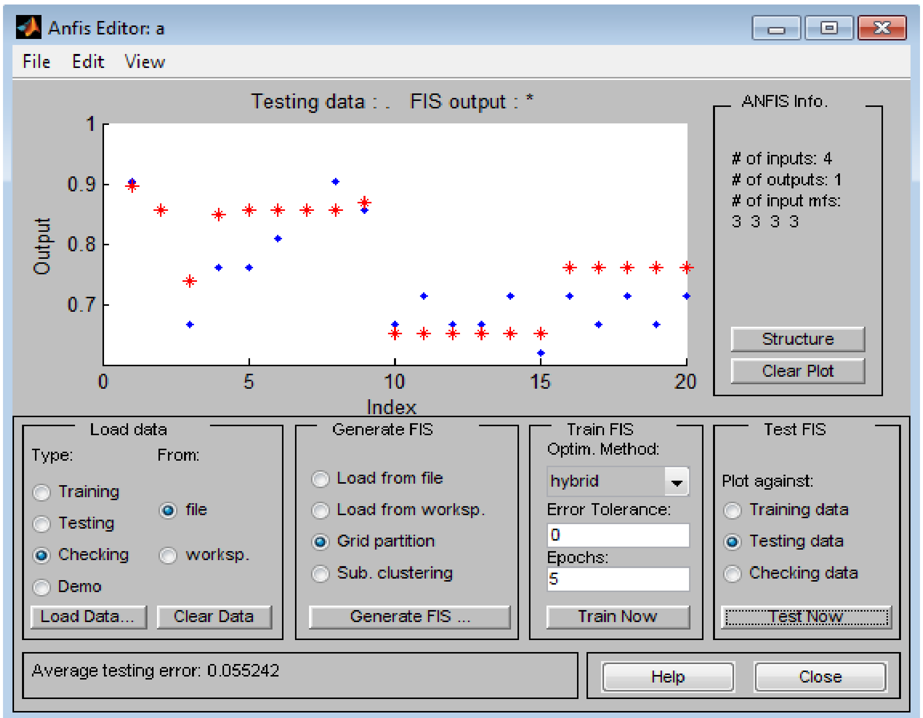


(c)

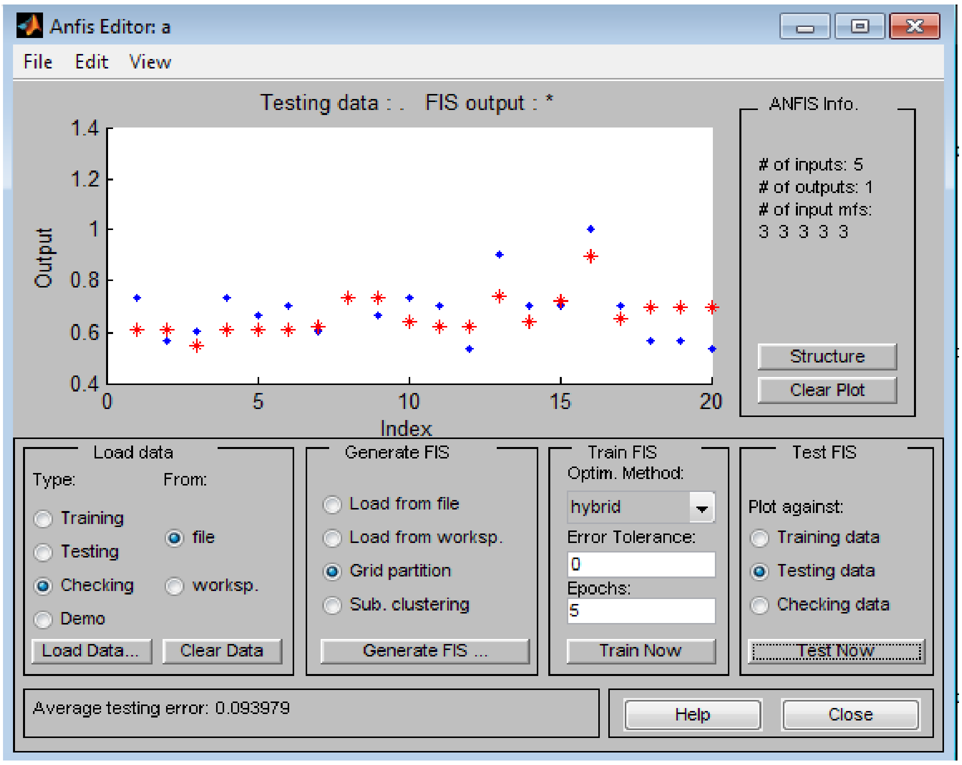
Figure 3.6 Distribution of predicted and actual response training: (a) comfortness, (b) balance, (c) luxuriousness



(a) comfortness



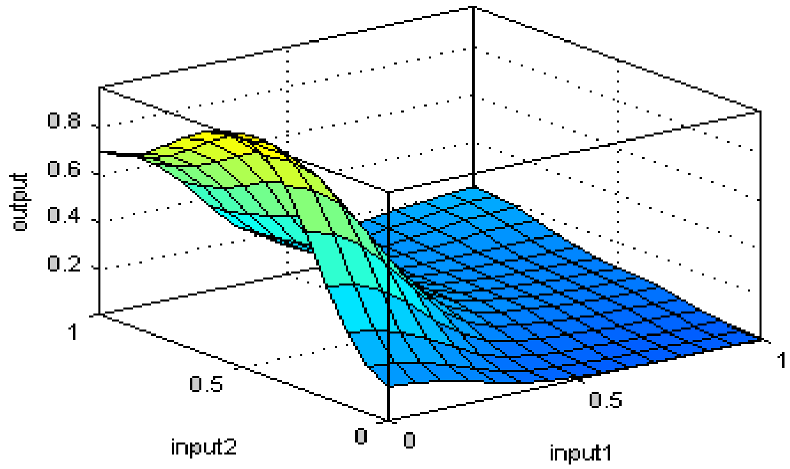
(b) balance



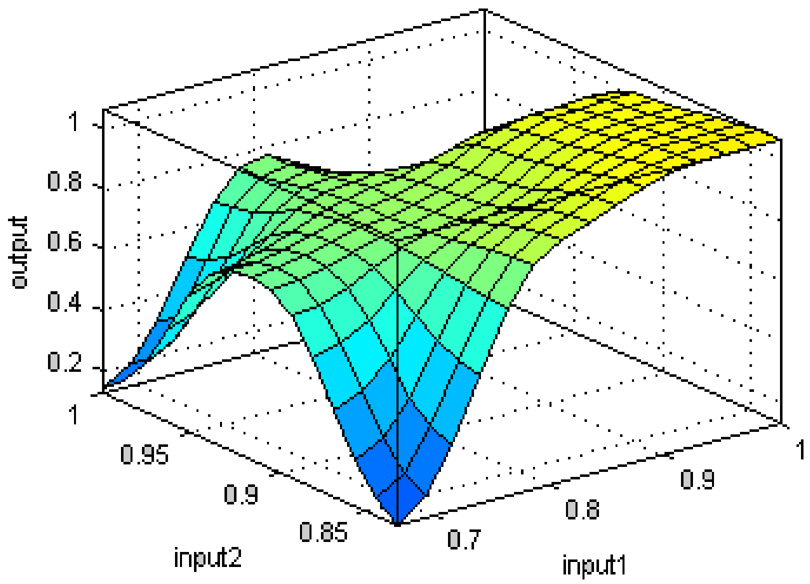
(c)luxuriousness

Figure 3.7 Distribution of predicted and actual response testing: (a) luxuriousness, (b) balance, (c) luxuriousness

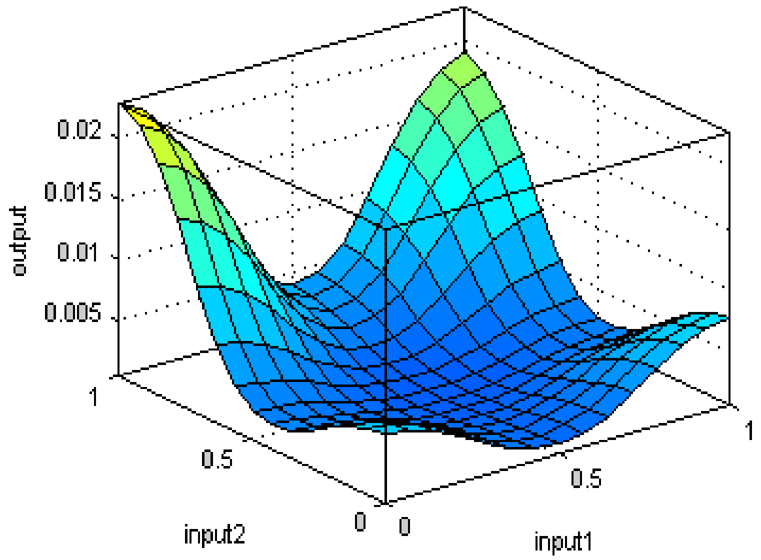
The surface plot shown in Figure 3.8 indicates that the total landscape of decision space is covered by the ANFIS model for QFD model 1 (comfortness).For the model 1(comfortness), Input 1 indicates 'tilt of backrest' and input 2 indicates 'number of controls'. Similarly for model 2 (balance), input 1 is 'width-height ratio of seat pan' and input 2 is 'width-height ratio of whole body' and for model 3(luxuriousness), input 1 is 'backrest height' and input 2 is 'use of pattern'.



(a) comfortness



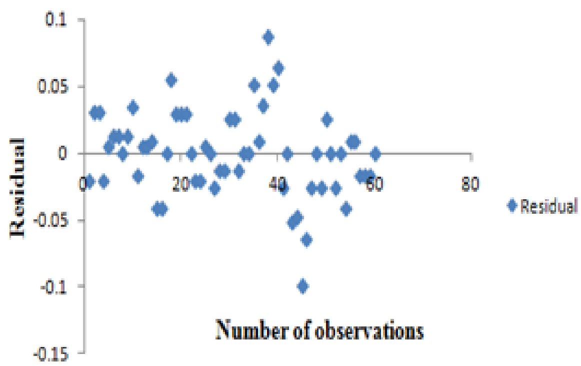
(b) balance



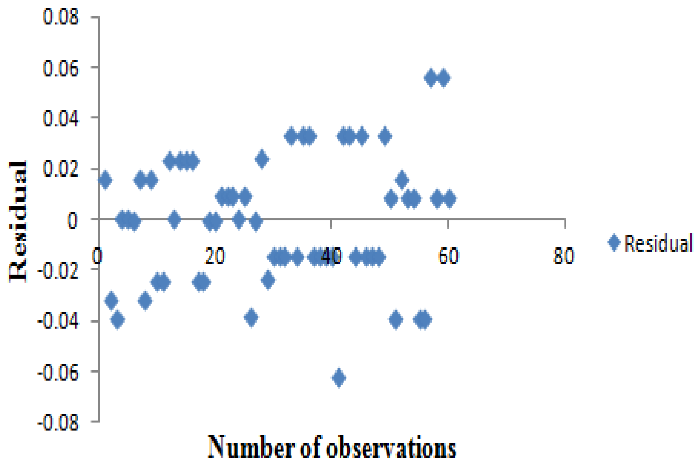
(c) luxuriousness

Figure 3.8 Surface plots: (a) comfortness (b) balance(c) luxuriousness

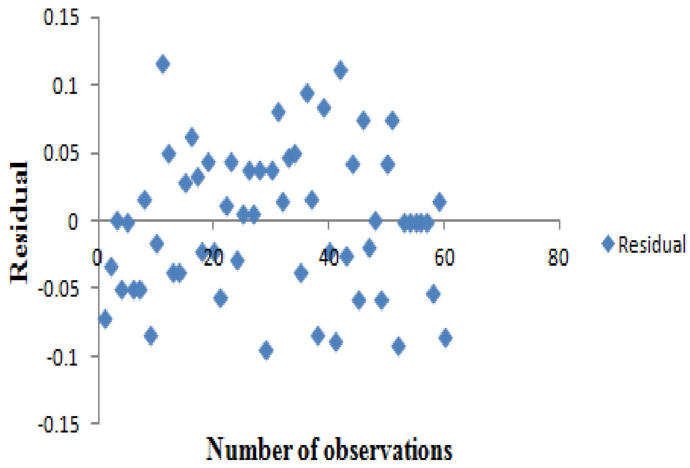
The residual analysis is carried out for the predicted values of the model by calculating the difference of actual and predicted values for training and testing data. The residual plots for three factors are depicted in Figure 3.9. It is observed that the residuals for three factors are distributed uniformly along the centre line. The absolute percentage relative error in training phase is 0.00039 and in testing phase 0.122164. The residuals are distributed normally when tested with Anderson-Darling test statistic. Similar procedure is adopted to predict the response for QFD model 2 (balance) and 3 (luxuriousness). The absolute percentage relative error for QFD model 2 (balance) is 0.025632 (training) and 0.063265 (testing). Similarly, absolute percentage relative error for QFD model 3 (luxuriousness) is 0.068057 (training) and 0.124575 (testing).Therefore, it can be stated that prediction of customer satisfaction can be made with ANFIS accurately.



(a) comfortness



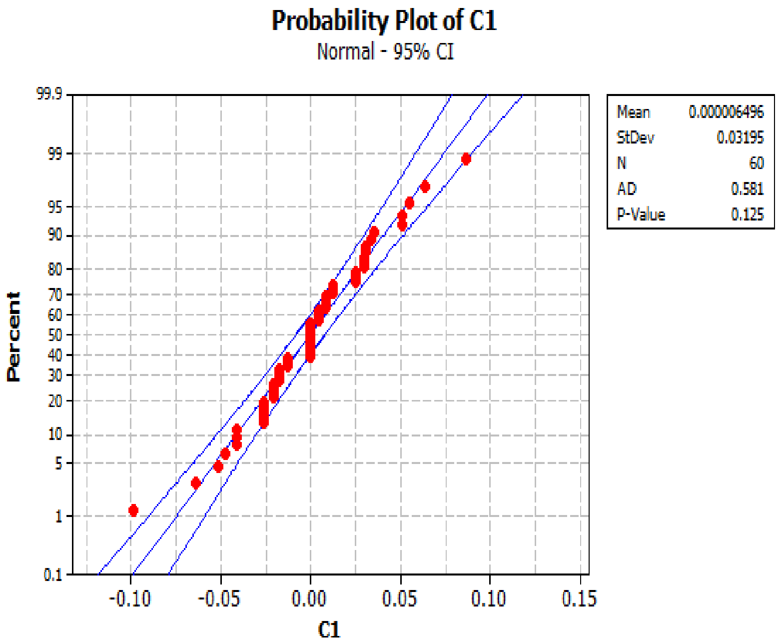
(b) balance



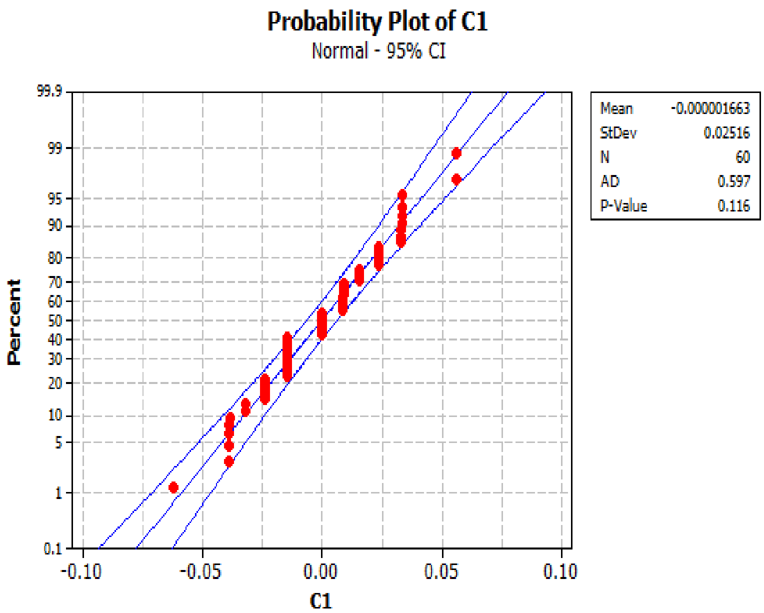
(c) luxuriousness

Figure 3.9 Residual plots: (a) comfortness (b) balance(c) luxuriousness

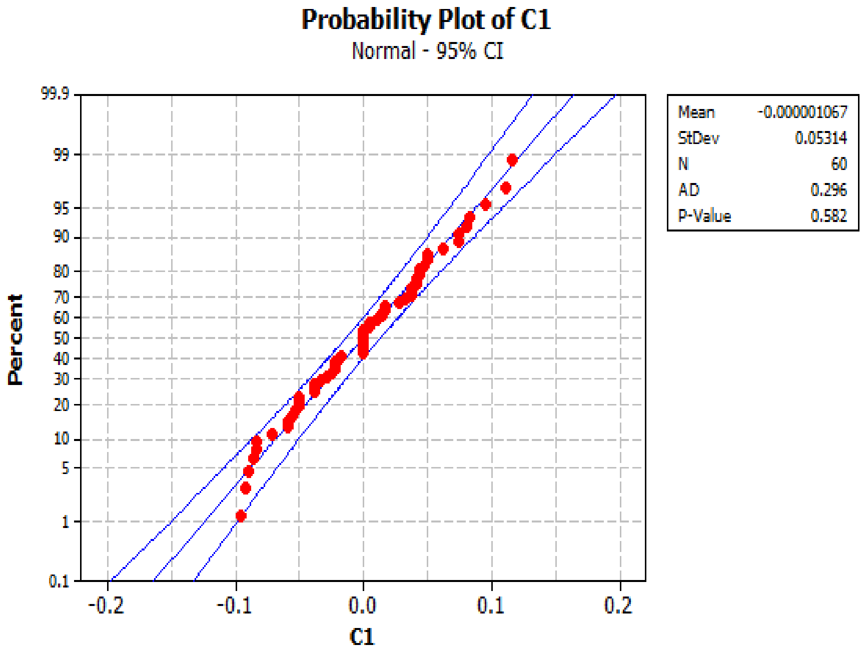
The Anderson-Darling test (AD Test) is also carried out in order to compare the fit of an observed cumulative distribution function to an expected cumulative distribution function. Smaller the AD value, greater is the evidence that the data fit to the normal distribution. The test results are shown in Figure 3.10 for respective factors (comfortness, balance, luxuriousness) standardized residue. The following figures suggest that all the data are normally distributed for the data obtained from ANFIS model. Similarly, the normal probability plot of residual for testing data of three models is shown in Figure. Since p-value of the normality plots is found to be above 0.05, it signifies that residue follows normal distribution.



(a) comfortness



(b) balance



(c) luxuriousness

Figure 3.10 Normal probability curve of residual at 95% confidence level:(a)comfortness(b)balance(c)luxuriousness

Table 3.11 Levels of various designs attributes (parameters)

Symbol	control parameters	Actual levels				Coded levels		
		Low	Medium	High	Maximum	Low	Medium	High
A	Use of pattern	No		Yes		0.000		1.000
B	Use of cushion	No		Yes		0.000		1.000
C	Use of decoration	No		Yes		0.000		1.000
D	Height adjustment(mm)	89.7	101.6	112.3	132.6	0.677	0.767	0.847
E	Overall height of backrest(mm)	370.5	426.0	528.0	584	0.635	0.730	0.921
F	Tilt of backrest(in degree)	18	19	26	32	0.563	0.594	0.813
G	Number of controls	No	One	Two	Two	0.000	0.500	1.000
H	Total height(mm)	990	1,110	1,245	1,245	0.795	0.892	1.000
I	Total width(mm)	535	620	838	838	0.638	0.740	1.000
J	Width-height ratio of backrest	0.712	0.833	0.935	1,066	0.668	0.782	0.877
K	Width-Length ratio of seat pan	0.941	0.992	1.024	1,128	0.834	0.879	0.907
L	Width-height ratio of whole body	0.200	0.486	0.638	0.854	0.234	0.569	0.747
M	Width-height ratio of armrest	0.228	0.319	0.55	0.55	0.415	0.580	1.000

Table 3.12 Experimental design using orthogonal array of $L_{36}\left(2^3 \times 3^{10}\right)$

L_{36} $\left(2^3 \times 3^{10}\right)$	A	B	C	D	E	F	G	H	I	J	K	L	M	Response	Mean
1	0	0	0	0.677	0.635	0.563	0.000	0.795	0.638	0.668	0.834	0.234	0.415	2.275	2.275
2	0	0	0	0.767	0.730	0.594	0.500	0.892	0.740	0.782	0.879	0.569	0.580	4.909	4.909
3	0	0	0	0.847	0.921	0.813	1.000	1.000	1.000	0.877	0.907	0.747	1.000	0.510	0.510
4	0	0	0	0.677	0.635	0.563	0.000	0.892	0.740	0.782	0.879	0.747	1.000	2.228	2.228
5	0	0	0	0.767	0.730	0.594	0.500	1.000	1.000	0.877	0.907	0.234	0.415	1.333	1.333
6	0	0	0	0.847	0.921	0.813	1.000	0.795	0.638	0.668	0.834	0.569	0.580	4.299	4.299
7	0	0	1	0.677	0.635	0.594	1.000	0.795	0.740	0.877	0.907	0.234	0.580	1.340	1.340
8	0	0	1	0.767	0.730	0.813	0.000	0.892	1.000	0.668	0.834	0.569	1.000	0.041	0.041
9	0	0	1	0.847	0.921	0.563	0.500	1.000	0.638	0.782	0.879	0.747	0.415	5.777	5.777
10	0	1	0	0.677	0.635	0.813	0.500	0.795	1.000	0.782	0.907	0.569	0.415	7.257	7.257
11	0	1	0	0.767	0.730	0.563	1.000	0.892	0.638	0.877	0.834	0.747	0.580	8.602	8.602
12	0	1	0	0.847	0.921	0.594	0.000	1.000	0.740	0.668	0.879	0.234	1.000	1.843	1.843
13	0	1	1	0.677	0.730	0.813	0.000	1.000	0.740	0.668	0.907	0.747	0.580	2.462	2.462
14	0	1	1	0.767	0.921	0.563	0.500	0.795	1.000	0.782	0.834	0.234	1.000	0.139	0.139
15	0	1	1	0.847	0.635	0.594	1.000	0.892	0.638	0.877	0.879	0.569	0.415	5.772	5.772
16	0	1	1	0.677	0.730	0.813	0.500	0.795	0.638	0.877	0.879	0.747	1.000	3.826	3.826
17	0	1	1	0.767	0.921	0.563	1.000	0.892	0.740	0.668	0.907	0.234	0.415	1.225	1.225
18	0	1	1	0.847	0.635	0.593	0.000	1.000	1.000	0.781	0.833	0.568	0.580	3.430	3.430

Thirteen important design attributes meeting all the three requirements such as comfortness, balance and luxuriousness of the customers (nine design attributes for comfortness, four design attributes from balance and five design attributes for luxuriousness) are treated as various factors for the design of office chair. The relationship of these attributes with customer satisfaction is established through ANFIS model. In order to search the best design, a large number of scenarios were generated using DOE approach. The criteria for best design parameter are based on 'larger-the-better' type, i.e., maximizing customer satisfaction level. The design attributes (parameters) are use of pattern, use of cushion, use of decoration, number of control used, range of height adjustment, backrest height, tilt of backrest, overall height, overall width, width-height ratio of backrest, width-length ratio of seat pan, width-height ratio of whole body and width-height ratio of armrest. Out of 13 parameters (design attributes), three parameters, each having two levels (low and high) and ten parameters, each having three levels (low, medium, high) are considered. This requires a total of (2^3 * 3^{10}) = 472,392 experiments. But Taguchi's mixed level experiments can produce same information using 36 experiments. Each parametric level is divided by the maximum value of design attribute (parameter) to set the levels. Because of frequency of occurrence maximum parametric values is comparatively less as observed in the survey. Therefore, frequently occurring parametric values are used to set the levels as shown in Table 3.9. Three ANFIS models (for QFD models 1, 2 and 3) were run considering respective design attributes to obtain the response (customer satisfaction). The customer satisfaction values obtained from three models are summed to provide the response for DOE scenario generation assuming equal weightage for customer requirement factors such as comfortness, balance and luxuriousness. The experimental layout along with the responses is shown in Table 3.10. The main effect plot shown in Figure 3.11 finds the optimal setting of design attributes as A_1 B_1 C_0 $D_{0.767}$ $E_{0.635}$ $F_{0.594}$ $G_{0.5}$ $H_{0.892}$ $I_{0.638}$ $J_{0.877}$ $K_{0.879}$ $L0_{.569}$ $M_{0.415}$.

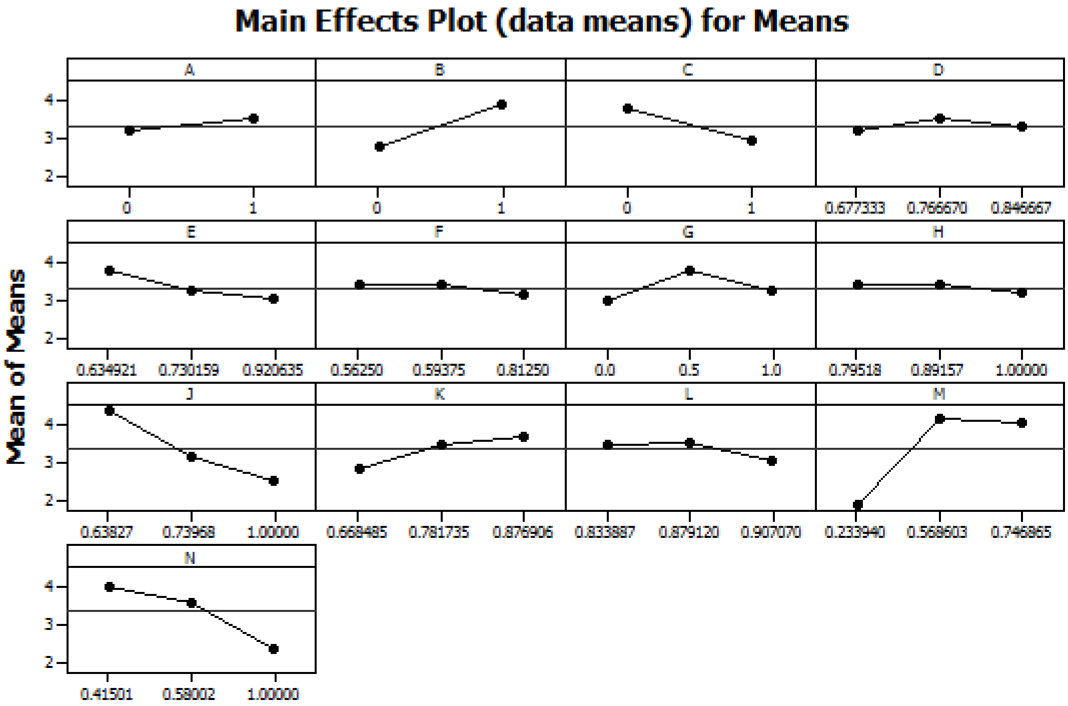


Figure 3.11 Effect of control design parameters on response

The values of optimal design attributes of office chair are shown in Table 3.11. These values are compared with office chair dimensions of BIS. However, BIS does not provide values of all the attributes considered in this work. Therefore, a few dimensions (design attributes) are selected to verify the design. It can be observed from the Table 11 that four design attributes such as height range adjustment (D), total height of backrest (E), whole body height (H), and whole body width (I) are within the limits. However, height range adjustment is slightly (1 to 2 millimeters) above the BIS limit. Four BIS elements such as width of the seat, depth of the seat, height of seat pan from the floor (higher range), and height of seat pan from the floor (lower range) are considered for comparing the design attribute values so obtained (Table 3.12). Width of the seat is obtained by deducting sum of armrest width and clearance from the overall seat width (arm rest width is obtained as 30 mm from the survey data and arm rest width both sides is 60 mm whereas a clearance of 3.5 mm is assumed). The width of seat is calculated as 471.5 mm which is more than the BIS specification of 450 mm. Depth of the seat is obtained by dividing width of seat by optimal width-depth ratio of seat pan. The calculated depth of seat is 475 mm which is above the minimum BIS limit. Height of seat pan from the floor (higher range) is calculated by subtracting total height of backrest from whole body height. The value is 452 mm which is below the maximum limit of 500 specified by BIS. Height of seat pan from the floor (lower range) is calculated by subtracting height range adjustment from height of seat pan from the floor (higher range). The value is calculated as 350 mm which is below the minimum BIS specification of 400 mm.

Table 3.13 Comparison of optimum parameter with Bureau of Indian Standard (BIS)

Sl. No	Design attributes	Optimal values of design attributes	BIS specifications(mm)
A	Use of pattern	Yes	
B	Use of cushion	Yes	
C	Use of decoration	No	
D	Height range adjustment(mm)	101.6	100
E	Total height of backrest(in degree)	538.0	250(minimum)
F	Tilt of backrest	19^0	
G	Number of controls	1	
H	Whole body height(mm)	990.0	785.0(minimum)
I	Whole body width(mm)	535.0	535.0(minimum)
J	Width-height ratio of backrest	0.9347	
K	Width-height ratio of seat pan	0.992	
L	Width-height ratio of whole body	0.486	
M	Width-height ratio of arm rest	0.228	

By considering these dimensions, a prototype of office chair is made using Auto CAD Version 10 as shown in Figure 3.8 and3.9.

Table 3.14 Dimensions of prototype (excluding known control parameter) for comparison

BIS elements	Calculation from design attributes	Optimal values(mm)	BIS specifications(in mm)
Width of the seat	Whole width of seat including armrest-(width of armrest clearance)	535.0-(60+3.5)=471.5	450(minimum)
Depth of seat	Width of seat÷width depth ratio of seat pan	471.5÷ 0.992=475.0	400(minimum)
Height of seat pan from the floor(higher range)	Whole body height-Total height of backrest	0.992-538.0=452.0	500(maximum)
Height of seat pan from the floor(lower range)	Height of seat pan from the floor(higher range)-height range adjustment	452.0-101.6=350.4	400(minimum)

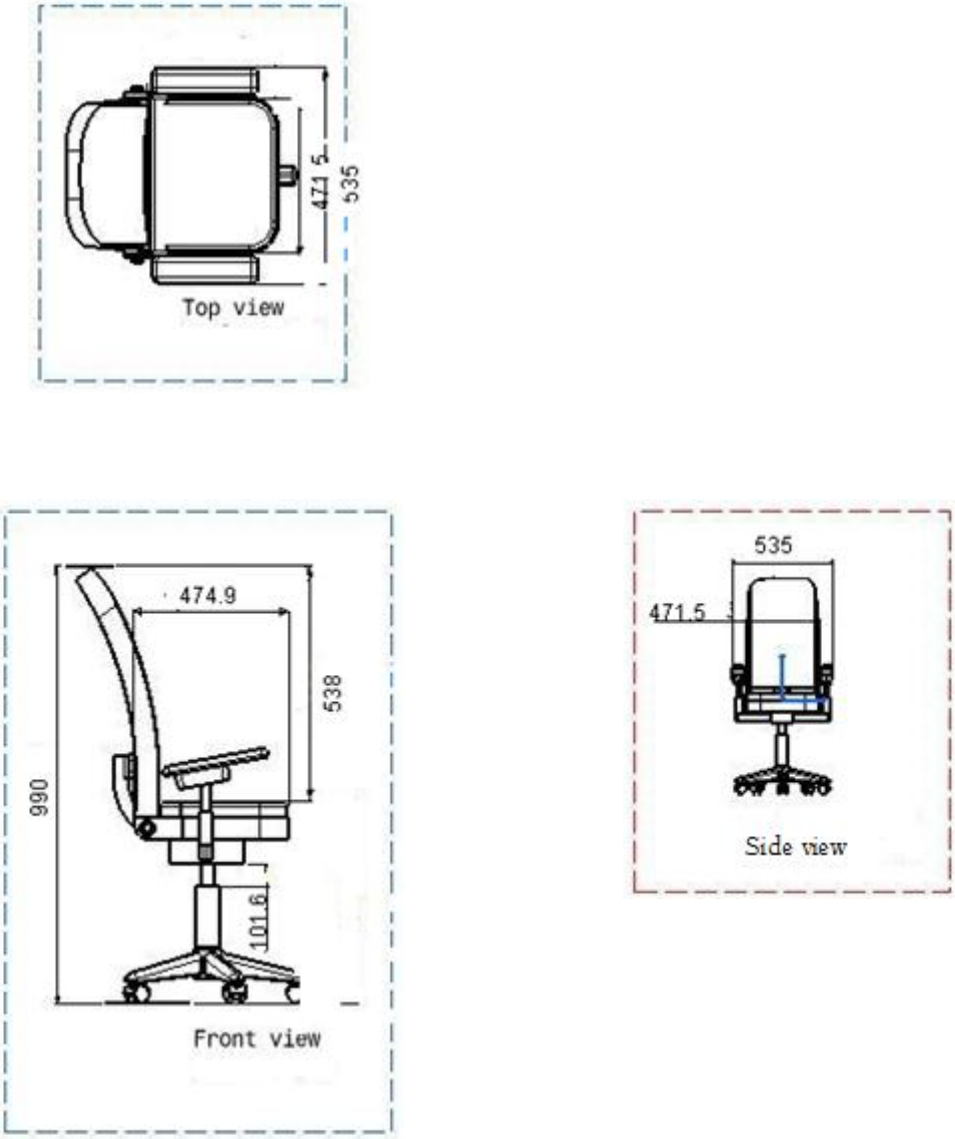


Figure 3.12 (a) Orthographic Projection (All dimensions are in mm)

Figure 3.12 (b) Prototype of office chair with optimized design parameter
(All dimensions are in mm)

3.4 Conclusions

Ergonomically designed industrial or office work environment considering both psychological and physical needs of employees helps to reduce fatigue when the employees continue prolonged work. Use of ergonomically designed equipment not only increases job satisfaction but also injury level can be prevented at the work place; hence enhance employees' efficiency and productivity. Since the design includes both subjective and objective criteria, it is not easy to design a product that improves user satisfaction. Therefore, an integrated approach using statistical and artificial intelligence techniques has been proposed in this article. The approach is described with the help of an office chair design. The user/customer requirements have been extracted through a cross-sectional survey. Factor analysis has been carried out on data to eliminate redundancy. The customer requirements are mapped to design attributes using QFD. A functional relationship has been developed among design attributes with customer satisfaction using adaptive neuro-fuzzy system. Finally, a Taguchi robust design approach is adopted to generate various scenario of office chairs having varied design attributes. Finally, the design that maximizes customer satisfaction has been chosen. The optimal design so obtained is compared with design specifications laid down in BIS. The proposed design satisfies most of comparable design elements of BIS. The variations are attributed to localization of sample data. The approach is quite general and can be adopted in any design.

CHAPTER 4

A NUMERICAL APPROACH FOR ERGONOMIC DESIGN

4.1 Introduction

Pressure ulcer is the localized area of tissue degeneration in sub-dermal tissue as a result of prolonged continuous mechanical load (National Pressure Ulcer Advisory Panel, 1989). External mechanical load (weight of the body) always induces a mechanical deformation in soft tissue (Chow and Odell, 1978). Excess pressure for a long time restricts the blood vessels resulting in the formation of tissue ischemia and ultimately tissue necrosis (Crenshaw and Vistnes, 1987). When a larger pressure is applied to soft tissue, it decreases the time of causing cell death and the tissue damage starts due to impaired capillary profusion giving rise to hypoxia (Kosiak et al., 1958). It has been indicated that the pressure sore mostly occurs at the lower part of body i.e. 43% at the sacrum and 5% at the ischial tuberocity (bony part). To lower the stress distribution, either the intensity of load or sitting time duration is to be reduced but at the same time the work at an office environment must not be compromised (Peterson,1976). Therefore, design modification of the product (chair seat cushion) or choosing the product with suitable properties should be emphasized to achieve this goal. Sitting comfort for a long time can decrease the rate of cell death. Seat cushion properties can be useful in reducing the deformation of tissues. Polyurethane foam with different properties can be used to investigate stress distribution at ischial tuberocity. Recently, number of studies have reported the effect of foam density, foam compressibility, strain rate and energy absorption of polymeric foam under uniaxial loading. Polyurethane foam under polymeric foam category is mostly used for seat cushion because it can undergo large compressive deformation and not only absorb but also dissipate considerable amount of energy under loading in comparison to solid specimen of equal volume (Avelle, 2001). Polyurethane foam exhibits viscoelastic behavior which depends upon the time scale of loading and temperature of material (Gibson, 2012; Lakes, 1999; Briody et al., 2012; Mills, 2007; Schrodt et al., 2005).

As the tissue lying below the bony part exhibits maximum stress under loading and undergoes tissue deformation, the present study focuses on the stress distribution at the tissue near bony prominence (ischial tuberocity) through numerical analysis by changing cushion properties. In this context, the mechanical condition of seat is considered by changing seat material properties and parameters to study change in stress distribution at ischial tuberocity. A rigid seat-buttock model is also considered for validation purpose. As the change in cushion properties are alone not sufficient for reduction in stress distribution at ischial tuberocity, further analysis with different thickness of cushion and loading angles has also been carried out. The objective of the present work is to develop a simple two dimensional finite element buttock-seat model with various material parameters, thicknesses of seat with different loading angle to predict stress at ischial tuberocity in order to provide guidelines to reduce occurrence of pressure ulcer.

4.2 Model descriptions

A volunteer weighing fifty five kilogram is contacted to obtain image of the buttock using magnetic resonance imaging (MRI) technique. The volunteer is scanned against a weight bearing posture sitting on MR compatible plastic chair with erect back rest and buttock support area 400 mm wide. Markers on the chairs are used to maintain the buttock position for the cushion by aligning the midline of body with a frontal marker on chair (Shabshin et al., 2010). Data on buttock of seated human including fats, muscles and ischial tuberocity is extracted from a double donut 0.5T open MR system for developing a 2D model representing buttock (Linder-Ganz et al.,2007; Linder-Ganz et al.,2008). Using the data from MRI, the position of ischial tuberocity, muscle and fats are traced and the boundary is located by maintaining the distance between ischial tuberocity and skin (Tang et al., 2010). A dimensional buttock model is made for exporting to simulation software. A non linear FE analysis using ANSYS 10.0 is developed to obtain the maximum stress distribution at ischial tuberocity due to the interaction of different seat cushion and buttock. Two different models comprising of human soft tissue-rigid seat (model I) and human soft tissue-soft polyurethane foam cushion (model II) are considered. The model includes a soft human tissue, ischial tuberocity (a bony part) and the seat as shown in Figure 4.1. Buttock-seat model is assumed to be two dimensional axisymmetric finite element model with an upright posture. Ischial tuberocity is assumed to be a circle of radius ten millimeters. The seat cushion has been modeled by a rectangular flat surface having thickness of 80 mm and area of 450×450 mm^2 (following standard office chair width of Bureau of Indian Standards specification). In order to analyze the structure, the model is divided into small sub-domains (elements) and the equations are discretized and solved within each of the sub-domains (elements).

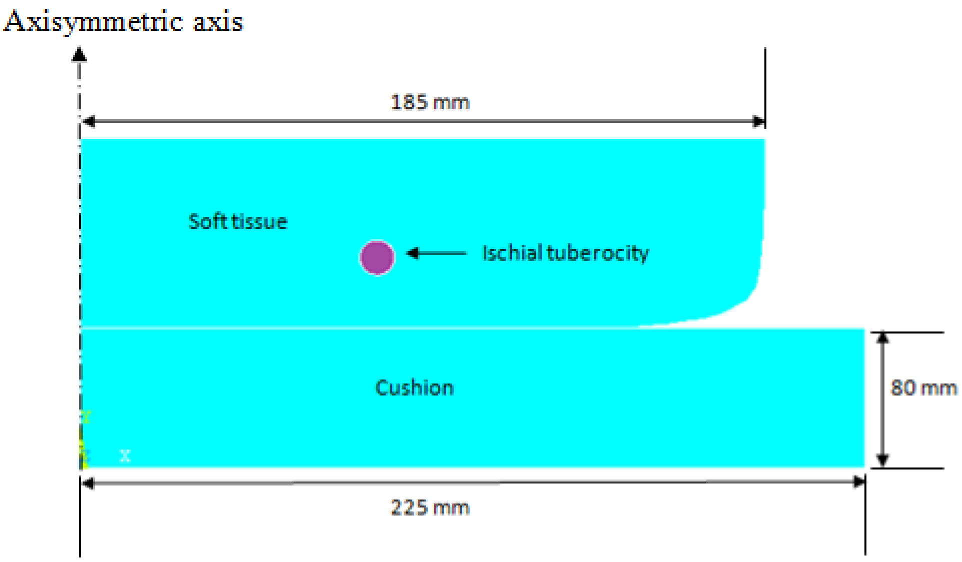


Figure 4.1 Model of seat cushion and buttock (soft tissue)

As seen from Figure 4.2, x-y plane is considered to present the meshed axisymmetric model of buttock as well as seat with boundary conditions. Bottom of the seat is fixed from all directions. Contact interface is determined to make an interaction between seat and buttock. Load is applied due to the weight of the upper part of the body. The load carried by the soft tissue is 22kg which is the half of the upper part of an average weighed human being (Tang et al., 2010). The components of both soft tissue and seat model are meshed with four-node first order quadrilateral finite elements. The simulation is conducted over a period of three hours to study the effect of time of loading on soft tissue. Displacement for all nodes along the axisymmetric line is fixed. The seat-buttock model is meshed with 1194 four-node quadrilateral solid finite elements. Plane 182 element type is used for simulation of both seat and buttock. An element is defined by four nodes and each node carries two degrees of freedom (translation along x and y directions). To model the interaction between human buttock and seat cushion, contact element CONTA 171 is used. A total of 100 steps are considered for each simulation run.

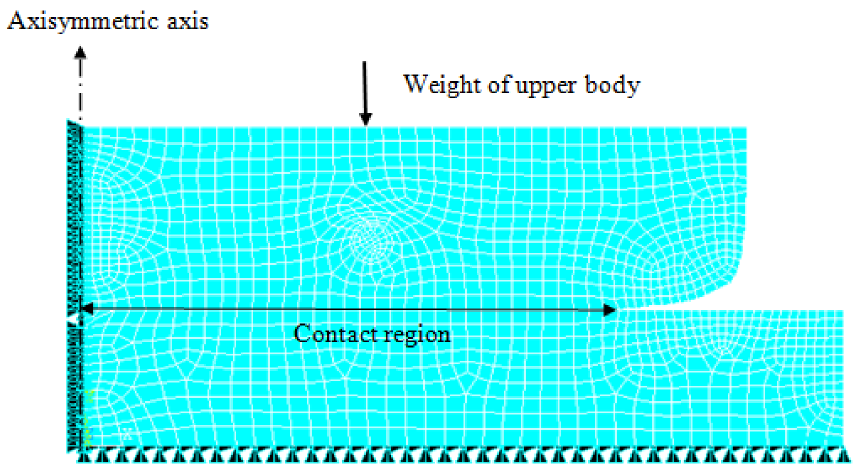


Figure 4.2 Finite element model of seat cushion and buttock (soft tissue)

The stress distribution throughout meshed model is studied by varying the material properties of seat cushion, angle of loading (sitting posture) and cushion thickness. The angle of loading ranges from 0^0 to 30^0. The thickness of cushion ranges from 60 mm to 80 mm.

4.2.1 Material properties for seat

Since polyurethane foam falls under elastomers category, hyper-elasticity is used to describe the material properties. Odgen hyper-elastic model based on stretch ratio is considered to describe the current state of deformation in soft cushion (Odgen, 1997).The governing equation used for the analysis is a strain energy function given as follows.

$$U = \sum_{i=1}^{N} \frac{2\mu_i}{\alpha_i^2} \left[\left(\hat{\lambda}_1^{\alpha_i} + \hat{\lambda}_2^{\alpha_i} + \hat{\lambda}_3^{\alpha_i} - 3 \right) + \frac{1}{\beta_i} \left(J^{el^{-\alpha_i\beta_i}} - 1 \right) \right] \quad (4.1)$$

where N is the order of fitting, μ_i, α_i and β_i are the temperature dependent material parameters to be determined, J^{el} and J^{th} are the elastic volumetric deformation and thermal volumetric deformation respectively, $\hat{\lambda}_1, \hat{\lambda}_2, \hat{\lambda}_3$ are the principal stretch ratios which provide a measure of deformation.

All the polyurethane foams exhibit some visco-elastic properties with deformation depending upon the load, time, and temperature. Stress relaxation is an important factor for analysis as the deformation exists even after the removal of the stress. Visco-elastic behavior occurs in the process of prolonged sitting and the behavior is defined in terms of time based Prony series model. The governing equation is given as:

$$G(t) = G_0 - \sum_{i=1}^{N} G_i \left(1 - e^{\frac{t}{\tau_i}}\right) \quad (4.2)$$

where τ_i (relaxation time), G_i (relaxation modulus) and G_0 (instantaneous shear modulus) are the material dependent parameters determined by relaxation test and N is the order of Prony series.

Three different types of seat materials are considered for analysis. For a rigid seat (model I), low carbon steel with elastic modulus of 210 GPa and Poisson's ratio of 0.3 is considered. The density (ρ) of the rigid seat is considered as 100kg/m^3. Model II allows the simulation of polyurethane foam cushion with two different material stiffness and density. Due to the rigidity of the bony part (ischial tuberocity), it allows only linear elastic material properties and having stiffness of E=80GPa and density, ρ =1600kg/m^3. The model II undergoes large elastic deformation with approximately 70% deformation for both the polyurethane material. One of the polyurethane foam considered as SAF 6060 having modulus of elasticity of E=200 kPa and density ρ =60 kg/m^3. Material parameters for SAF 6060 cushion is highlighted in Table 4.1. A strain energy function of second order under uniaxial compression test was implemented to find out the material properties of soft foam (Schrodt,2005).The test indicates that material properties of the foam depend upon the temperature and humidity. Similarly, by choosing the order of Prony series and performing a curve fitting from the experimental results of relaxation test, the visco-elastic parameters can be estimated (Gru-jicic, 2009). Table 4.2 shows visco-elastic material parameters under time based Prony series model of second order.

Table 4.1 Material properties for Ogden hyper-foam (SAF 6060) for soft cushion (E=200 kPa, ρ = 60 kg/m^3)

μ_1(MPa)	α_1	β_1	μ_2(MPa)	α_2	β_2
0.481×10^{-2}	0.198×10^{2}	0.145×10^{-1}	0.36×10^{-2}	0.198×10^{2}	0.65×10^{-2}

Table 4.2 Coefficients of Prony series parameters for cushion exhibiting viscoelasticity

N	G(i)	τ(sec)
1	0.3003	0.010014
2	0.1997	0.1002

The second polyurethane foam considered in the present analysis also belongs to polyurethane foam category but having elastic modulus of E=20 kPa and density of ρ = 40 kg/m^3. The data of material properties is obtained from uniaxial compression test (Briody, 2011). The Ogden hyper-foam model of second order is shown in Table 4.3. A set of Prony series material parameters of third order from relaxation test is defined in Table 4.4 (Briody, 2011).

Table 4.3 Material properties for Ogden hyper-foam for soft cushion (E=20 kPa, ρ = 40 kg/m^3)

μ_1(MPa)	α_1	β_1	μ_2(MPa)	α_2	β_2
0.44185×10^{-1}	21.4556	0	$.37050\times10^{-5}$	-6.8900	0

Table 4.4 Coefficients of Prony series parameters for cushion exhibiting viscoelasticity

N	G(i)	τ(sec)
1	0.0973	0.30639
2	0.1740	11.21
3	0.1290	1011

4.2.2 Material properties for human soft tissue

The buttock part of the human soft tissue is modeled with visco-hyper-elastic model. This hyper-elastic behavior of soft tissue is represented by polynomial strain energy potential function (U) based on strain invariant which shows the nonlinear, incompressible, isotropic, hyper-elastic polynomial behavior.

$$U = \sum_{i+j-1}^{N} C_{ij}\left(\bar{I}_1 - 3\right)^i\left(\bar{I}_2 - 3\right)^j + \sum_{i-1}^{N}\frac{1}{D_i}\left(J^{el} - 1\right)^{2i} \tag{4.3}$$

where U is the strain energy potential, J^{el} is the elastic volumetric deformation, $\bar{I}_1$ and $\bar{I}_2$ are the principal invariants which are independent of coordinate system used to measure the strain. N is the order of fitting and C_{ij} and D_i are the material parameters. C_{ij} describes the shear behaviour of the material and D_i denotes the compressibility. In this work, second order hyper-elastic parameters of tissue are considered as shown in Table 4.5 (Tang et al., 2010). The density of soft tissue is considered as 1000 kg/m^3 (Pennestrì, 2005).

Table 4.5 Material parameters for hyperelastic material to define the soft human tissue

C_{10}	C_{01}	C_{20}	C_{11}	C_{02}	D_1	D_2
0.08556	-0.05841	0.039	-0.02319	0.00851	3.65273	0

Viscoelastic parameter for soft tissue are considered as shear modulus, G_1=0.5, Bulk modulus, K_1=0.5 and relaxation time, τ_1 =0.8 secs which are taken from the work of Tang and Tsui,2006.

4.3 Results and discussions

Model I as shown in Figure 4.1 is simulated for three hours using ANSYS 10.0 and the von Mises stress distribution at ischial tuberocity after each half an hour interval is noticed to quantify the stresses for erect sitting posture. Figure 4.3 shows the variation of stress at ischial tuberocity for a rigid seat (Model I) at each half an hour for different seat thickness. Figure 4.4 shows the red patches depicting high stress region which is most probably the damage area for seat thickness of 80 mm. Both the Figures 4.3 and 4.4 indicate that the von Mises stress at ischial tuberocity goes on increasing with sitting time. However, the stress becomes constant after an interval of one and a half hours for seat thickness of 60 and 70 mm and two hours for seat thickness of 80 mm (Figure 3). It is evident from Figure 4.4 that the area of high stress region increases with time. Experimental studies report that tissue stiffening occurs after one hour of continuous loading of 32kPa (Linder-Ganz et al., 2006). The stress developed in human tissue within one hour of sitting is sufficient for causing cell death. After one hour of sitting, tissues have been stiffened and hence stresses on the tissue may not increase substantially. However, the intensity of load for stipulated time duration significantly influences cell damage. For example, a pressure of 11.5kPa for 360 minute of loading can cause the same damage as pressure of 35kPa for 15 minutes (Linder-Ganz et al., 2007). Figure 4.4(a) shows a maximum von Mises stress of 37193Pa at ischial tuberocity after sitting for half an hour. The result obtained through the present work is comparable with experimental value (26.7 kPa) obtained in Verver et al. (2004).

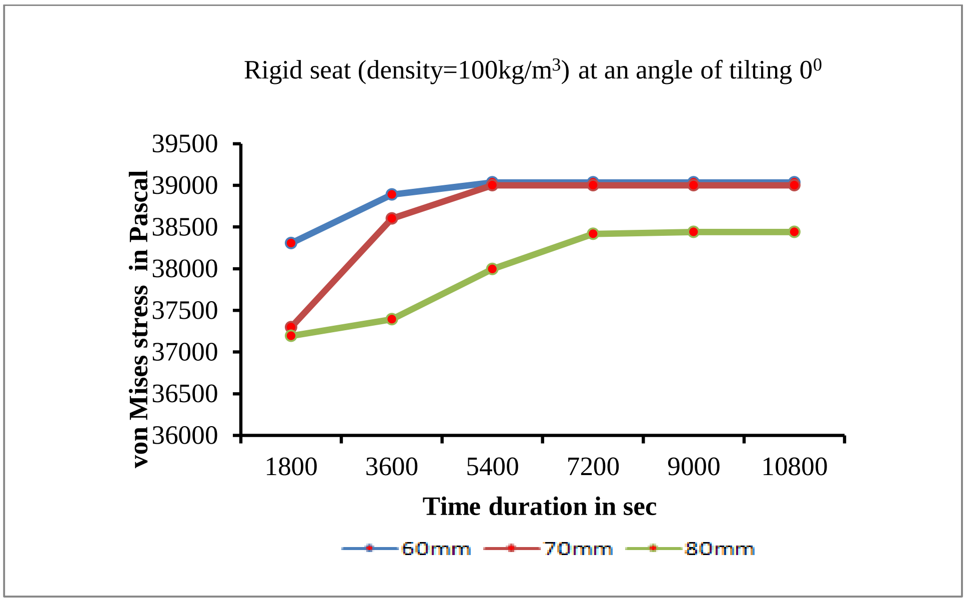


Figure 4.3 Variation of von Mises stress with increase in time for different thickness of seat

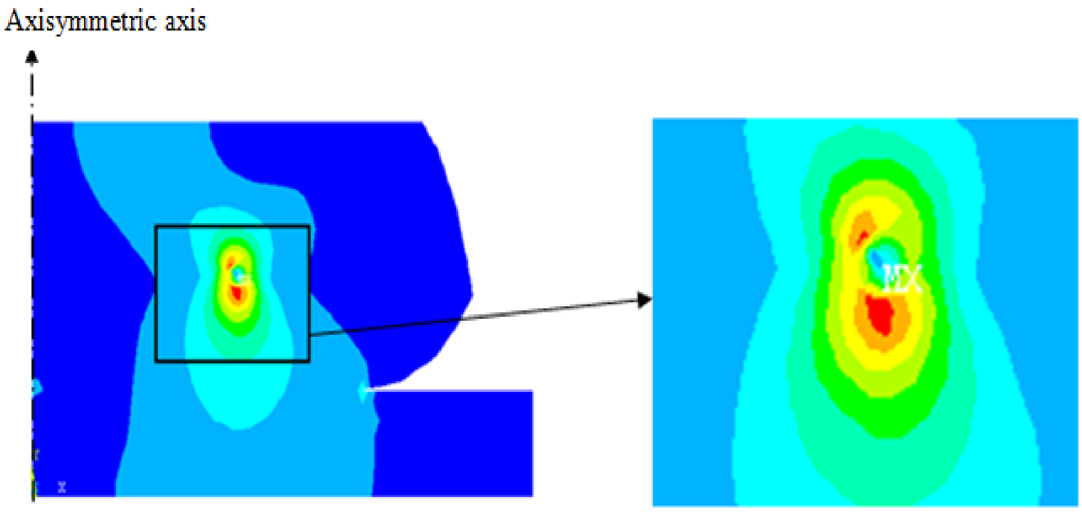


Figure 4.4 (a) Finite element model for rigid seat with magnification of muscle region subjected to high stress

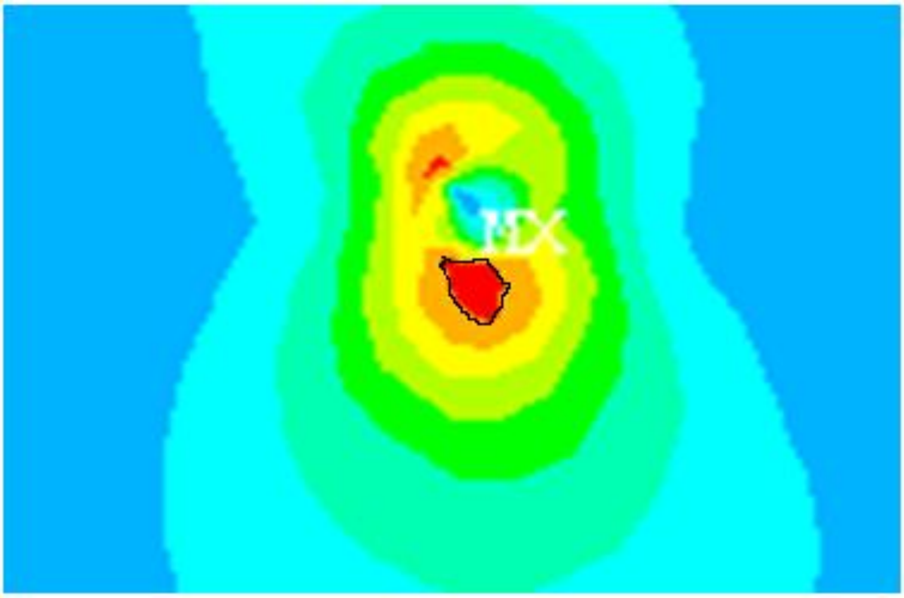


Figure 4.4 (b) Stress distribution at ischial tuberocity for erect immobilized continuous sitting on rigid seat of thickness of 80mm for 1800 sec (von Mises stress=37193Pa High stress area=11.20 mm^2)

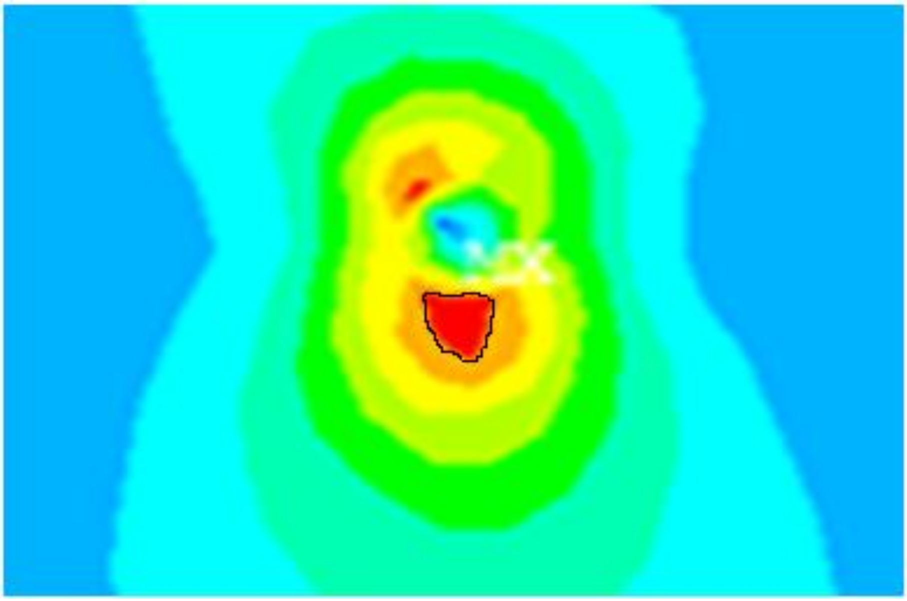


Figure 4.4 (c) Stress distribution at ischial tuberocity for erect immobilized continuous sitting on rigid seat of thickness of 80 mm for 5400 sec (von Mises stress=37997 Pa High stress area=17.02 mm^2)

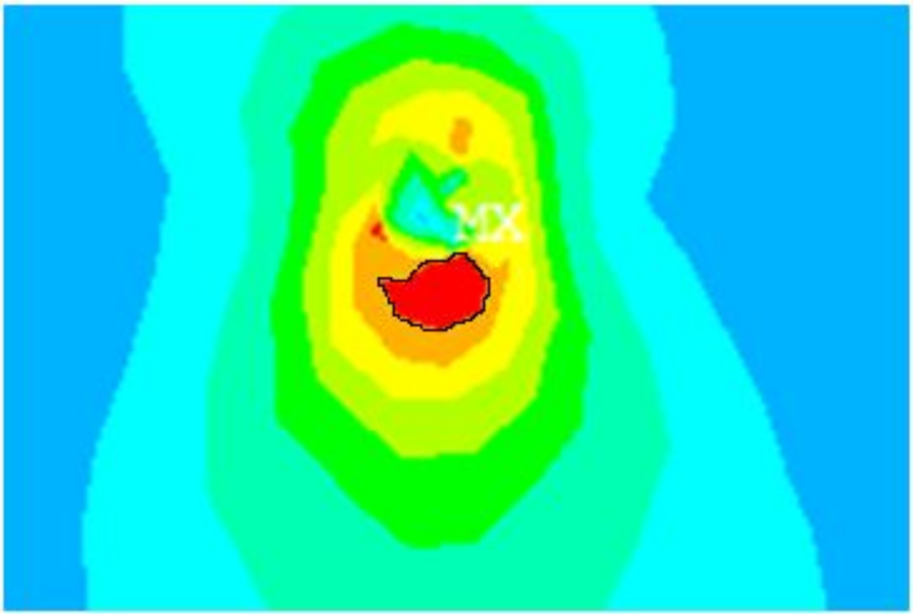
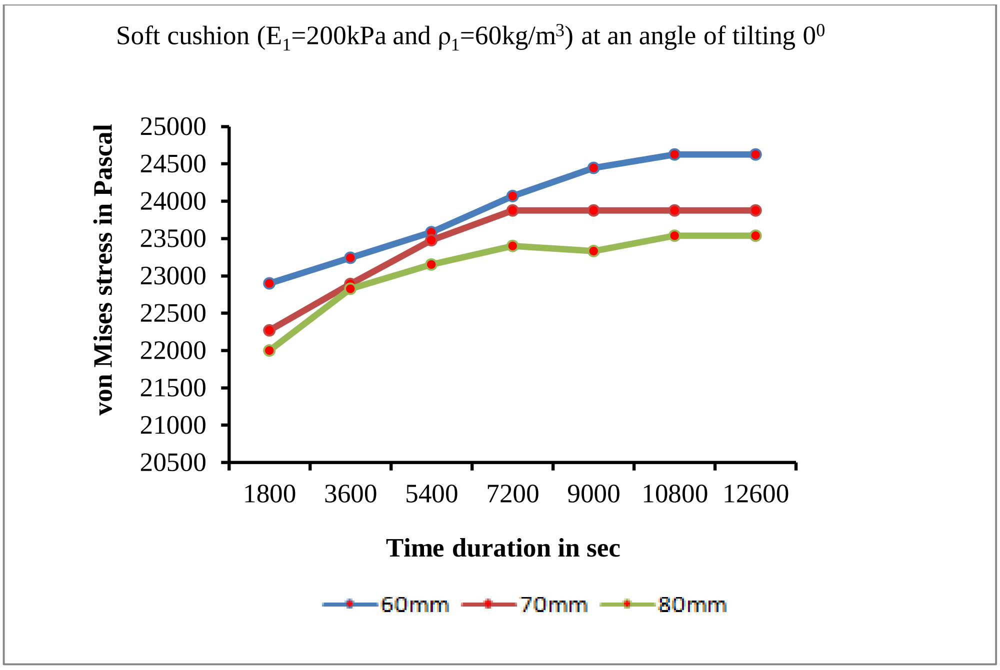


Figure 4.4 (d) Stress distribution at ischial tuberocity for erect immobilized continuous sitting for rigid seat of thickness of 80 mm for 9000 sec (von Mises stress=38442 Pa High stress area=23.36 mm^2)

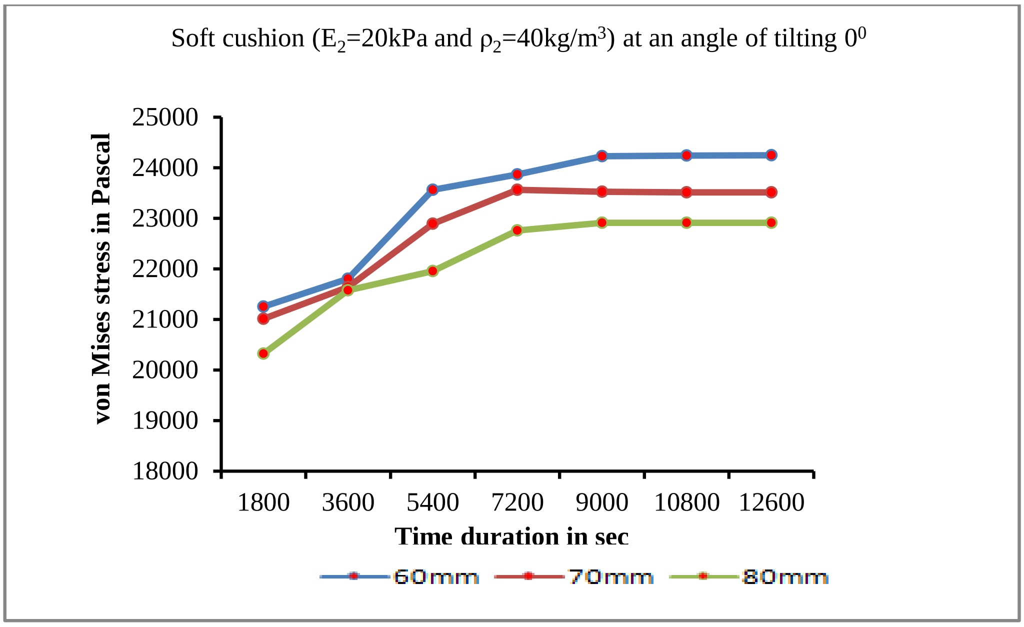
4.3.1 Model validation

The model is validated using rigid seat as described above. However, sitting on rigid seat is not a practical condition in an office environment. Soft cushion is used to provide a comfortable working environment. Hence, further analysis is carried out on soft cushion considering Model II with different cushion properties and cushion thickness. Experimental studies show that mild tissue stiffness generally occurs just after ninety minutes of continuous loading on a rigid seat due to tissue dehydration (Gefen et al., 2005). Therefore, a soft cushion should be considered in order to avoid the stiffening of soft muscle tissues in a short interval of time. As the visco-elastic materials have the capacity to absorb the energy on impact of load (Ferguson-Pell, 1990), soft cushion made of polyurethane foam with two different set of visco-hyper-elastic cushion properties is considered here to estimate the effect of cushion properties in predicting stress distribution in muscle tissue. The Young's modulli and density for these two cushion type are E_1=200kPa, E_2= 20kPa, and $\rho_1 = 60 kg/m^3$ $\rho_2 = 40 kg/m^3$ having cushion thickness of 80 mm.

As shown in Figure 4.5 (a and b), for both polyurethane cushion properties of model II, comparatively less stress is developed at ischial tuberocity than that of rigid seat (Figure 4.3). The pattern of increase in stress is same as that of rigid seat for one and a half an hours. After one and half hour, the stress go on increasing at slower rate up to three hours instead of remaining constant as in case of rigid seat. This phenomenon indicates that the tissue muscles take comparatively longer time to become stiffened when interact with soft cushion than that of rigid seat.



(a)



(b)

Figure 4.5 Variation of von Mises stress over time for soft cushion of (a) elastic modulus=200kPa and density= 60kg/m^3 (b) elastic modulus=20kPa and density=40kg/m^3 for erect immobilized continuous sitting

Figure 4.6 shows the morphological changes at ischial tuberocity due to von Mises stress in soft muscle tissues (for model II) for different continuous sitting time interval. As depicted from the Figure 4.6, the size of damage area increases continuously with time.

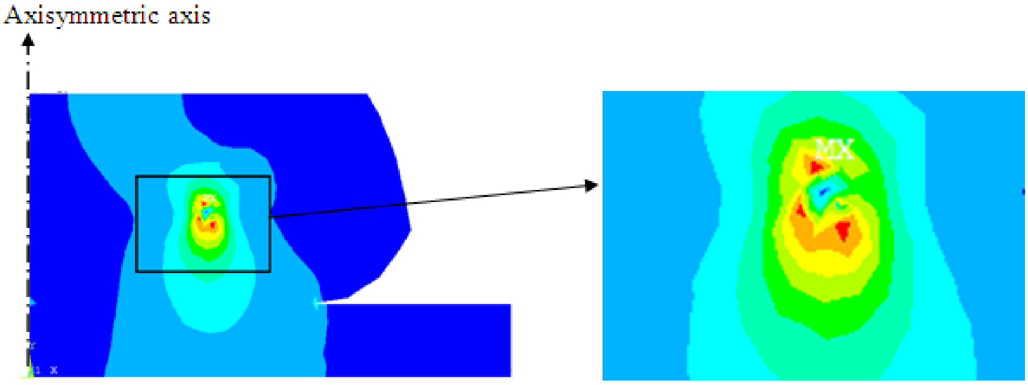


Figure 4.6 (a) Finite element model for soft seat cushion (E=200kPa and ρ =60kg/m^3) with magnification of muscle region subjected to high stress

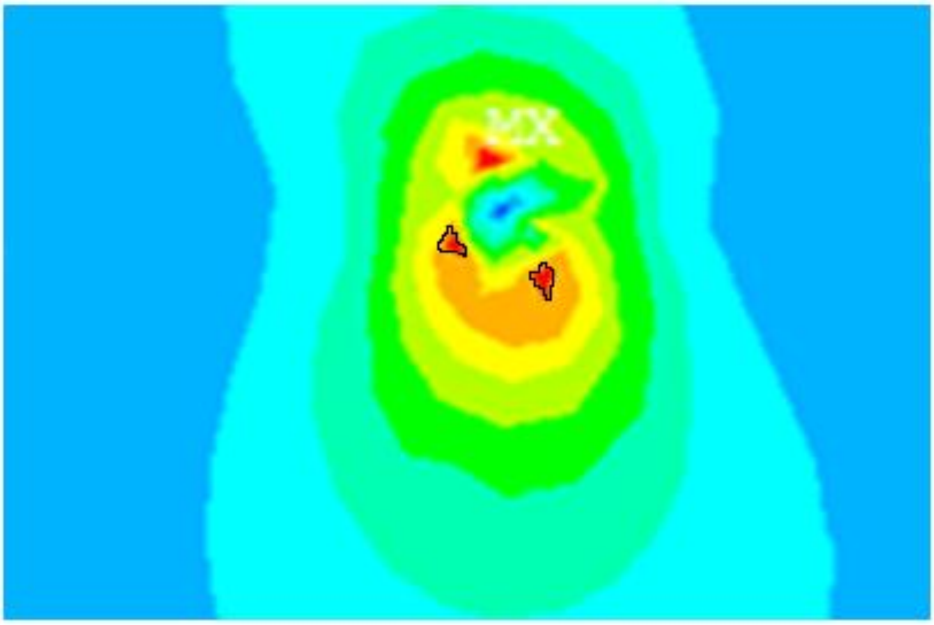


Figure 4.6 (b) Stress distribution at ischial tuberocity for erect immobilized continuous sitting on soft cushion (E=200kPa and ρ =60kg/m^3) for 1800 sec (von Mises stress=22002Pa High stress area=1.24 mm^2)

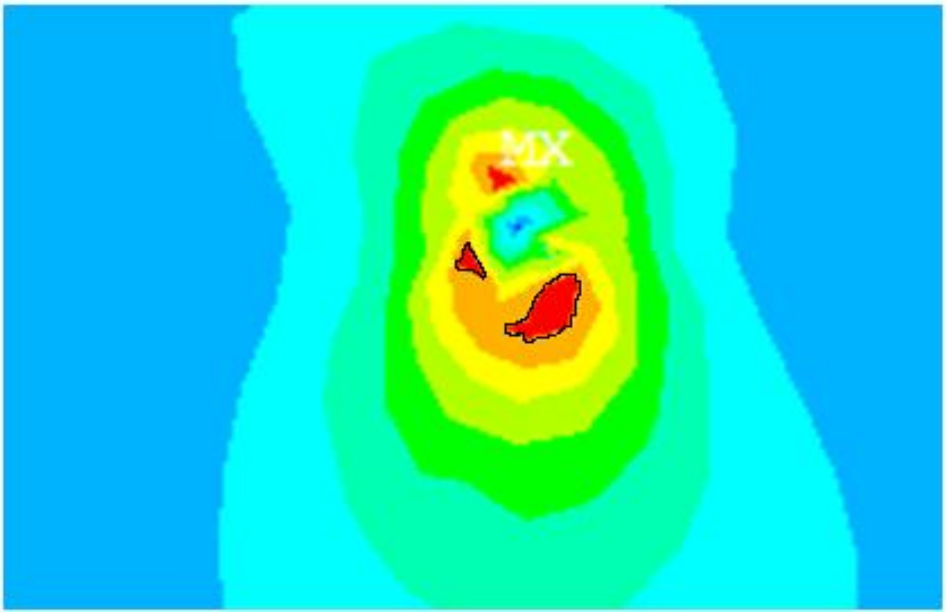


Figure 4.6 (c) Stress distribution at ischial tuberocity for erect immobilized continuous sitting on soft cushion (E=200kPa and ρ =60kg/m^3) for 5400 sec (von Mises stress=23153Pa High stress area=11.49 mm^2)

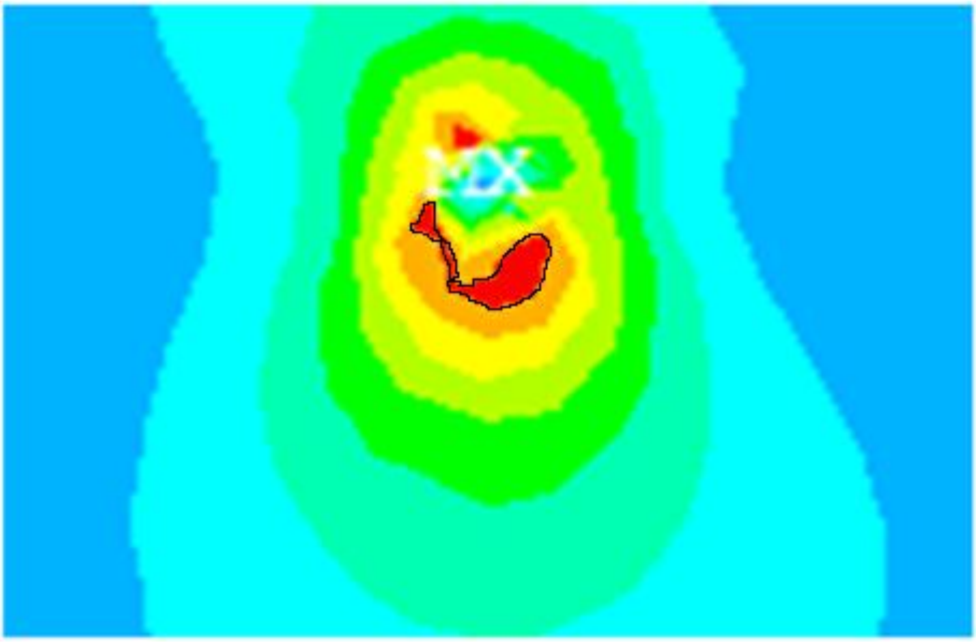


Figure 4.6 (d) Stress distribution at ischial tuberocity for erect immobilized continuous sitting on soft cushion (E=200kPa and ρ =60kg/m^3) for 9000 sec (von Mises stress=23400Pa High stress area=24.23 mm^2)

Figure 4.7 shows a von Mises stress distribution in soft tissue muscles for a cushion having elastic modulus of 20kPa and density of 40 kg/m^3. Comparing Figures 4.6 and 4.7, it can be observed that the maximum stress affected area is less in case of soft cushion of elastic modulus of 20kPa and density 40 kg/m^3 than that for the cushion having elastic modulus of 200kPa and density 60kg/m^3. Model II (E=20kPa and density40kg/m^3) predicts a maximum stress of 20324Pa at ischial tuberocity after a continuous sitting duration of half an hour and the value approaches to the maximum experimental value (nearly 19500Pa) (Verver et al., 2004). But the trend of increasing stress at ischial tuberocity is nearly similar for both the cushion. Comparing Figures 4.4, 4.6 and 4.7, it can be deduced that the size of the affected zone as well as the stress is much larger for a rigid seat (Model I) as compared to that of soft cushion (Model II). It is evident from Figures 4.6 and 4.7 that the cushion having elastic modulus 20kPa and density 40kg/m^3 shows less stress distribution at ischial tuberocity in comparison to cushion having elastic modulus 200kPa and density 60kg/m^3. Therefore, further analysis carried out on soft cushion having elastic modulus 20kPa and density 40kg/m^3.

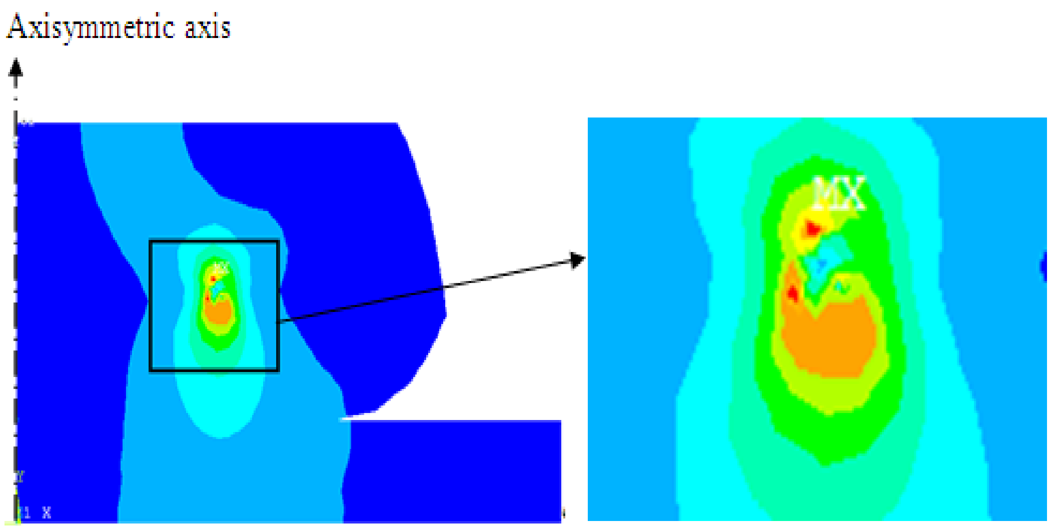


Figure 4.7 (a) Finite element model for soft seat cushion (E=20kPa and ρ =40kg/m^3) with magnification of muscle region subjected to high stress

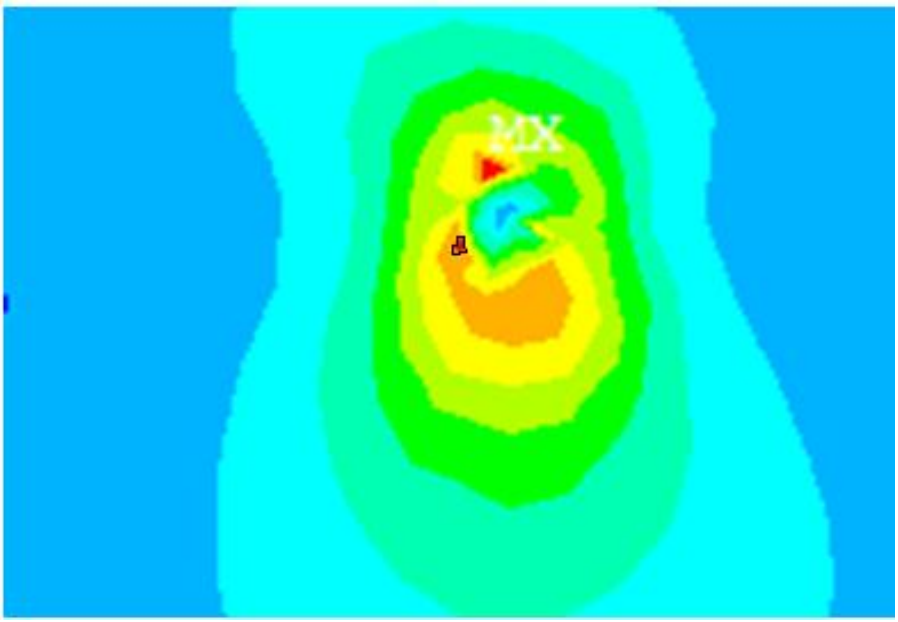


Figure 4.7 (b) Stress distribution at Ischial tuberocity for erect immobilized continuous sitting on soft cushion (E=20kPa and ρ =40kg/m^3) for 1800 sec (von Mises stress=20324Pa High stress area=0.17mm^2)

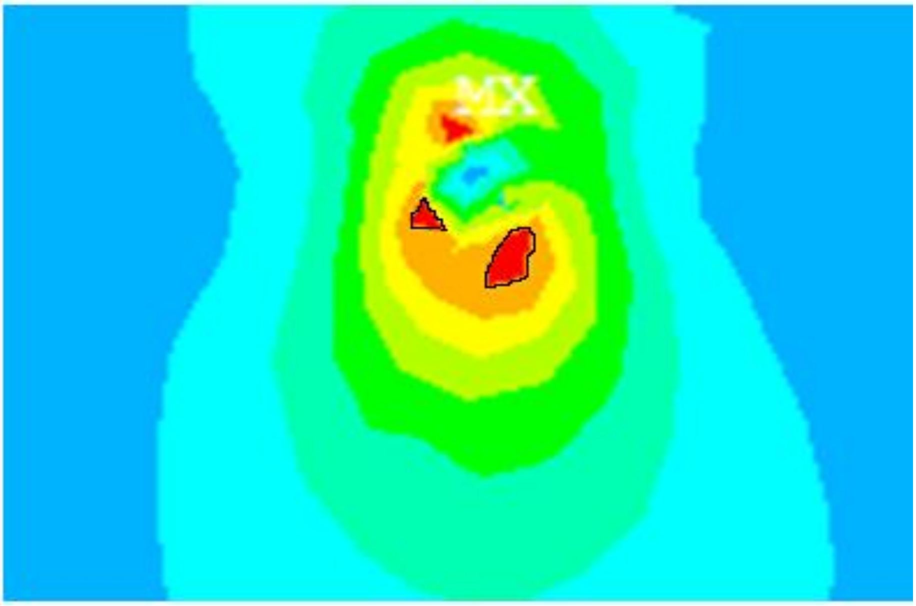


Figure 4.7 (c) Stress distribution at Ischial tuberocity for erect immobilized continuous sitting on soft cushion (E=20kPa and ρ=40kg/m^3) for 5400 sec (von Mises stress=21953Pa High stress area=6.77 mm^2)

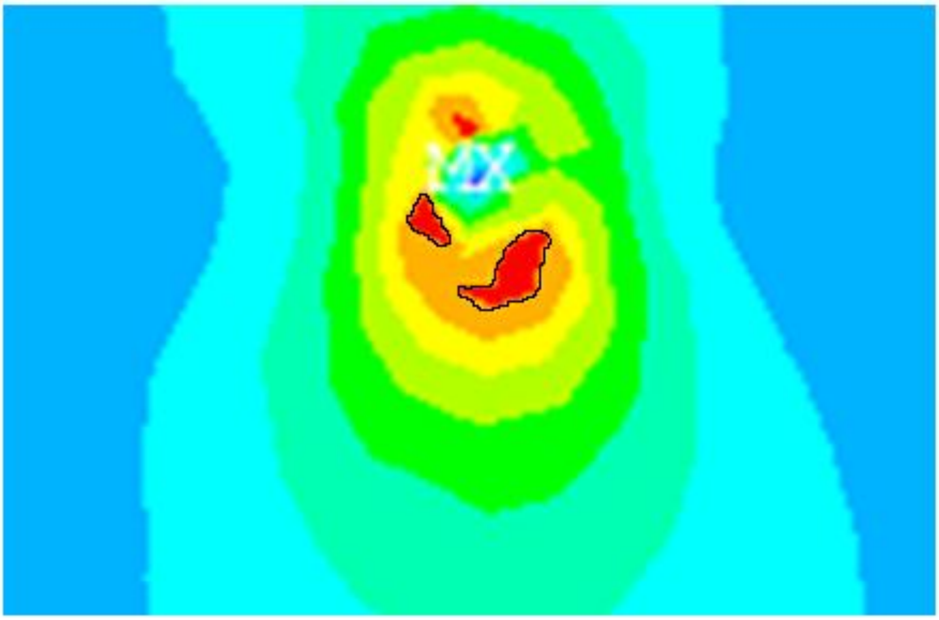


Figure 4.7 (d) Stress distribution at Ischial tuberocity for erect immobilized continuous sitting on soft cushion (E=20kPa and ρ=40kg/m^3) for 9000 sec (von Mises stress=22914Pa High stress area=9.32 mm^2)

The above discussions demonstrate dependence of von Mises stress at ischial tuberocity on time of erect immobilized continuous sitting for different properties of seats. Frequent immobilized continuous sitting makes the muscle tissues intolerable for further compression even for soft polyurethane foam. Also in an erect immobilized sitting, a transverse load is acted along the direction of fibers of muscles tissue present below ischial tuberocity (Verver et al., 2005). Therefore, in order to make the stress relax or to reduce the direct load on fibers either a postural changes or a leisure time should be preferred after certain duration of sitting. Different posture showing sidewise leaning are illustrated in Figure 4.8. Lifting from seat or a leisure time after certain duration of continuous sitting make the body relaxes somewhat but does not recover the muscle stiffness again back to starting zero level of relaxation. During vertical sitting, the longissimus and gluteus muscles are loaded by the sacrum and ischial tuberosities. Since the postural change causes change in position of the ischial tuberocity, the longissimus and gluteus muscles are not subjected to that much vertical load as in case of neutral position. Only a fraction of total vertical load acts on ischial tuberocity and hence on the muscles just lies below it.

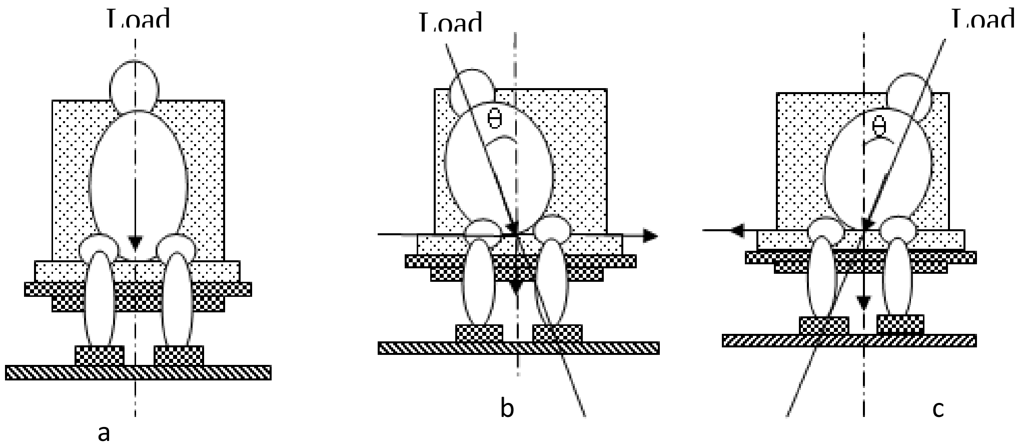


Figure 4.8 Postures (a) neutral position (b) left wise leaning (c) right-wise leaning

Postural change transfers the load to those regions of body other than on ischial tuberocity and relieves the muscles below ischial tuberocity by distributing the stress towards thighs and waist. The analysis for posture shown in Figure 4.8. It has been observed that stress drops from 37193Pa to 34500Pa with a change in tilting angle from 0^0 (erect sitting) to 30^0 while interacting with rigid seat for half an hour. The stress drops from 20324Pa to 14632Pa for soft cushion of elastic modulus of 20kPa with density 40kg/m^3 for change in tilting angle from 0^0 (erect sitting) to 30^0. However, sitting continuously with same tilting angle (30^0) or posture from thirty minutes to three hours, the stress increases from 34500Pa to 35600Pa while interacting with rigid seat. Similarly, sitting continuously with same tilting angle (30^0) or posture from thirty minutes to three hours, the stress increases from 14632Pa to 16922Pa while interacting with soft cushion of elastic modulus 20kPa and density 40kg/m^3. Stress distribution is shown in Figure 4.9. Figure 4.10 displays a maximum shear stress of 8438Pa after thirty minutes of continuous sitting with 30^0 tilting posture and the shear stress increases gradually when the time increases.

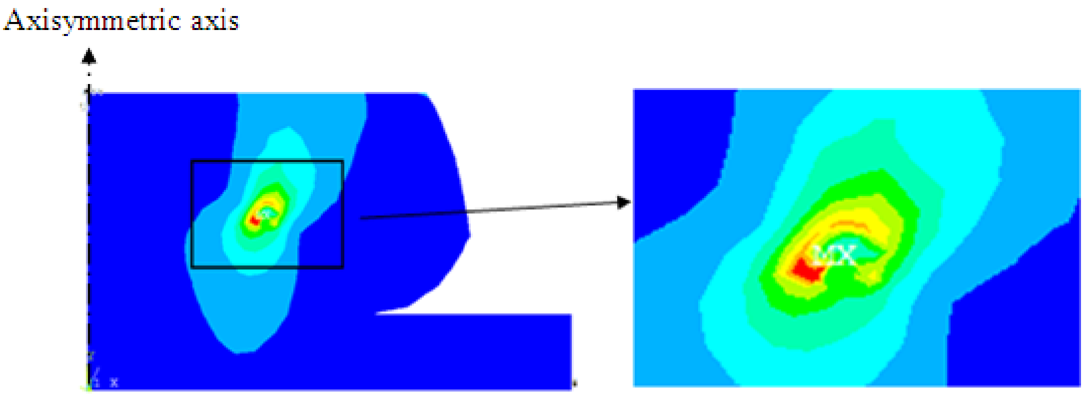


Figure 4.9 (a) Finite element model for immobilized continuous sitting with tilting angle of 30^0 for soft cushion with elastic modulus of 20kPa and density $40kg/m^3$

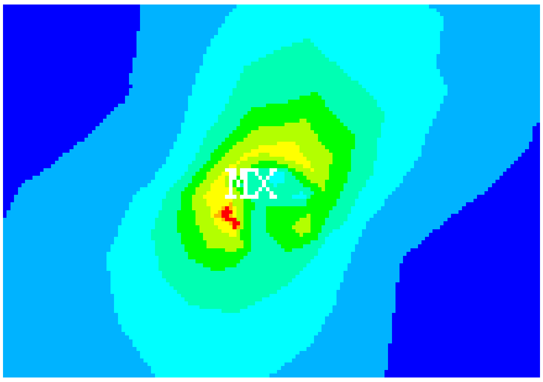


Figure 4.9 (b) Stress distributions at ischial tuberocity on immobilized continuous sitting with tilting angle of 30^0 for soft cushion of elastic modulus of 20kPa and density $40kg/m^3$ (von Mises stress=14632Pa Time=1800sec)

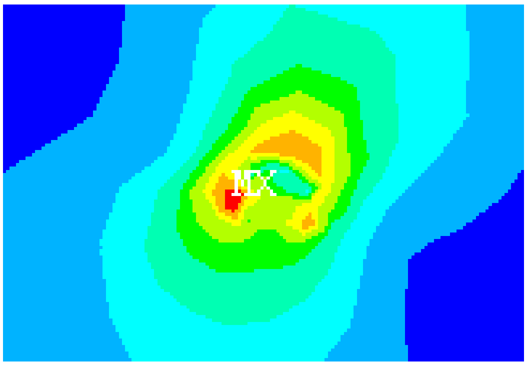


Figure 4. 9 (c) Stress distributions at ischial tuberocity on immobilized continuous sitting with tilting angle of 30^0 for soft cushion of elastic modulus of 20kPa and density $40kg/m^3$ (von Mises stress=15069Pa Time=3600sec)

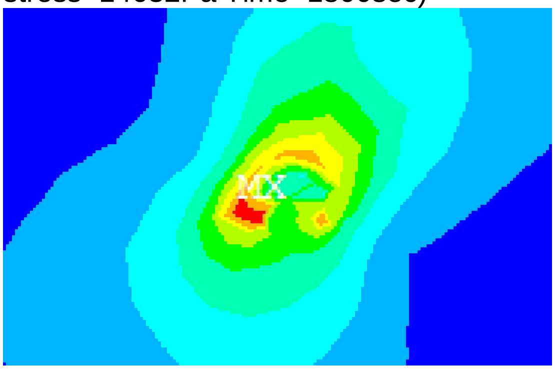


Figure 4.9 (d) Stress distributions at ischial tuberocity on immobilized continuous sitting with tilting angle of 30^0 for soft cushion of elastic modulus of 20kPa and density $40kg/m^3$ (von Mises stress=15975Pa Time=5400sec)

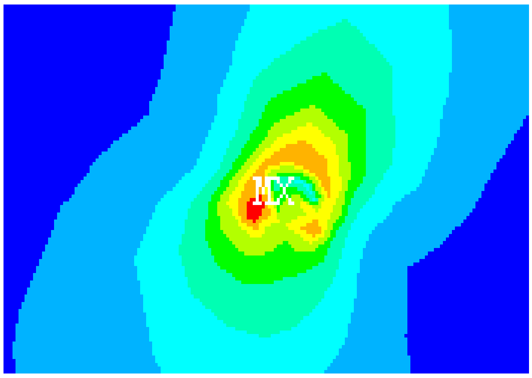


Figure 4.9 (e) Stress distributions at ischial tuberocity on immobilized continuous sitting with tilting angle of 30^0 for soft cushion of elastic modulus of 20kPa and density $40kg/m^3$ (von Mises stress=16922Pa Time=7200sec)

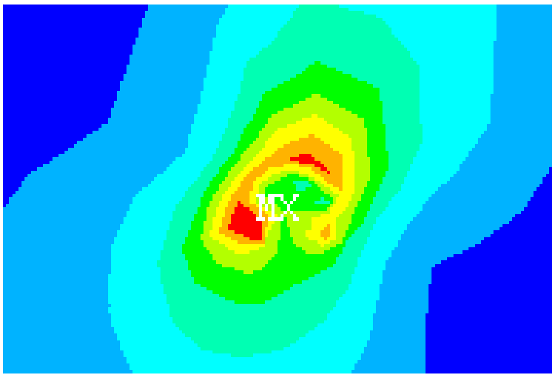


Figure 4.9 (f) Stress distributions at ischial tuberocity on immobilized continuous sitting with tilting angle of 30^0 for soft cushion of elastic modulus of 20kPa and density 40kg/m^3 (von Mises stress=16395Pa Time=9000sec)

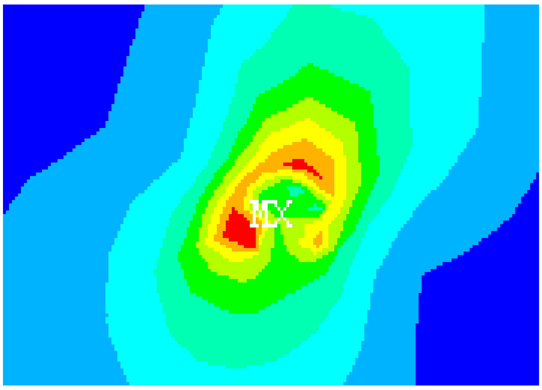


Figure 4.9 (g) Stress distributions at ischial tuberocity on immobilized continuous sitting with tilting angle of 30^0 for soft cushion of elastic modulus of 20kPa and density 40kg/m^3 (von Mises stress=16922Pa Time=10800sec)

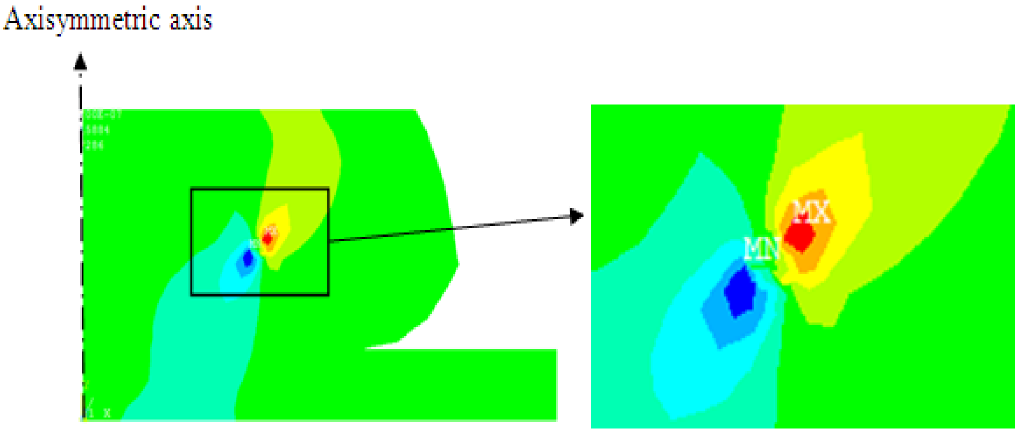


Figure. 4.10 (a) Finite element model for immobilized continuous sitting with tilting angle of 30^0 for soft cushion with elastic modulus of 20kPa and density 40kg/m^3

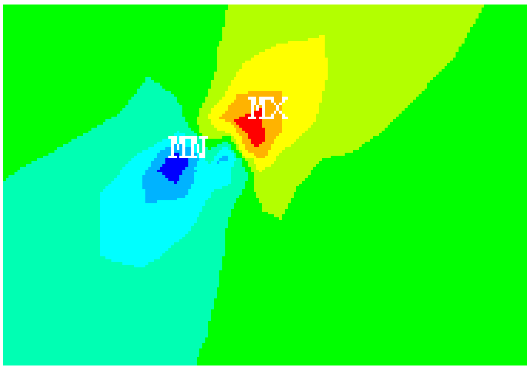


Figure 4.10 (b) Shear stress distribution at ischial tuberocity on immobilized continuous sitting with tilting angle of 30^0 for soft cushion of elastic modulus 20kPa and density 40kg/m^3 (Shear stress=8438Pa Time=1800sec)

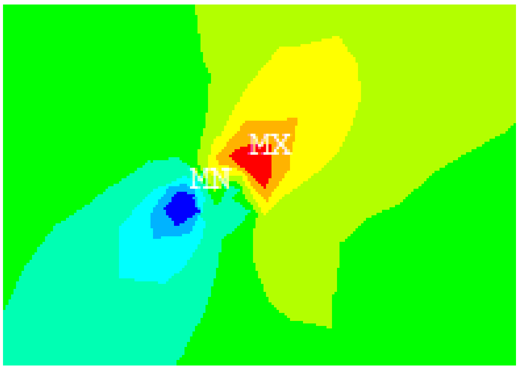


Figure 4.10 (c) Shear stress distribution at ischial tuberocity on immobilized continuous sitting with tilting angle of 30^0 for soft cushion of elastic modulus 20kPa and density 40kg/m^3 (Shear stress=8554Pa Time=3600sec)

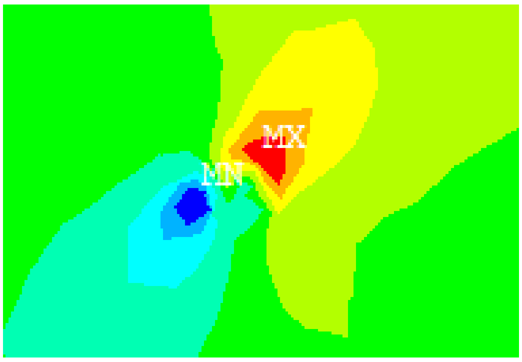


Figure 4.10 (d) Shear stress distribution at ischial tuberocity on immobilized continuous sitting with tilting angle of 30^0 for soft cushion of elastic modulus 20kPa and density 40kg/m^3 (Shear stress=8738Pa Time=5400sec)

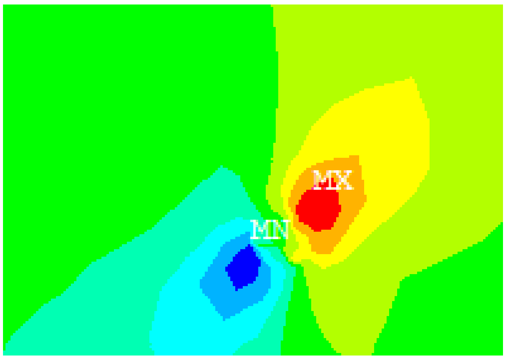


Figure 4.10 (e) Shear stress distribution at ischial tuberocity on immobilized continuous sitting with tilting angle of 30^0 for soft cushion of elastic modulus 20kPa and density 40kg/m^3 (Shear stress=8922Pa Time=7200sec)

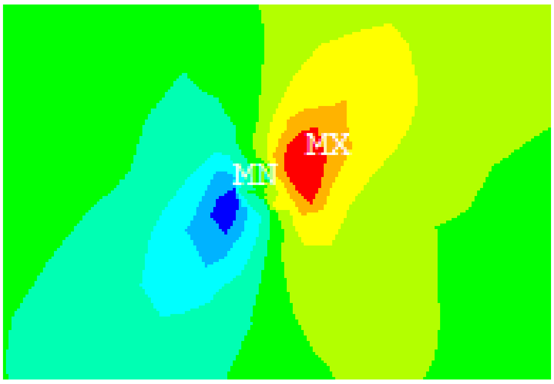


Figure 4.10 (f) Shear stress distribution at ischial tuberocity on immobilized continuous sitting with tilting angle of 30^0 for soft cushion of elastic modulus 20kPa and density 40kg/m^3 (Shear stress=9183Pa Time=9000sec)

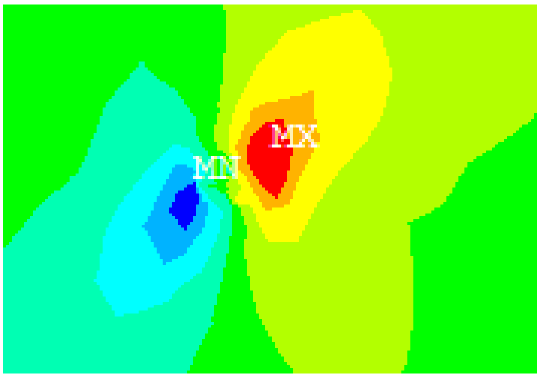
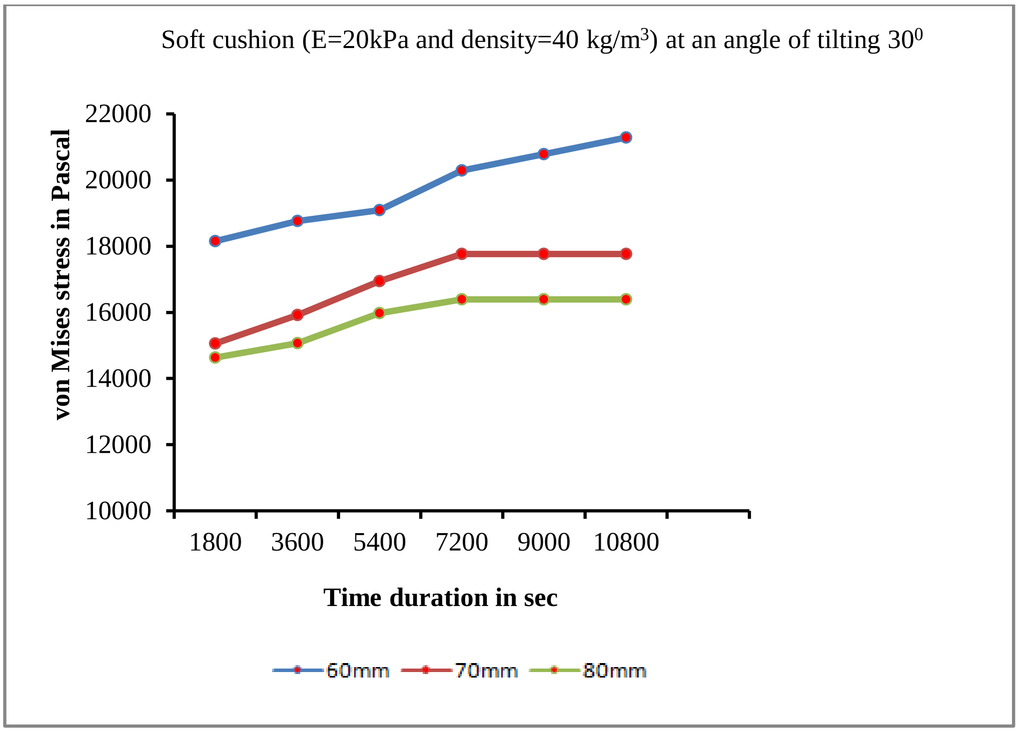
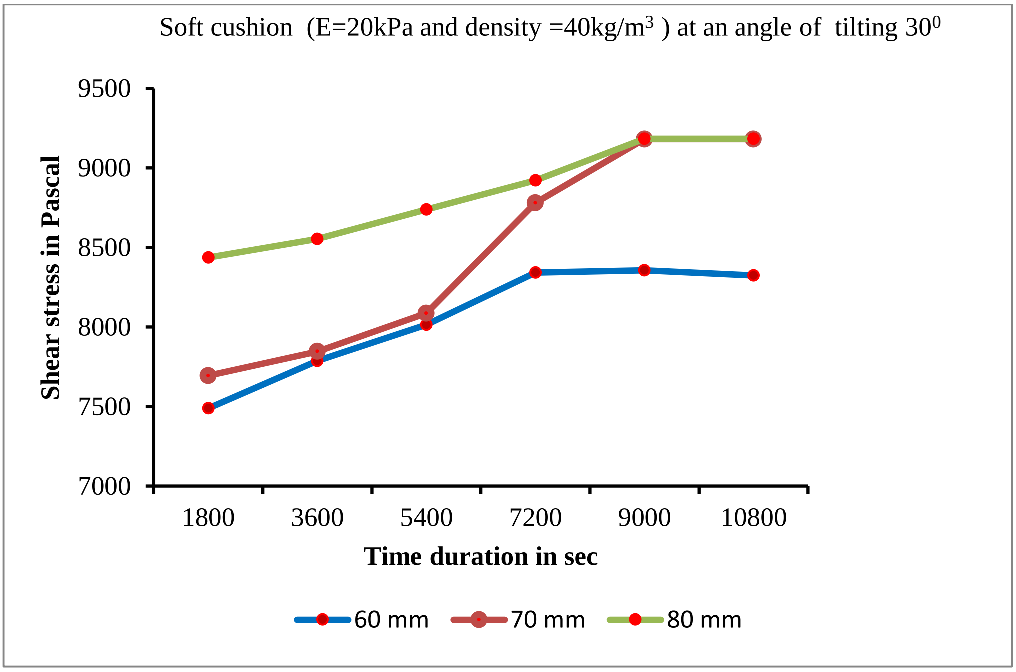


Figure 4.10 (g) Shear stress distribution at ischial tuberocity on immobilized continuous sitting with tilting angle of 30^0 for soft cushion of elastic modulus 20kPa and density 40kg/m^3 (Shear stress=9183Pa Time=10800sec)

The pattern of change of von Mises stress and shear stress at ischial tuberocity is analyzed for change in cushion thickness as shown in Figures 4.11a and 4.11b respectively. It has been found that increase of cushion thickness is effective in reducing von Mises stress for any time duration of continuous sitting. However, shear stress increases with thickness of cushion. The thickness of cushion is increased up to eighty mill meters since the cushion thickness beyond this value is ineffective in decreasing the stress beneath the ischial tuberocity (Chow and Odell., 1978).



(a)



(b)

Figure 4.11 Effect of time duration of tilted (30^0) sitting on (a) von Mises stress (b) shear stress for soft cushion (E= 20kPa and density=40kg/m^3)

4.4 Conclusions

The present study presents a numerical approach for analyzing the stresses being developed beneath ichibial tuberocity due to continuous working in office environment in sitting posture on office chair. The analysis provides insight into the problem and suggests the ways to reduce the stress on bony prominence causing cell death of muscle tissue. The methodology provides guidelines to avoid suffering from pressure sore to some extent in an office environment. Although analysis shows that stress within muscle decreases with proper cushion thickness and postural changes but a postural change always deals with the change in position of ischial tuberocity during leaning (Gefen et al., 2005). In order to overcome this limitation, the present study deals with calculation of stress beneath the ischial tuberocity. It has been shown that use of right kind of foam for seat cushion and thickness can substantially reduce the stress level at ischial tuberocity. This work considers a simple 2D formulation to provide guidelines for the designers to analyze behavior of interaction of soft human tissue and cushion material. The study can be improved by considering a real model with 3D formulation.

CHAPTER 5

A NOVEL MULTI-ATTRIBUTE DECISION MAKING APPROACH FOR PRODUCT SELECTION CONFORMING ERGONOMIC CONSIDERATIONS

5.1 Introduction

Competition in the market place demands high workload in an office environment resulting in prolonged sitting. Prolonged sitting may cause health risk like muscular disorders (Hales and Bernard, 1996). Therefore, ergonomically designed office chair possessing capability of maintaining compatibility between the user and product may lead to reduce fatigue. While designing or procuring an office chair, the psychological needs must be fulfilled in addition to physical needs to improve user satisfaction. Selection of an office chair with salient features satisfying ergonomic needs (both physical and psychological needs) becomes a complex decision making process. Keeping in view of complexity of the problem, multi-attribute decision making (MADM) approach can be considered during product design focusing on the requirements of user in terms of conflicting criteria in order to solve the task of selection of an ergonomically designed product. In a decision making process, it is unlikely that decision makers can express their preferences using crisp rating for attributes (Jee and Kang, 2000; Shanian and Savadogo, 2006; Jahan et al., 2010). As experts are not able to exactly specify to their preferences, linguistic variables using a fuzzy scale is used to conveniently deal with impreciseness and ambiguity in judgement (Chen, 2000; Chen et al., 2006; Girubha and Vinodh, 2012). Decision making in fuzzy environment has been suitably articulated by Zadeh (1965), Zadeh and Bellman (1970) and Carlsson and Fuller (1996). Still the decision making becomes inconsistent because most of the approaches consider either objective or subjective attributes (Rao, 2012; Maniya and Bhatt, 2010). In decision making, usually some attributes are objective and some are subjective in nature. The attributes need to be properly evaluated for estimating attribute weights integrating both objective and subjective criteria (Rao and Patel, 2010). The subjective attributes can be dealt using eigen method (Saaty, 1977) or Delphi method (Hwang and Lin, 1987) whereas the objective attributes can be effectively managed by entropy method (Hwang and Yoon, 1981) for weight estimation. To address this issue, a novel decision making technique is proposed in this work considering both subjective and objective weights for attributes in order to facilitate the decision maker to deal with objective information regarding the product as well as the uncertainty of human judgment. The attribute ratings obtained from multiple experts are aggregated for effective decision making.

Three different popular MADM methods such as TOPSIS (Techniques for Order Preference by Similarity to Identical Solution), VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenjea) and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) are used to solve the selection problem of choosing the best ergonomically designed office chair. All the methods are considered under same managerial decision. TOPSIS, a linear weighting technique developed by Hwang and Yoon (1981) in its crisp form and then in expanded form by Chen and Hwang (1992), is based on the concept that the chosen alternative should have the shortest Euclidean distance from positive ideal solution and farthest from negative ideal solution (Rao, 2006). VIKOR, on the other hand, determines a compromise solution which is feasible and closest to the ideal solution but makes an agreement by mutual concession which the help of the decision maker to take a decision with conflicting criteria (Opricovic and Tzeng, 2004). It introduces the multi-criteria ranking index based on the particular measure of ‘‘closeness” to the ‘‘ideal” solution (Opricovic, 1998). PROMETHEE proceeds to a pair-wise comparison of alternatives in each single criterion in order to determine partial binary relations denoting the strength of preference of an alternative ‘a’ over alternative ‘b’ (Rao and Rajesh, 2009). In order to check the stability of ranking with respect to different weighted attributes, a sensitivity analysis has been performed considering different proportion of attribute weight (subjective and objective) and the evaluation carried under three different MADM methods.

5.2 Proposed Methodology

MADM has established as an effective methodology for solving a large variety of multi-criteria decision making and ranking problems (Hwang and Yoon, 1981). In this study, a novel approach of MADM has been proposed to find a suitable ergonomically designed product with respect to design characteristics (attributes). The best alternative is chosen from a set of n alternatives {A_1,A_2, …, A_n} whereas the performance of the alternatives are decided on the basis of m attributes {C_1, C_2, …, C_m} by a group of k decision maker (DMs) {DM_1, DM_2, …, DM_k}as given in Table 5.1. The weight for the attributes are considered as {w_1, w_2, ….w_m}.

Table 5.1 Decision matrix

Alternatives	Attributes				
	C_1 (w_1)	C_2 (w_2)	-	-	C_m (w_m)
A_1	x^*_{11}	x^*_{12}	-	-	x^*_{1m}
A_2	x^*_{21}	x^*_{22}	-	-	x^*_{2m}
-	-	-	-	-	-
-	-	-	-	-	-
A_n	x^*_{n1}	x^*_{n2}	-	-	x^*_{nm}

Different steps of the proposed work are described in Figure 5.1. The methodology consists of six major computational steps as discussed below.

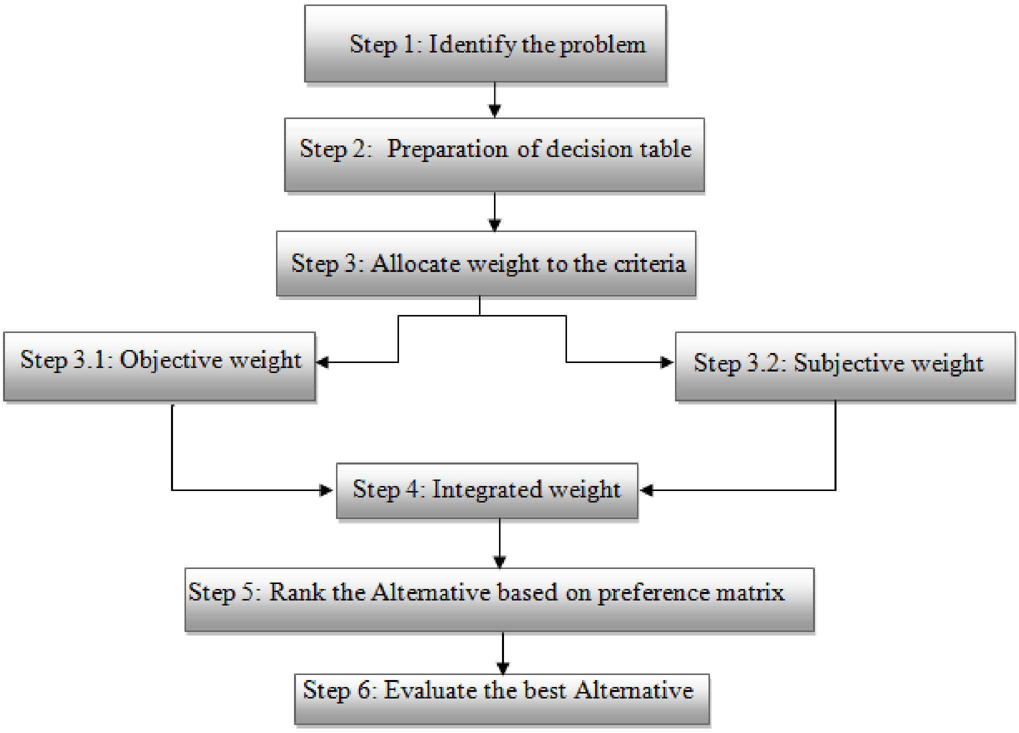


Figure 5.1 Graphical representation of generic MADM model

Step 1: Identify the problem

To illustrate the approach, an ergonomically designed office chair selection problem is considered as a case study. As the selection of an ergonomically designed office chair includes technical specification as well as user preference, it becomes a difficult task to choose an office chair with specific features that satisfy a range of customers. In addition to design characteristics in terms of technical specifications provided by manufacturers, expert opinion is also considered to take into account the customer preferences. A group of DMs analysed the possible attributes and alternatives from a set of available office chairs in the market place and important attributes and alternatives are considered. Since impreciseness and ambiguity exist to assign rating for each attribute and alternative, a linguistic scale is used to express decision makers' opinion on each alternative with respect to attribute.

Step 2: Preparation of decision table

To model decision makers' judgement, fuzzy scales are employed which translate the linguistic terms into triangular fuzzy numbers as linguistic variables deal with ambiguity and subjectivity (Zadeh, 1975). To convert the qualitative terms into quantitative values, a five point fuzzy scale with triangular fuzzy numbers based on the works of Chen (1985) is chosen. As shown in Figure 5.2, linguistic terms "very low"(VL), "low"(L), "medium"(M), "high"(H), "very high"(VH) are included to measure the performance of each alternative with respect to each attribute. The crisp score of fuzzy number 'M' is obtained as follows (Chen, 1985):

$$\mu_{max}(x) = \begin{cases} x, 0 \le x \le 1 \\ 0, \text{otherwise} \end{cases} \tag{5.1}$$

$$\mu_{min}(x) = \begin{cases} 1 - x, 0 \le x \le 1 \\ 0, \text{otherwise} \end{cases} \tag{5.2}$$

The fuzzy max and fuzzy min of fuzzy numbers are defined in a manner such that absolute location of fuzzy numbers can be automatically incorporated in the comparison case. The left score of each fuzzy number 'M_i' is defined as

$$\mu_L(M_i) = \operatorname*{Sup}_x[\mu_{min}(x) \wedge \mu_{Mi}(x)] \tag{5.3}$$

The $\mu_L(M_i)$ score is a unique, crisp, real number in (0, 1). It is the maximum membership value of the intersection of fuzzy number M_i and the fuzzy min. The right score is obtained as:

$$\mu_R(M_i) = \operatorname*{Sup}_x[\mu_{max}(x) \wedge \mu_{Mi}(x)] \tag{5.4}$$

Again $\mu_R(M_i)$ is a crisp number (0, 1). Given the left and right scores, the total crisp score of a fuzzy number M_i is defined as:

$$\mu_T(M_i) = [\mu_R(M_i) + 1 - \mu_L(M_i)]/2 \tag{5.5}$$

These ratings may be given by a single or a group of decision maker. Yue (2011) states that MADM problems can provide reliable results if analysis of multiple experts is taken into account instead of the analysis of a single expert.

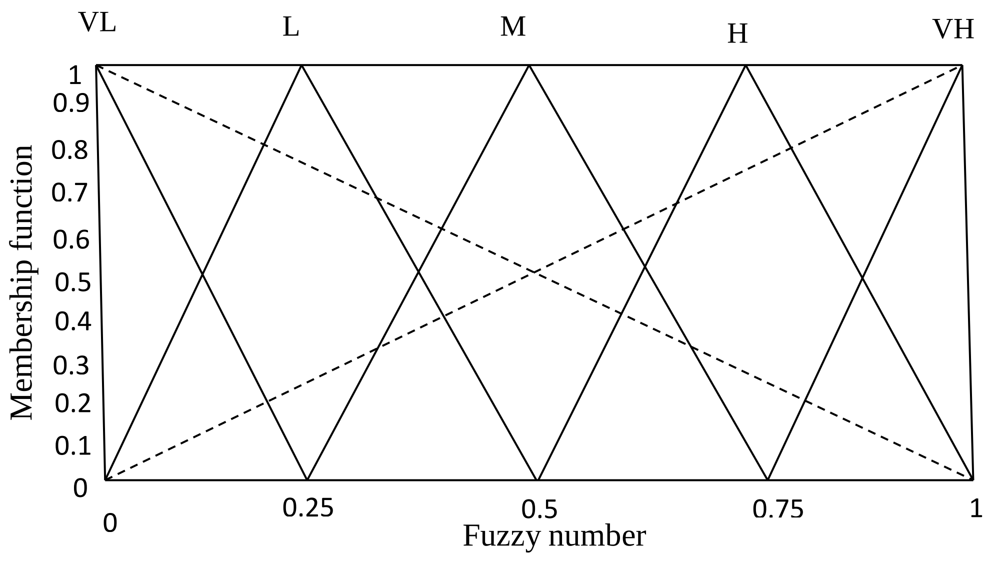


Figure 5.2 Linguistic terms to fuzzy numbers conversion (5-point scale)

After evaluation of aggregate crisp score value (x_{ij}), the rating value for alternative i with respect to each attribute j, the aggregate crisp values are normalized so that rating values given by the decision makers can be converted into a common scale. Considering the normalized value (x_{ij}^{*}), a decision table is prepared. Normalization is carried out using following relationship.

$$x_{ij}^{*} = \frac{x_{ij}}{(x_{ij})_{max}} \tag{5.6}$$

where, x_{ij} is the aggregate crisp score of alternative 'i' under attribute 'j'.

Step 3: Allocate the weights of importance of the identified attributes

The proposed methodology uses integrated weights of objective and subjective preference for assigning attribute weights. By varying proportion of objective and subjective weights, a large number of decision making scenarios can be generated to provide the decision makers a wide range of solutions to choose the best one.

Step 3(a): Computation of objective weights of importance of the attributes

The objective weights can be computed by using the normalized data given in decision matrix developed in previous step. As the statistical variance gives a measure of dispersion of data points around their mean value (Rao and Patel, 2010), the proposed method determines the objective weight of attributes in terms of statistical variance method. The statistical variance for determining the objective weights of importance of the attributes is given by the following equation.

$$v_j = (1/n)\sum_{i=1}^{n}\left(x_{ij}^{*} - (x_{ij}^{*})_{mean}\right)^2 \tag{5.7}$$

where v_j is the variance of the data corresponding to the j^th^ attribute and $(x_{ij}^{*})_{mean}$ is the average value of x_{ij}^{*} .

The objective weight of the j^th^ attribute, w_j^0 can be computed by dividing the statistical variance of the j^th^ attribute with the total value of the statistical variances for m number of attributes. Thus, w_j^0 can be computed by the following equation.

$$w_j^0 = v_j \Big/ \sum_{j=1}^{m} v_j \tag{5.8}$$

Step 3(b): Computation of subjective weights of importance of the attributes

The subjective preferences can be evaluated through pair-wise comparison of the attributes. A pair-wise comparison matrix (m × m) for all attributes can be constructed with respect to objective by using Saaty's 1-9 scale of pair-wise comparisons so that each attribute can compared with each other attribute. For each comparison, the decision maker decides which of the attribute is most important among two and then assigns a score to show how much more important it is than the other. After making the pair-wise comparisons, the consistency is checked by using the following computations.

Consistency Index, $CI = \frac{\lambda_{max} - m}{m - 1}$ (5.9)

where, λ_{max} is the maximum Eigen value of the matrix and m is matrix size

Consistency Ratio, $CR = \frac{CI}{RI}$ (5.10)

Consistency ratio (C.R.) can be defined as the ratio of consistency index (C.I.) and randomly generated consistency index (R.I.) values (Saaty, 1980). The judgement matrix is consistent if a CR value is less than 0.10.

Step 4: Computation of integrated weights of importance of the attributes

For utilizing both objective and subjective weights of the attributes, an integrated weight of importance is to be calculated. The integrated weight can be described by using the following equation.

$$w_j^i = w^o \times w_j^o + w^s \times w_j^s \quad (5.11)$$

where, w_j^i , w_j^o and w_j^s denote the integrated, objective and subjective weight of the jth attribute respectively. The weightings are taken in between 0 and 1. w^o and w^s represent the weightings proportion considered for objective and subjective weights respectively. The weightings are taken between 0 and 1.

Step 5: Determination of ranking of the alternatives

Each decision matrix has three main components viz., (a) alternatives, (b) attribute, (c) weight or relative importance of each attribute. Three different MADM methods such as Techniques for Order Preference by Similarity to Identical Solution (TOPSIS), a compromise ranking method known as VIseKriterijumska Optimizacija I Kompromisno Resenjea (VIKOR) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) are considered to measure the performance of alternative. The selected MADM methods adopt different strategies for ranking the alternatives. TOPSIS ranks the alternative based on shortest distance from the positive ideal solution and the farthest distance from the negative-ideal solution whereas VIKOR method provides a compromising solution in which an agreement is established between two mutual concessions. PROMETHEE method uses ‘‘net preference flow'' function to rank the alternatives (Brans et al., 1984). Both VIKOR and PROMETHEE methods use linear normalization as shown in equation 5.6. TOPSIS method uses vector normalization and the normalized value can be obtained by following equation.

$$x_{ij}^{*} = x_{ij} \Big/ \left[\sum_{j=1}^{m} x_{ij}^{2} \right]^{1/2} \quad (5.12)$$

5.2.1 Techniques for Order Preference by Similarity to Identical Solution (TOPSIS)

TOPSIS method is based on calculation of preference index in order to evaluate the ranking of alternatives by computing the shortest Euclidean distances to both positive ideal solution and negative ideal solution simultaneously. It is based on the idea that the chosen alternative should have the shortest distance from the positive ideal solution and on the other hand, the farthest distance from the negative ideal solution. Here, the normalized decision matrix can be obtained by equation 5.13.

$$x_{ij}^{*} = x_{ij} \Big/ \left[\sum_{j=1}^{m} x_{ij}^{2} \right]^{1/2} \quad (5.13)$$

The weighted normalized decision matrix considering integrated weights can be expressed as $Y_{ij} = W_{j}^{i} \times X_{ij}^{*}$. The positive ideal solution and negative ideal solution can be calculated using following formulae.

The positive ideal (best) solutions can be expressed as:

$$A^{*} = \{y_1^{*}, \ldots\ldots\ldots, y_m^{*}\} = \left\{ \left(\max_{i} y_{ij} \mid j \in J' \right), \left(\min_{i} y_{ij} \mid j \in J'' \right) \right\} \quad (5.14)$$

The negative ideal (worst) solutions can be expressed as:

$$A^{-} = \{y_1^{-}, \ldots\ldots\ldots, y_m^{-}\} = \left\{ \left(\min_{i} y_{ij} \mid j \in J' \right), \left(\max_{i} y_{ij} \mid j \in J'' \right) \right\} \quad (5.15)$$

where J' is associated with beneficial attribute and J'' is associated with non-beneficial attribute.

The separation of each alternative from the ideal one is given by the Euclidean distance. The separation of each alternative from the positive ideal solution is given as

$$D_i^{*} = \sqrt{\sum_{j=1}^{m} \left(y_{ij} - y_j^{*} \right)^2}, i = 1, \ldots I \quad (5.16)$$

Similarly, the separation of each alternative from the negative ideal solution is expressed as

$$D_i^- = \sqrt{\sum_{j=1}^{m} \left(y_{ij} - y_j^-\right)^2}, i = 1, \ldots I \tag{5.17}$$

After calculating the separation the relative closeness to the ideal solution is carried out. The relative closeness (preference index) of the alternatives to the ideal solution is defined as

$$C_i^* = \frac{D_i^-}{D_i^* + D_i^-}, \; i = 1, \ldots I \tag{5.18}$$

C_i^* is also called as the overall performance score of alternative. A set of alternatives is generated according to the value of C_i^* indicating the most preferred and least preferred feasible solutions. The alternative which has highest value of performance score will be given top ranking in the order. Ranking will be done for different proportion of subjective and objective weights. The final selection of the best alternative will be assessed through the analysis of final ranking matrix.

5.2.2 VIseKriterijumska Optimizacija I Kompromisno Resenjea (VIKOR)

The foundation for compromise solution was established by Yu (1973) and Zeleny (1982) and later advocated by Oprocovic and Tzeng (2002, 2007) and Tzeng et al. (2002, 2005). The compromise solution is closest to the ideal solution which is a feasible solution. The compromise ranking algorithm of the VIKOR method has the following steps:

For alternative A_i the rating of j^{th} attribute is expressed as f_{ij}

Step 1: The first step is to determine the objective, also determine the best, i.e., f_j^* and the worst, i.e. f_j^-, values of all attributes.

$$f_j^* = \max_i f_{ij}, j=1,2,\ldots\ldots m \tag{5.19(a)}$$

$$f_j^- = \min_i f_{ij}, j=1,2,\ldots\ldots m \tag{5.19(b)}$$

Step 2: Compute the values S_j and R_j, i=1,2,…,n.

$$S_i = \sum_{j=1}^{n} w_j \left(f_j^* - f_{ij}\right) \big/ \left(f_j^* - f_j^-\right) \tag{5.20}$$

$$R_i = \max_j w_j \left(f_j^* - f_{ij}\right) \big/ \left(f_j^* - f_j^-\right) \tag{5.21}$$

where w_j, are the weights of the attribute expressing the relative importance.

Step 3: Compute the values Qi, i=1,2,…n by the following relation

$$Q_i = \upsilon\left(S_i - S^*\right)/\left(S^- - S^*\right) + (1-\upsilon)\left(R_i - R^*\right)/\left(R^- - R^*\right) \quad (5.22)$$

where S^* is the minimum value of S_i i.e. $S^* = \min_i S_i$ and S^- is the maximum value of S_i i.e. $S^- = \max_i S_i$

Similarly, R^* is the minimum value of the R_i i.e. $R^* = \min_i R_i$ and R^- is the maximum value of R_i i.e $R^- = \max_i R_i$

υ is introduced as the weight of strategy of " the majority of attribute" (or the maximum group utility"), usually $\upsilon = 0.5$.

Step 4: By arranging the alternatives in the ascending order of S, R and Q values, the three ranking lists can be obtained. The compromise ranking list for a given υ is obtained by ranking with Q_i measures. The best alternative, ranked by Q_i, is the one with the minimum value of Q_i.

Step 5: Propose a compromise solution for alternative A_k

Under a given weight of attribute, alternative A_k is the best ranked by Q value (Minimum) if the following two conditions are satisfied (Tzeng et al., 2005):

Condition 1: 'Acceptable advantage': $Q(A_K) - Q(A_1) \geq DQ$ (5.23)

$$DQ = 1/(N-1) \quad (5.24)$$

where, A_1 the second best alternative in the ranking list by Q. N is the number of alternatives.

Condition 2:'Acceptable stability in decision making': Alternative A_k must also be the best ranked by S or/and R. This compromise solution is stable within a decision making process, which could be ''voting by majority rule'' (when $(\upsilon > 0.5)$ is needed), or ''by consensus'' ($\upsilon \approx 0.5$), or ''with veto'' $(\upsilon < 0.5)$. Here, υ is the weight of the decision making strategy ''the majority of attribute'' (or ''the maximum group utility'').

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

1- Alternatives A_K and A_1 if only condition 2 is not satisfied

2- Alternatives $A_K, A_1, \ldots.. A_P$ if condition 1 is not satisfied; A_P is determined by the relation $Q(A_P) - Q(A_1) < DQ$

5.2.3 Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE)

PROMETHEE method was introduced by Brans et al. (1984). Like all other ranking methods, PROMETHEE deals with a pair wise comparison of alternatives for each single attribute in order to determine partial binary relations denoting the strength of preference of an alternative A_1 over alternative A_2. The alternatives are evaluated on different attribute. The implementation of PROMETHEE also requires relative importance or the weights of the attribute considered and information on the decision maker preference function, which he/she uses when comparing the contribution of the alternatives in terms of each separate attribute. The preference function (P_i) translates the difference between the evaluations obtained by two alternatives (A_1 and A_2) in terms of a particular attribute, into a preference degree ranging from 0 to 1.The method covers the following steps given below

Here the decision maker gives his/her preference function by comparing the contribution of one alternative with respect to another in terms of each separate attribute. The preference function (P_i) finds a difference between two alternatives (A_1 andA_2) for a particular attribute in terms of a preference degree 0 or 1. Let $P_{j,\ A1A2}$ be the preference function associated to the attribute C_j.

$$P_{j,A1A2} = G_j\left[C_j(A_1) - C_j(A_2)\right] \tag{5.25}$$

$$0 \le P_{i,A1A2} \le 1$$

where, G_j is a non-decreasing function of the observed deviation (d) between two alternativesA_1 and A_2 over the attribute C_j. Let the decision maker have specified a preference function P_j and weight w_j for each attribute C_j(j=1, 2, . . . , m). The multiple attribute preference index $\Pi_{A_1A_2}$ is then defined as the weighted average of the preference functions P_j

$$\Pi_{A_1A_2} = \sum_{j=1}^{m} w_j P_{j.A_1A_2} \tag{5.26}$$

$\Pi_{A_1A_2}$, represents the intensity of preference of the decision maker of alternative A_1over alternative A_2 when considering simultaneously all the attribute and the value ranges from 0 to 1. This preference index determines a valued outranking relation on the set of actions. As an example, the schematic calculation of the preference indices for a problem consisting of three alternatives and four attribute is given in Figure 5.3 (Marinoni, 2005).

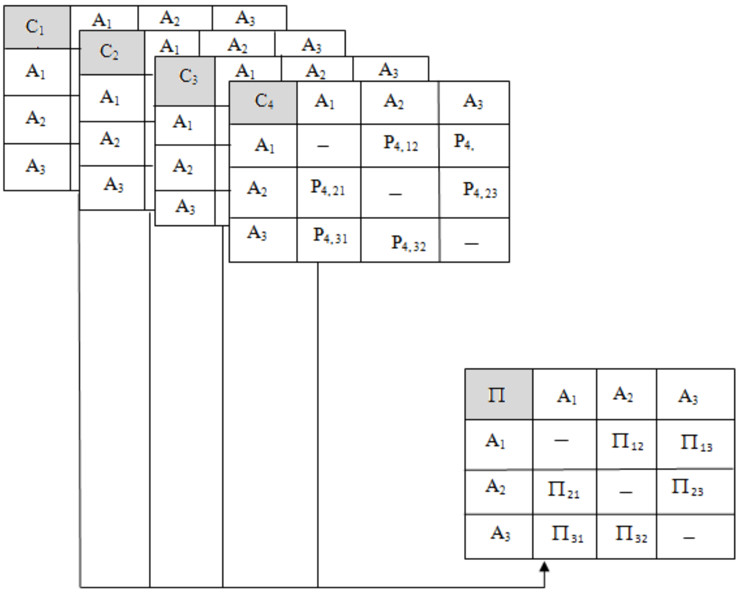


Figure 5.3 Preference indices for a problem consisting of three alternatives and four attributes.

For PROMETHEE outranking relations, the leaving flow, entering flow and the net flow for a particular alternative(A) belonging to a set of alternatives 'A' are defined by the following equations:

$$\varphi^{+}(A) = \sum_{x\varepsilon A} \Pi_{xa} \tag{5.27}$$

$$\varphi^{-}(A) = \sum_{x\varepsilon A} \Pi_{ax} \tag{5.28}$$

$$\varphi(A) = \varphi^{+}(A) - \varphi^{-}(A) \tag{5.29}$$

$\varphi^{+}(A)$ is called the leaving flow, $\varphi^{-}(A)$ is called the entering flow and $\varphi(A)$ is called the net flow. $\varphi^{+}(A)$ is the measure of the outranking character of A (i.e. dominance of alternative 'A' overall other alternatives) and $\varphi^{-}(A)$ gives the outranked character of A(i.e. degree to which alternative A is dominated by all other alternatives). The net flow, $\varphi(A)$ represents a value function, whereby a higher value reflects a higher attractiveness of alternative A. The net flow values are used to indicate the outranking relationship between the alternatives. For example, for each alternative A, belonging to the set of alternatives (A_1, A2….A_n), $\Pi_{A_1A_2}$ is an overall preference index of A_1 over A_2, taking into account all the attribute. Alternative A_1 outranks A_2 if $\varphi(A_1) > \varphi(A_2)$ and A_1 is said to be indifferent to A_2 if $\varphi(A_1) = \varphi(A_2)$.

5.3 Results and discussions

Keeping view with the increasing demand for a suitable ergonomically designed office chair, six different alternatives with respect to ten design characteristics (attribute) are considered as shown in Figure 5.4. The attribute are considered with an extensive literature review of previous report for ergonomically designed office chair (Mohanty and Mahapatra, 2014). A survey among manufacturers of chairs and opinion of experts specialized in ergonomically designed chair revealed that the evaluation of office chair should carry ten important design characteristics. Based on the evaluation of four decision makers, a decision matrix is made considering six alternatives {A_1, A_2, A_3, A_4, A_5, A_6} and ten attributes {C_1, C_2… C_{10}}. Relative weights {w_1, w_2 ….w_{10}} are assigned to each design characteristic (attribute) to represent the DM's preference information.

Figure 5.4 Office chair model for analysis

Ten important attributes considered are Depth of seat (C_1), Overall depth (C_2), Width of seat (C_3), Size of base (C_4), Width height ratio (C_5), Seat adjustment (C_6), Backrest height (C_7), Swivel angle (C_8), Decoration (C_9), and Density of cushion (C_{10}). Based on the dimensions considered and comparison with Bureau of Indian standard data, the attributes are classified into beneficial and non-beneficial category. Out of ten attribute, C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8 and C_9 are beneficial (higher the value is desired) and C_{10} is non-beneficial attribute (lower the value is desired). As the alternatives (Office chair) based on attributes are of conflicting in nature, a five point fuzzy scale with triangular fuzzy numbers is chosen to rate the alternatives. A team of four decision makers, DM_1, DM_2, DM_3 and DM_4 has been formed to evaluate the alternatives. An individual decision maker's judgment is evaluated by using fuzzy rating scale with triangular membership functions in order to extract the rating values of alternatives where individual attribute is given linguistic terms as is given in Table 5.2. Linguistic terms are further converted to their corresponding fuzzy numbers as shown in Table 5.3. In order to assess with each attribute weight, individual fuzzy numbers are aggregated as is highlighted in Table 5.4. Aggregate fuzzy numbers are then transformed into crisp values and the corresponding values are given in Table 5.5.

Table 5.2 Linguistic rating for alternatives selection

Decision Maker	Alternative	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
D_1	A1	L	L	VL	M	L	H	M	M	VL	L
	A2	M	M	H	H	H	M	M	M	H	L
	A3	L	H	M	M	L	L	H	VL	VL	M
	A4	L	VL	L	H	M	M	H	VL	M	M
	A5	M	H	M	M	M	M	M	L	VH	L
	A6	L	L	VL	M	L	H	M	L	M	L
D_2	A1	M	M	L	H	M	VH	H	H	L	M
	A2	H	M	H	H	VH	H	H	H	M	L
	A3	M	H	H	H	M	M	VH	L	L	H
	A4	M	M	M	VH	M	H	H	L	M	H
	A5	VH	H	H	M	H	H	H	M	H	L
	A6	M	M	L	M	M	VH	M	M	M	M
D_3	A1	H	M	M	M	M	VH	H	VH	L	L
	A2	VH	H	VH	VH	VH	VH	VH	VH	H	M
	A3	H	VH	H	M	M	H	VH	L	VL	H
	A4	H	M	M	VH	H	VH	VH	L	M	H
	A5	VH	VH	H	M	H	VH	H	H	VH	M
	A6	H	M	M	L	M	VH	H	M	H	L
D_4	A1	VL	L	VL	H	L	M	M	M	M	L
	A2	M	L	M	VH	M	M	M	L	VH	L
	A3	L	M	M	M	L	L	H	VL	L	M
	A4	L	VL	L	H	L	M	H	VL	M	M
	A5	M	M	M	M	M	M	M	L	H	L
	A6	VL	L	VL	L	L	M	L	VL	M	L

Table 5.3 Fuzzy numbers associated with alternatives

		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
D_1	A_1	L(0,0.3,0.5)	L(0,0.3,0.5)	VL(0,0,0.3)	M(0.3,0.5,0.7)	L(0,0.3,0.5)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	VL(0,0,0.3)	L(0,0.3,0.5)
	A_2	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	H(0.5,0.7,1)	H(0.5,0.7,1)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	H(0.5,0.7,1)	L(0,0.3,0.5)
	A_3	L(0,0.3,0.5)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	L(0,0.3,0.5)	L(0,0.3,0.5)	H(0.5,0.7,1)	VL(0,0,0.3)	VL(0,0,0.3)	M(0.3,0.5,0.7)
	A_4	L(0,0.3,0.5)	VL(0,0,0.3)	L(0,0.3,0.5)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	H(0.5,0.7,1)	VL(0,0,0.3	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)
	A_5	M(0.3,0.5,0.7)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	L(0,0.3,0.5)	VH(0.7,0.7,1)	L(0,0.3,0.5)
	A_6	L(0,0.3,0.5)	L(0,0.3,0.5)	VL(0,0,0.3)	M(0.3,0.5,0.7)	L(0,0.3,0.5)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	L(0,0.3,0.5)	M(0.3,0.5,0.7)	L(0,0.3,0.5)
D_2	A_1	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	L(0,0.3,0.5)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	VH(0.7,0.7,1)	H(0.5,0.7,1)	H(0.5,0.7,1)	L(0,0.3,0.5)	M(0.3,0.5,0.7)
	A_2	H(0.5,0.7,1)	M(0.3,0.5,0.7)	H(0.5,0.7,1)	H(0.5,0.7,1)	VH(0.7,0.7,1)	H(0.5,0.7,1)	H(0.5,0.7,1)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	L(0,0.3,0.5)
	A_3	M(0.3,0.5,0.7)	H(0.5,0.7,1)	H(0.5,0.7,1)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	VH(0.7,0.7,1)	L(0,0.3,0.5)	L(0,0.3,0.5)	H(0.5,0.7,1)
	A_4	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	VH(0.7,0.7,1)	M(0.3,0.5,0.7)	H(0.5,0.7,1)	H(0.5,0.7,1)	L(0,0.3,0.5)	M(0.3,0.5,0.7)	H(0.5,0.7,1)
	A_5	VH(0.7,0.7,1)	H(0.5,0.7,1)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	H(0.5,0.7,1)	H(0.5,0.7,1)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	H(0.5,0.7,1)	L(0,0.3,0.5)
	A_6	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	L(0,0.3,0.5)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	VH(0.7,0.7,1)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)
D_3	A_1	H(0.5,0.7,1)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	VH(0.7,0.7,1)	H(0.5,0.7,1)	VH(0.7,0.7,1)	L(0,0.3,0.5)	L(0,0.3,0.5)
	A_2	VH(0.7,0.7,1)	H(0.5,0.7,1)	VH(0.7,0.7,1)	VH(0.7,0.7,1)	VH(0.7,0.7,1)	VH(0.7,0.7,1)	VH(0.7,0.7,1)	VH(0.7,0.7,1)	H(0.5,0.7,1)	M(0.3,0.5,0.7)
	A_3	H(0.5,0.7,1)	VH(0.7,0.7,1)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	H(0.5,0.7,1)	VH(0.7,0.7,1)	L(0,0.3,0.5)	VL(0,0,0.3)	H(0.5,0.7,1)
	A_4	H(0.5,0.7,1)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	VH(0.7,0.7,1)	H(0.5,0.7,1)	VH(0.7,0.7,1)	VH(0.7,0.7,1)	L(0,0.3,0.5)	M(0.3,0.5,0.7)	H(0.5,0.7,1)
	A_5	VH(0.7,0.7,1)	VH(0.7,0.7,1)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	H(0.5,0.7,1)	VH(0.7,0.7,1)	H(0.5,0.7,1)	H(0.5,0.7,1)	VH(0.7,0.7,1)	M(0.3,0.5,0.7)
	A_6	H(0.5,0.7,1)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	L(0,0.3,0.5)	M(0.3,0.5,0.7)	VH(0.7,0.7,1)	H(0.5,0.7,1)	M(0.3,0.5,0.7)	H(0.5,0.7,1)	L(0,0.3,0.5)
D_4	A_1	VL(0,0,0.3)	L(0,0.3,0.5)	VL(0,0,0.3)	H(0.5,0.7,1)	L(0,0.3,0.5)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	L(0,0.3,0.5)
	A_2	M(0.3,0.5,0.7)	L(0,0.3,0.5)	M(0.3,0.5,0.7)	VH(0.7,0.7,1)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	L(0,0.3,0.5)	VH(0.7,0.7,1)	L(0,0.3,0.5)
	A_3	L(0,0.3,0.5)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	L(0,0.3,0.5)	L(0,0.3,0.5)	H(0.5,0.7,1)	VL(0,0,.3)	L(0,0.3,0.5)	M(0.3,0.5,0.7)
	A_4	L(0,0.3,0.5)	VL(0,0,0.3)	L(0,0.3,0.5)	H(0.5,0.7,1)	L(0,0.3,0.5)	M(0.3,0.5,0.7)	H(0.5,0.7,1)	VL(0,0,0.3)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)
	A_5	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	M(0.3,0.5,0.7)	L(0,0.3,0.5)	H(0.5,0.7,1)	L(0,0.3,0.5)
	A_6	VL(0,0,0.3)	L(0,0.3,0.5)	VL(0,0,0.3)	L(0,0.3,0.5)	L(0,0.3,0.5)	M(0.3,0.5,0.7)	L(0,0.3,0.5)	VL(0,0,0.3)	M(0.3,0.5,0.7)	L(0,0.3,0.5)

Table 5.4 Aggregate fuzzy number of alternatives

Alternatives	Criteria									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	(0.2,0.375,0.625)	(0.15,0.4,0.6)	(0.075,0.2,0.45)	(0.4,0.6,0.85)	(0.15,0.4,0.6)	(0.55,0.65,0.925)	(0.4,0.6,0.85)	(0.45,0.6,0.85	(0.075,.275,0.5)	(0.075,0.35,0.55)
A2	(0.45,0.6,0.85)	(0.275,0.5,0.725)	(0.5,0.65,0.925)	(0.6,0.7,1)	(0.55,0.65,0.925)	(0.45,0.6,0.85)	(0.45,0.6,0.85)	(0.375,0.55,0.8)	(.5,0.65,0.925)	(0.075,0.35,0.55)
A3	(0.2,0.45,0.675)	(0.5,0.65,0.925)	(0.4,0.6,0.85)	(0.35,0.55,0.775)	(0.15,0.4,0.6)	(0.2,0.45,0.675)	(0.6,0.7,1)	(0,0.15,0.4)	(0,0.15,0.4)	(0.4,0.6,0.85)
A4	(0.2,0.45,0.675)	(0.15,0.25,0.5)	(0.15,0.325,0.55)	(0.6,0.7,1)	(0.275,0.5,0.725)	(0.45,0.6,0.85)	(0.55,0.7,1)	(0,0.15,0.4)	(0.3,0.5,0.7)	(0.4,0.6,0.85)
A5	(0.5,0.6,0.85)	(0.5,0.65,0.925)	(0.4,0.6,0.85)	(0.3,0.5,0.7)	(0.4,0.6,0.85)	(0.45,0.6,0.85)	(0.4,0.6,0.85)	(0.2,0.45,0.675)	(0.6,0.7,1)	(0.075,0.35,0.55)
A6	(0.2,0.375,0.625)	(0.15,0.4,0.6)	(0.075,0.2,0.45)	(0.15,0.4,0.6)	(0.15,0.4,0.6)	(0.55,0.65,0.925)	(0.275,0.5,0.725)	(0.15,0.325,0.55)	(0.35,0.55,0.775)	(0.075,0.35,0.55)

Table 5.5 Crisp ratings of alternatives

Alternatives	Criteria									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0.409574	0.41	0.268889	0.59	0.41	0.6582	0.59	0.600867	0.318665	0.36642
A2	0.60087	0.5	0.645354	0.702797	0.6582	0.60087	0.60087	0.554043	0.645354	0.36642
A3	0.45551	0.645354	0.59	0.545493	0.41	0.45551	0.702797	0.225217	0.225217	0.59
A4	0.45551	0.313636	0.362788	0.702797	0.5	0.60087	0.688963	0.225217	0.5	0.59
A5	0.612727	0.645354	0.59	0.5	0.59	0.60087	0.59	0.45551	0.702797	0.36642
A6	0.409574	0.41	0.268889	0.41	0.41	0.6582	0.5	0.362788	0.545493	0.36642

Table 5.6 Normalized crisp ratings

Alternatives	Criteria									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0.668445	0.63531	0.416653	0.839503	0.622911	1	0.839503	1	0.453424	0.621051
A2	0.980648	0.774769	1	1	1	0.912898	0.854969	0.922072	0.918265	0.621051
A3	0.743415	1	0.914227	0.776175	0.622911	0.692054	1	0.374821	0.320459	1
A4	0.743415	0.485991	0.562153	1	0.759648	0.912898	0.980316	0.374821	0.711443	1
A5	1	1	0.914227	0.711443	0.896384	0.912898	0.839503	0.758088	1	0.621051
A6	0.668445	0.63531	0.416653	0.583383	0.622911	0.999999	0.711443	0.603774	0.776175	0.621051

The aggregate crisp values of attribute are now normalized using equation 5.6 so that the attribute ratings given by the decision makers can be converted into a common scale. The normalized decision matrix for attribute is shown in Table 5.6.

On the basis of statistical variance method, the variance and the objective weights of the attributes are computed by using equations 5.7 and 5.8. The variance and the objective weight value for ten attribute are given in Table 5.7.

Table 5.7 Objective weights of attribute

Attribute	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Variance	0.0189	0.0369	0.0602	0.0224	0.0220	0.0105	0.0093	0.0598	0.0580	0.0320
Objective weights	0.057	0.112	0.182	0.068	0.0668	0.032	0.028	0.181	0.176	0.096

Analytic Hierarchy Process (AHP) is used to calculate subjective weights of attribute. A pair-wise comparison matrix (10×10) as shown in Table 5.8 can be constructed for attribute based upon the intensity of importance. The value of CR is calculated by using equations 5.9 and 5.10. The value of CR obtained is 0.0654 which is less than 0.1 and hence the result is acceptable. The subjective weights are calculated using geometric means and the result is shown in Table 5.9.

Table 5.8 Pair wise comparison matrix.

	Depth	Overall depth	Width of seat	Size of base	Width height ratio	Seat adjustment	Back rest height	Swivel angle	Decoration	Density
Depth	1	3	2	3	1	2	4	3	6	1/4
Overall depth	1/3	1	1/3	1/4	1/6	1/5	1/2	1/5	2	1/5
Width of seat	½	3	1	3	1/3	2	4	3	5	1/4
Size of base	1/3	4	1/3	1	1/3	1	4	1/3	4	1/2
Width height ratio	1	6	3	3	1	4	5	3	6	1/4
Seat adjustment	½	5	1/2	1	1/4	1	2	1/3	3	1/5
Backrest height	¼	2	1/4	1/4	1/5	1/2	1	1/4	1/2	1/6
Swivel angle	1/3	5	1/3	3	1/3	3	4	1	3	1/3
Decoration	1/6	1/2	1/5	1/4	1/6	1/3	2	1/3	1	1/6
Density	4	5	4	2	4	5	6	3	6	1

To check the consistency of matrix eigen value λ_{max} is to be calculated

Consistency index (CI):

$$\frac{\lambda_{max} - n}{n-1} = \frac{10.86 - 10}{10 - 1} = 0.0956$$

Consistency ratio (CR):

$$= \frac{CI}{RI} = \frac{0.0956}{1.45} = 0.0654 < 0.1$$

Table 5.9 Subjective weight design attributes

	Criterion	Weight
1	Depth seat pan	0.143
2	Overall depth	0.027
3	Width of seat	0.110
4	Size of base	0.065
5	Width height ratio	0.188
6	Seat adjustment	0.0611
7	Backrest height	0.0268
8	Swivel angle	0.0881
9	Decoration	0.0259
10	Density	0.261

The integrated weights of attributes are obtained using equation 5.11. Table 5.10 gives the integrated weights of attributes considering the different weightings proportion of the objective and subjective weights within the range 0 to 1.

Table 5.10 Integrated Weight calculation

Importance of Objective weight (w^0)	Importance of Subjective weight (w^s)	Integrated Weights of Attribute Attributes									
		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
		$w^i_{c_1}$	$w^i_{c_2}$	$w^i_{c_3}$	$w^i_{c_4}$	$w^i_{c_5}$	$w^i_{c_6}$	$w^i_{c_7}$	$w^i_{c_8}$	$w^i_{c_9}$	$w^i_{c_{10}}$
1.0	0	0.057	0.111	0.182	0.068	0.066	0.032	0.028	0.181	0.175	0.096
0.8	0.2	0.074	0.094	0.167	0.067	0.091	0.037	0.028	0.162	0.145	0.129
0.6	0.4	0.091	0.077	0.153	0.066	0.115	0.043	0.027	0.143	0.115	0.162
0.5	0.5	0.100	0.069	0.146	0.066	0.127	0.046	0.027	0.134	0.100	0.178
0.4	0.6	0.108	0.060	0.138	0.066	0.139	0.049	0.027	0.125	0.085	0.195
0.2	0.8	0.125	0.043	0.124	0.065	0.163	0.055	0.027	0.106	0.055	0.228
0	1.0	0.143	0.027	0.110	0.065	0.188	0.061	0.026	0.088	0.025	0.261

The normalized decision matrix for TOPSIS is obtained using equation 5.13 and the decision matrix is shown in Table 5.11. The ranking of the alternatives is illustrated by considering purely subjective weight (w^o = 1 and w^s = 0). By multiplying normalized decision matrix with corresponding integrated attribute weights, the weighted normalized decision matrix can be obtained as is given in Table 5.12.

Table 5.11 Normalized decision matrix

Alternatives	Attribute									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A_1	0.336	0.333	0.228	0.411	0.330	0.448	0.391	0.570	0.251	0.330
A_2	0.493	0.406	0.548	0.490	0.531	0.410	0.398	0.526	0.508	0.330
A_3	0.373	0.524	0.501	0.381	0.330	0.310	0.466	0.214	0.177	0.531
A_4	0.373	0.255	0.308	0.490	0.403	0.410	0.456	0.214	0.394	0.531
A_5	0.502	0.524	0.501	0.350	0.476	0.410	0.391	0.432	0.553	0.330
A_6	0.335	0.333	0.228	0.286	0.330	0.449	0.331	0.344	0.430	0.330

The positive ideal solution and the negative ideal solution for the alternatives are calculated using equations 5.14 and 5.15 respectively. The positive ideal solution is given as {0.0288, 0.058, 0.099, 0.033, 0.035, 0.014, 0.013, 0.103, 0.097, and 0.032}. Similarly, the negative ideal solution is given by {0.019, 0.028, 0.041, 0.019, 0.022, 0.009, 0.009, 0.038, 0.031, and 0.051}. The positive and negative separation (D_i^* and D_i^-) of each alternative from ideal solutions is calculated using equations 5.16 and 5.17 respectively. The Preference index (C_i^*) showing the ranking of alternatives can be obtained by using equation 5.18. and the final ranking of six alternatives are depicted in Table 5.13. In the similar manner, the ranking order of six alternatives considering integrated weights of different proportions is given in Table 5.14.

Table 5.12 Weighted normalized matrix for alternatives

Alternatives	Attributes									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A_1	0.019	0.037	0.042	0.028	0.022	0.014	0.011	0.103	0.044	0.032
A_2	0.028	0.045	0.099	0.033	0.035	0.013	0.011	0.095	0.090	0.032
A_3	0.021	0.058	0.091	0.026	0.022	0.009	0.013	0.038	0.031	0.051
A_4	0.021	0.028	0.056	0.033	0.027	0.013	0.013	0.038	0.070	0.051
A_5	0.029	0.058	0.091	0.0240	0.031	0.013	0.011	0.078	0.097	0.032
A_6	0.020	0.037	0.041	0.020	0.022	0.014	0.009	0.062	0.075	0.032

Table 5.13 Ranking index (C_i^*) of alternatives

Alternatives	Positive Separation Measure	Negative Separation Measure	Preference Index	Ranking of the alternatives
	D_i^*	D_i^-	C_i^*	
A_1	0.0057	0.0043	0.4389	3
A_2	0.0002	0.0093	0.9762	1
A_3	0.0076	0.0028	0.2692	5
A_4	0.0070	0.0014	0.1692	6
A_5	0.0006	0.0080	0.9213	2
A_6	0.0055	0.0025	0.3153	4

Table 5.14 Ranking of alternatives considering integrated weight

Alternatives	$w^o = 1$ $w^s = 0$	$w^o = 0.8$ $w^s = 0.2$	$w^o = 0.6$ $w^s = 0.4$	$w^o = 0.4$ $w^s = 0.6$	$w^o = 0.2$ $w^s = 0.8$	$w^o = 0$ $w^s = 1$
A_1	3	3	3	3	3	3
A_2	1	1	1	1	1	1
A_3	5	5	5	5	5	5
A_4	6	6	6	6	6	6
A_5	2	2	2	2	2	2
A_6	4	4	4	4	4	4

The normalized decision matrix for VIKOR method can be obtained in a linear method as shown in Table 5.6. Keeping in view with the normalized decision matrix, the best value (f_j^*) and the worst value (f_j^-) for the attributes are obtained using equations 5.19(a) and 5.19(b) respectively. The best values and worst values are: f_j^* = (1, 1, 1, 1, 1, 1, 1, 1, 1, and 0.621051) and f_j^- = (0.668445, 0.485991, 0.416653, 0.583383, 0.622911, 0.692054, 0.711443, 0.374821, 0.320459, 1). For ranking the alternatives, the methodology needs to calculate S_i, R_i along with the final values of Q_i as given in Table 5.15 based on equations 5.20, 5.21 and 5.22 where i=1, 2,….n. It has been seen alternative A_2 is best ranked by 'minimum Q value' and the stability in decision making is completely satisfied (condition 2) for all weighing proportion but the acceptance advantage (condition 1) is not satisfied as $Q(A_2)-Q(A_5)=0.15<0.2$. Therefore, a final ranking of alternatives as shown in Table 5.15 is obtained through a compromise solution satisfying equations 5.23 and 5.24 i.e. the alternative in the second position (A_5) forms a compromise solution together with the alternative (A_2) in the first position satisfying the conditions provided in VIKOR method. Considering integrated weight with different proportion of objective and subjective weights, the ranking of the alternatives is illustrated.

Table 5.15 The ranking and the compromise solutions

Weight		A_1	A_2	A_3	A_4	A_5	A_6	Ranking	Compromise solution
$w^o = 0$ $w^s = 1$	S	0.522	**0.066**	0.786	0.720	0.180	0.618	$A_2>A_5>A_1>A_6>A_4>A_3$	A_2
	R	0.188	**0.0176**	0.261	0.261	0.051	0.188	$A_2>A_5>A_6=A_1>A_4=A_3$	A_2
	Q	0.667	**0**	1	0.953	0.150	0.733	$A_2>A_5>A_1>A_6>A_4>A_3$	A_2, A_5
$w^o = 0.2$ $w^s = 0.8$	S	0.569	0.120	0.660	0.699	0.187	0.654	$A_2>A_5>A_1>A_6>A_4>A_3$	A_2
	R	0.182	0.049	0.181	0.181	0.047	0.182	$A_2>A_5>A_1=A_6>A_4=A_3$	A_2
	Q	0.888	0.006	0.961	0.995	0.058	0.962	$A_2>A_5>A_1>A_6>A_4>A_3$	A_2, A_5
$w^o = 0.4$ $w^s = 0.6$	S	0.560	0.108	0.685	0.702	0.185	0.647	$A_2>A_5>A_1>A_6>A_4>A_3$	A_2
	R	0.168	0.041	0.162	0.162	0.063	0.168	$A_2>A_5>A_1=A_6>A_4=A_3$	A_2
	Q	0.880	0	0.9634	0.978	0.150	0.953	$A_2>A_5>A_1>A_6>A_4>A_3$	A_2, A_5
$w^o = 0.6$ $w^s = 0.4$	S	0.550	0.097	0.710	0.7077	0.183	0.640	$A_2>A_5>A_1>A_6>A_4>A_3$	A_2
	R	0.153	0.034	0.162	0.162	0.055	0.153	$A_2>A_5>A_1=A_6>A_4=A_3$	A_2
	Q	0.834	0	1	0.997	0.154	0.906	$A_2>A_5>A_1>A_6>A_4>A_3$	A_2, A_5
$w^o = 0.8$ $w^s = 0.2$	S	0.540	0.086	0.735	0.711	0.182	0.631	$A_2>A_5>A_1>A_6>A_3>A_4$	A_2
	R	0.140	0.026	0.195	0.195	0.048	0.140	$A_2>A_5>A_1=A_6>A_3=A_4$	A_2
	Q	0.684	0	1	0.981	0.138	0.754	$A_2>A_5>A_1>A_6>A_3>A_4$	A_2
$w^o = 1$ $w^s = 0$	S	0.530	0.076	0.760	0.715	0.180	0.624	$A_2>A_5>A_1>A_6>A_3>A_4$	A_2
	R	0.163	0.020	0.228	0.228	0.045	0.163	$A_5>A_1>A_4=A_3>A_1=A_6$	A_5
	Q	0.678	0	1	0.966	0.140	0.746	$A_2>A_5>A_1>A_6>A_3>A_4$	A_2, A_5

In PROMETHEE method, the decision maker gives his/her preference in order to compare the alternatives for each attribute. A preference value ranging between 0 and 1 will be assigned to the 'better' alternative whereas the 'worst' alternative receives a value 0. Based on this theory, a pair-wise comparison of attribute 'depth of seat' is prepared as shown in Table 5.16. As 'depth of seat' is a beneficial attribute, higher values are desired. Considering $w^o = 1$ and $w^s = 0$, the leaving (the measure of the outranking character, $\varphi^+(A)$ (i.e. dominance of alternative A to other alternatives)), entering ($\varphi^-(A)$ (i.e. degree to which alternative A is dominated by all other alternatives) and net flows ($\varphi(A)$) are evaluated using equations 5.27, 5.28 and 5.29 respectively. The final ranking is illustrated in Table 5.17.

Table 5.16 Preference function(P_i) resulting from the pair wise comparisons of the six alternatives with respect to criterion depth of cut.

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	-	0	0	0	0	0
A_2	1	-	1	1	1	1
A_3	1	0	-	1	0	1
A_4	1	0	0	-	0	1
A_5	1	0	1	1	-	1
A_6	0	0	0	0	0	-

Table 5.17 Positive $(\varphi^+(A))$, negative $(\varphi^-(A))$ and net flows $(\varphi(A))$ for the scenario

	A_1	A_2	A_3	A_4	A_5	A_6	$\varphi^+(A)$	$\varphi^-(A)$	$\varphi(A)$	Rank
A_1	-	0.213	0.213	0.391	0.213	0.210	1.24	2.967	-1.727	5
A_2	0.787	-	0.696	0.843	0.517	0.968	3.811	0.995	2.816	1
A_3	0.543	0.303	-	0.543	0.303	0.543	2.235	2.056	0.179	3
A_4	0.608	0.125	0.276	-	0.193	0.432	1.634	2.912	-1.278	4
A_5	0.787	0.354	0.514	0.775	-	0.968	3.398	1.226	2.172	2
A_6	0.242	0	0.357	0.360	0	-	0.959	3.121	-2.162	6

Similarly, net flows for different proportion of objective and subjective weight for all the attributes can be tried. The ranking thus obtained based on $\varphi(A)$ value is given in Table 5.18.

Table 5.18 Ranking of alternatives considering integrated weight

Alternatives	$w^o = 1$ $w^s = 0$	$w^o = 0.8$ $w^s = 0.2$	$w^o = 0.6$ $w^s = 0.4$	$w^o = 0.4$ $w^s = 0.6$	$w^o = 0.2$ $w^s = 0.8$	$w^o = 0$ $w^s = 1$
A_1	5	5	5	5	5	5
A_2	1	1	1	1	1	1
A_3	3	3	3	3	3	2
A_4	4	4	4	4	4	4
A_5	2	2	2	2	2	3
A_6	6	6	6	6	6	6

The preference index values for different alternatives with respect to three MADM methodologies are shown in Figures. 5.5, 5.6 and 5.7 for different weight proportion. It is observed that alternate A_2 is the best among all when attribute weight became more subjective. The ranking order for alternatives changes according to the change in proportion of attribute weight (subjective and objective). It has been found ranking order for the alternatives change with increase of the proportion of objective weight for all the methods. However, change of ranking order with increase of objective weight is more pronounced in the VIKOR method. When only objective weight for attributes is considered, A_3 becomes best alternative instead of A_2 in case of VIKOR. In case of TOPSIS method, the ranking of alternative remains same whatever may the weighing proportion. The final ranking of alternatives considering different weighting proportion of objective and subjective weights is summarized in Table 5.19.

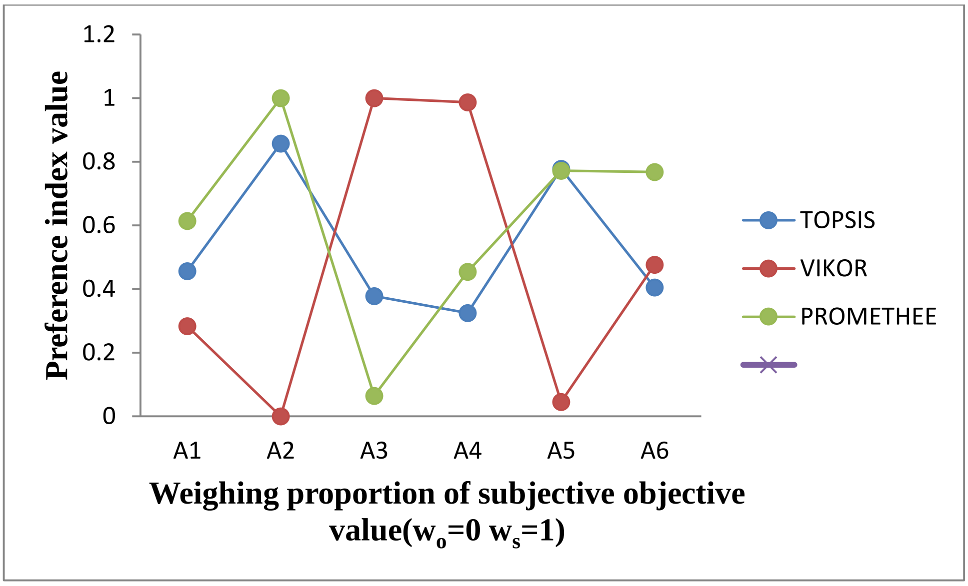


Figure 5.5 Integrated subjective objective weight with w^o=0 and w^s=1

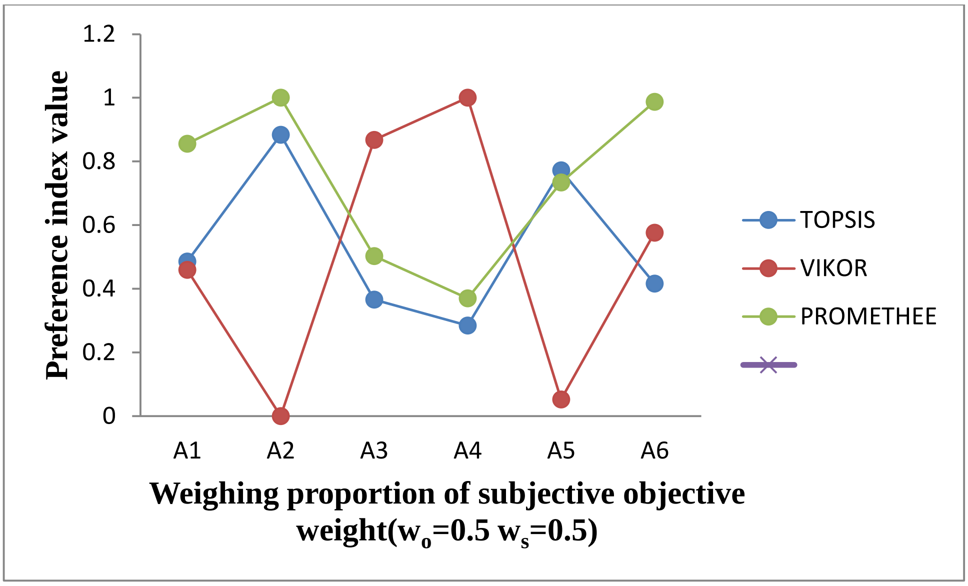


Figure 5.6 Integrated subjective objective weight with w^o=0.5 and w^s=0.5

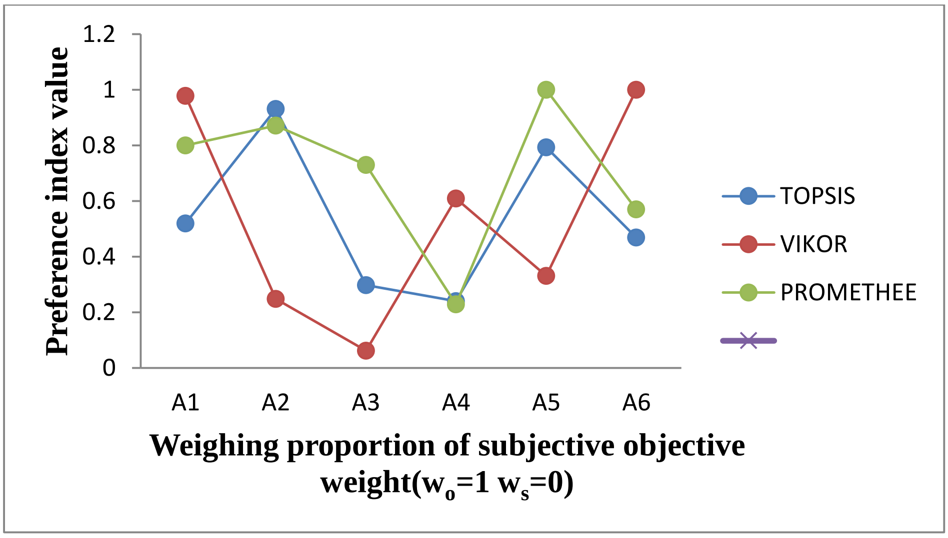


Figure 5.7 Integrated subjective objective weight with w^o=1 and w^s=0

Table 5.19 Ranking order comparison

Alternatives	$w^o = 1$ $w^s = 0$			$w^o = 0.8$ $w^s = 0.2$			$w^o = 0.6$ $w^s = 0.4$		
	TOPSIS	**VIKOR**	**PROMETHEE**	**TOPSIS**	**VIKOR**	**PROMETHEE**	**TOPSIS**	**VIKOR**	**PROMETHEE**
A_1	3	3	5	3	3	5	3	3	5
A_2	1	1	1	1	1	1	1	1	1
A_3	5	5	3	5	5	3	5	6	3
A_4	6	6	4	6	6	4	6	5	4
A_5	2	2	2	2	2	2	2	2	2
A_6	4	4	6	4	4	6	4	4	6

Alternatives	$w^o = 0.4$ $w^s = 0.6$			$w^o = 0.2$ $w^s = 0.8$			$w^o = 0$ $w^s = 1$		
	TOPSIS	**VIKOR**	**PROMETHEE**	**TOPSIS**	**VIKOR**	**PROMETHEE**	**TOPSIS**	**VIKOR**	**PROMETHEE**
A_1	3	3	5	3	3	5	3	3	5
A_2	1	1	1	1	1	1	1	1	1
A_3	5	5	3	5	5	3	5	6	2
A_4	6	6	4	6	6	4	6	5	4
A_5	2	2	2	2	2	2	2	2	3
A_6	4	4	6	4	4	6	4	4	6

5.4 Conclusions

In this research, an attempt has been made to select best office chair with ergonomic considerations using three important MADM methodologies. In the selected MADM approaches, attribute weights are determined using combination of objective and subjective weights to emulate real life decision making process. It is observed that the best alternative chosen remains same for different weighing proportions although the selected MADM methods use different types of normalization to eliminate the units of criterion functions and different ranking index measurement method. The proposed method attempts to consider both subjective and objective weights of qualitative and quantitative attributes and integrates them to decide the importance of weights of the alternatives. Considering $w^o = 1$ and $w^s = 0$, the ranking of the alternatives is illustrated for all the three methods such as TOPSIS, VIKOR, and PROMETHE. The alternatives are arranged in the descending order of their preference as A_2-A_5-A_1-A_6-A_3-A_4. From the above values of preference index, it is understood that the alternative designated as A_2 is the first right choice for the given design application under the given conditions considering ten attributes of the product. It is observed that alternative 2 becomes the best choice in all the three methods even if the weighting proportion of the objective and subjective weight changes. It is also found that ranking order of alternatives 1, 3, 4 and 6 in PROMETHE changes with weighting proportion of objective and subjective weights. In VIKOR method, preference order of alternatives 3 and 4 is altered when the proportion of objective weight decreases. However, the second alternative is the best alternative in all of the three methods whatever may be the proportion of weights of the attributes. The result indicates that all MADM methods considered in this work behave in a similar manner resulting same best alternative irrespective of proportion of weightings for objective and subjective weights. Therefore, the decision makers have the liberty of choosing the best method depending on ease of computational procedure. The method uses only ten features of the product. In future, more features of the product can be incorporated in the decision making process and other MADM approaches may be explored.

CHAPTER 6

HUMAN UPPER ARM POSTURE PREDICTION WITHIN ISOCOMFORT WORK ZONE

6.1 Introduction

Posture analysis is an important issue for the performance analysis of tasks because it is responsible for promoting health by minimizing stress and discomfort during work (Haslegrave, 1994). Musculoskeletal disorders are frequently observed in work environment during manual operation due to abnormal and poor working postures of the body (Haslegrave, 1994; Westgaard and Aaras, 1984). However, it is difficult to identify specific comfort posture (comfort link configuration) as the redundancy of human arm develops many link configurations and joint motions to perform the same task (Gragg et al., 2013). Extra degree of freedom (DOF) due to redundancy helps in free positioning and moves around or between obstacles (Conkur and Buckingham, 1997; Chiaverini, 1997). As deviations from normal postures over a prolonged period of time results in stress in joint muscles and other soft tissue muscles, it is important to design a workspace to place all materials tools, and equipment within the work envelope so that they are easily accessible by the operators (Grandjean and Hunting, 1977; Corlettet et al., 1979, Corlett and Manenica, 1980; Das and Gardy, 1983). Improved layout of workspace enables the operators to use their hands safely avoiding awkward postures and thereby prevents the operators from serious injury problem (Kee, 2002). Therefore, prediction of good posture within comfort workspace becomes a useful way for enhancing the productivity by minimizing operator’s stress and injury (Lim and Hoffmann, 1997).

Most of the posture prediction model relies on analytical and heuristic approaches to provide feasible postures with redundant degrees of freedom and infinite feasible movements of arm (Jung et al., 1992; Kee et al., 1992). Although inverse kinematic (IK) approach finds joint angle by considering the hand position in space but the complexity of the IK solution increases with higher redundancy due to increase in number of DOF. Increase in DOF leads to non-linear equations and singularity problem resulting in indeterminate situation for posture (joint angles) evaluation. Since analytical, geometric, iterative or algebraic method finds difficulty to provide complex IK solutions, the present work proposes two artificial intelligence techniques to predict kinematic model of upper arm posture with a comfort work envelop. Least Squares Support Sector Machines (LSSVM) and Adaptive Neuro Fuzzy Inference System (ANFIS) enhance the model capabilities by providing an infinite number of postures for highly redundant hand. A kinematic model of human arm with seven degrees of freedom is considered to generate a three dimensional workspace around operator. In order to avoid the physical constraint, an isocomfort joint angle range (Diffrient et al., 1985) is considered to determine the workspace. With the help of Indian anthropometric data for segment lengths, a forward kinematics (FK) model is employed to develop a relation between human comfort range of joint angles and the position of kinematic hand. Finally, a workspace is generated with possible positions of kinematic hand. Once the positions inside workspace (comfort work zone) obtained through FK solution, the model becomes trained through LSSVM and ANFIS for estimating the IK solution of a 7-DOF kinematic chain model (human arm model) to predict a comfort posture within the comfort work zone.

6.2 Model description

Posture of human arm is predicted with a range of comfort joint angles and link parameters. Human arm consists of three parts such as upper arm, lower arm and hand. Although upper body can generate infinite postures with many degrees of freedom of different parts, present work focuses only on arm for simplifying the model analysis. The model considers a three link system of a kinematic chain with seven degrees of freedom such as three glenohumeral joint, two elbow joints and two wrist joints.The glenohumeral joint (also known as shoulder joint) is formed by the humeral head and the glenoid cavity of the scapula. In general, it has three rotational degrees of freedom such as flexion and extension, abduction and adduction and internal and external rotation. The elbow joint can be regarded as a hinge joint with two degrees of freedom such as flexion-extension and pronation-supination. Finally, wrist, a pivot joint, has two degrees of freedom like flexion-extension and wrist deviation. Although the effect of spine develops discomfort and fatigue, the spine and other parts are assumed to perform no joints movements. The joints in the model are connected through links. Three links describe the segment lengths such as upper arm, lower arm and hand. In order to carry out the kinematic analysis, different segment measurements are selected from previous literature (Kaur et al., 2011, Singh et al., 2013). The coordinate frames at each joint are defined by Denavit-Hartenberg (D-H) convention. Four parameters (referred as D-H parameters) describe the relative motion between two coordinate frames.

Kinematic analysis

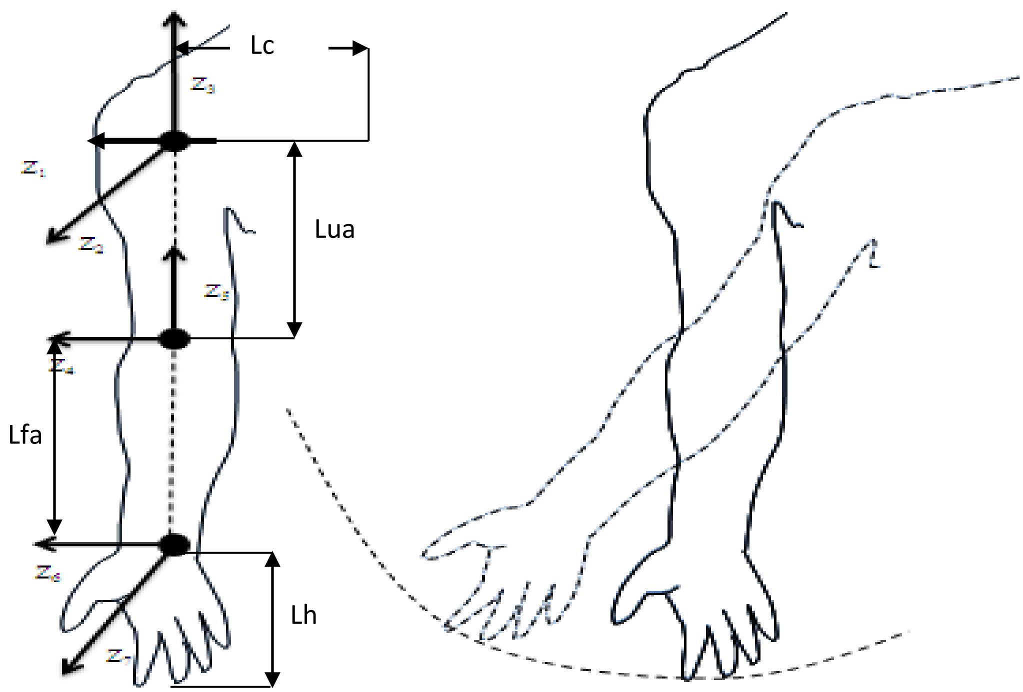


Figure 6.1 Human model arm representation(a) human arm(b)Coordinate frame

Figure 6.1 shows three coordinate frames correspnding to three joints with seven degrees of freedom. For the present study, D-H notation is adopted to describe kinematic model of human upper arm.

6.2.1 Denavit -Hartenberg Representation

D-H notation uses a 4 × 4 homogeneous transformation matrix representing each link's coordinate system at the joint with respect to the adjacent link's coordinate system. A kinematic chain model carries n joints (from 1 to n) with $n+1$ links (from 0 to n, starting from base) and each joint is placed between two links. By this convention, joint i connects link $i-1$ to link i. It is considered that the location of the joint i to be fixed with respect to link $i-1$. Each link of the kinematic chain model is rigidly attached to a coordinate frame for performing the kinematics analysis.

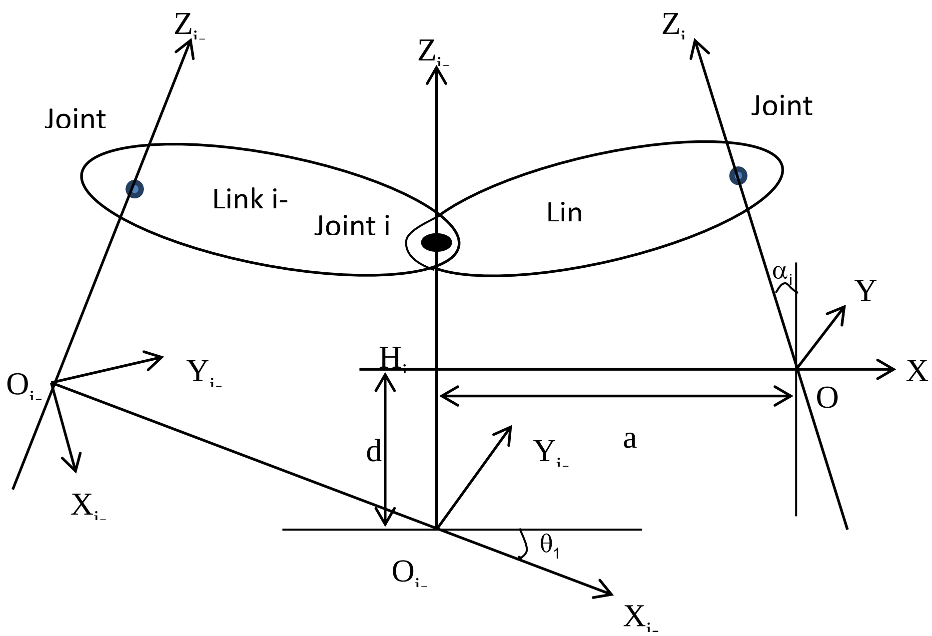


Figure 6.2 The denavit Hartenberg notation (Mittal and Nagrath, 2007)

Figure 6.2 shows two length parameters (a_i and d_i) and two angle parameters (α_i and θ_i). For a joint, the parameters, a_i, α_i, and d_i are constant and determined by the geometry of the link. a_i is the distance between axes z_{i-1} and z_i (link length), d_i is the distance between axes x_{i-1} and x_i measured along axis z_{i-1} (joint distance). α_i is the angle between axes z_{i-1} and z_i, measured about axis x_i (twist angle). θ_i is the angle between axes x_{i-1} and x_i, measured about axis z_{i-1} (joint angle). As the joint moves, only the parameter θ_i becomes the variable that represents the joint angular displacement. With these four parameters, the transformation matrix, T_i^{i-1} can be obtained showing the position and orientation of each coordinate frame with respect to previous frame with its position and orientation.

An overview of all the parameters, used to describe the kinematic arm model, is presented in Table 6.1.

Table 6.1 D-H parameters of human arm model

	θ	d	a	α
Link 1	$\left(\left(\frac{\pi}{2}\right)+\theta_1\right)$	0	0	0
Link 2	$\left(\left(\frac{\pi}{2}\right)+\theta_2\right)$	0	0	$\left(\frac{\pi}{2}\right)$
Link 3	$\left(\left(\frac{\pi}{2}\right)+\theta_3\right)$	-lua	0	$\left(\frac{\pi}{2}\right)$
Link 4	(θ_4)	0	0	$\left(-\frac{\pi}{2}\right)$
Link 5	(θ_5)	-lfa	0	$\left(\frac{\pi}{2}\right)$
Link 6	$\left(\left(\frac{\pi}{2}\right)+\theta_6\right)$	0	0	$\left(\frac{\pi}{2}\right)$
Link 7	(θ_7)	0	-lh	$\left(\frac{\pi}{2}\right)$

The segment lengths are collected from (Murray, 2004). Where, Lc, the length of clavicle i.e. the distance from sternum to the shoulder, Lua, the length of upper arm, Lfa, the length of lower arm and Lh, the length of hand. The joint angle range for different comfort level (comfort zone) is derived from previous estimation (Diffrient et al., 1985) and provided in Table 6.2.

Table 6.2 Joint angle range for comfort zone (Diffrient et al., 1985)

Joint Posture	Comfort Zone different comfort range
Shoulder extension-flexion	-15^0—35^0
Shoulder adduction-abduction	-25^0-0^0
Shoulder rotation	-20^0-45^0
Elbow flexion	15^0-100^0
Elbow supination-pronation	-90^0—30^0
Wrist ulnar radial deviation	-15^0-5^0
Wrist extension-flexion	-25^0-45^0

D-H notation of the joint is introduced with some convention to solve this matrix. The convention and steps for D-H notation is presented as follows.The following steps based on D-H notation are used for deriving the forward kinematics.

Step 1: Base frame is assigned. Set the origin anywhere on the $z_0-\text{axis}$. The x_0 and y_0 axes are chosen conveniently to form a right-hand frame.

Step 2: The origin o_i is located, where the common normal to z_i and z_{i-1} intersects at z_i. If z_i intersects z_{i-1}, a_i located at this intersection. If z_i and z_{i-1} are parallel, locate o_i in any convenient position along z_i.

Step 3: x_i is considered along the common normal between z_{i-1} and z_i through o_i, or in the direction normal to $z_{i-1} - z_i$ plane if z_{i-1} and z_i intersect.

Step 4: y_i is established to complete a right-hand frame.

Step 5: The end-effector frame is assigned as $o_n x_n y_n z_n$. Assuming the n[th] joint is revolute, set $z_n = a$ along the direction z_{n-1}. The origin o_n is taken conveniently along z_n direction, preferably at the centre of the gripper or at the tip of any tool that the manipulator may be carrying.

Step 6: All the link parameters $\theta_i, a_i, d_i, \alpha_i$ are tabulated.

Step 7: The homogeneous transformation matrices A_i is determined by substituting the parameters from table 6.1 in equation 6.1.

Step 8: Then the global transformation matrix ${}^0T_{End}$ is formed using equation 6.2. This then gives the position and orientation of the frame expressed in base coordinates.

In this convention, each homogeneous transformation matrixis A_i represented as a product of four basic transformations:

$$A_i = \begin{bmatrix} \cos(\theta_i) & -\sin(\theta_i)\cos(\alpha_i) & \sin(\theta_i)\sin(\alpha_i) & a_i\cos(\theta_i) \\ \sin(\theta_i) & \cos(\theta_i)\cos(\alpha_i) & -\cos(\theta_i)\sin(\alpha_i) & a_i\sin(\theta_i) \\ 0 & \sin(\alpha_i) & \cos(\alpha_i) & d_i \\ 0 & 0 & 0 & l \end{bmatrix} \quad (6.1)$$

Where four quantities $\theta_i, a_i, d_i, \alpha_i$ are parameter associated with link i and joint j. The four parameters $\theta_i, a_i, d_i, \alpha_i$ in the above equation are generally given name as joint angle, link length, link offset, and link twist respectively.By substituting the D-H parameters from Table 6.2 in equation 6.1, the individual transformation matrices A_1 to A_{End} can be obtained and the global transformation matrix $({}^0T_{End})$ from the first joint to the last joint of the 7-DOF Redundant manipulator can be derived by multiplying all the individual transformation matrices. So,

$${}^0T_{End} = A_1A_2A_3A_4A_5A_6A_7A_{End} = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6.2)$$

Where, p_x, p_y, p_z are the positions and $\{(n_x, n_y, n_z), (o_x, o_y, o_z), \text{and} (a_x, a_y, a_z)\}$ are the orientations of the end-effector. The orientation and position of the end-effector can be calculated in terms of joint angles and the D-H parameters of the manipulator are shown in following equations:

$$\begin{aligned} n_x = & (c_7c_6c_5 - s_7s_5)\{c_3c_4(c_1c_2 - s_1s_2) - s_4(c_1s_2 + s_1c_2)\} + (c_7s_5c_6 + s_7c_5)\{s_3(s_1s_2 - c_1c_2)\} \\ & + s_6c_7\{c_3s_4(s_1s_2 - c_1c_2) - c_4(c_1s_2 + s_1c_2)\} \end{aligned} \tag{6.3}$$

$$\begin{aligned} n_y = & (c_7c_6c_5 - s_7s_5)\{c_3c_4(s_1c_2 + c_1s_2) + s_4(c_1c_2 - s_1s_2)\} + (c_7s_5c_6 + s_7c_5)\{-s_3(s_1c_2 + c_1s_2)\} \\ & + s_6c_7\{-c_3s_4(s_1c_2 + c_1s_2) + c_4(c_1c_2 - s_1s_2)\} \end{aligned} \tag{6.4}$$

$$n_z = c_7c_6s_3c_4s_5 - c_7c_6s_5c_3 + c_7s_6s_3c_3 + c_7s_6s_3s_4 + s_7c_3c_5 - s_7s_3c_4s_5 \tag{6.5}$$

$$\begin{aligned} o_x = & c_6\{c_3s_4(s_1s_2 - c_1c_2) - c_4(c_1s_2 + s_1c_2)\} - s_6c_5\{c_3c_4(c_1c_2 - s_1s_2) - s_4(c_1s_2 + s_1c_2)\} \\ & - s_6s_5\{s_3(s_1s_2 - c_1c_2)\} \end{aligned} \tag{6.6}$$

$$\begin{aligned} o_y = & c_6\{-c_3s_4(s_1c_2 + c_1s_2) + c_4(c_1c_2 - s_1s_2)\} - s_6c_5\{c_3c_4(s_1c_2 + c_1s_2) + s_4(c_1c_2 - s_1s_2)\} \\ & - s_6s_5\{-s_3(s_1c_2 + c_1s_2)\} \end{aligned} \tag{6.7}$$

$$o_z = s_6s_3c_4c_5 + s_5c_3s_6 + s_3c_4c_6 \tag{6.8}$$

$$\begin{aligned} a_x = & (s_7c_6c_5 + c_7s_5)\{c_3c_4(c_1c_2 - s_1s_2) - s_4(c_1s_2 + s_1c_2)\} + (s_7s_5c_6 - c_7c_5)\{s_3(s_1s_2 - c_1c_2)\} \\ & + s_6s_7\{c_3s_4(s_1s_2 - c_1c_2) - c_4(c_1s_2 + s_1c_2)\} \end{aligned} \tag{6.9}$$

$$\begin{aligned} a_y = & (s_7c_6c_5 + c_7s_5)\{c_3c_4(s_1c_2 + c_1s_2) + s_4(c_1c_2 - s_1s_2)\} + (s_7c_6s_5 - c_7c_5)\{-s_3(s_1c_2 + c_1s_2)\} \\ & + s_7s_6\{-c_3s_4(s_1c_2 + c_1s_2) + c_4(c_1c_2 - s_1s_2)\} \end{aligned} \tag{6.10}$$

$$a_z = s_7c_6s_3c_4c_5 - s_7c_6s_5c_3 + s_7s_6s_4s_3 + c_7c_4s_3s_5 - c_3c_5c_7 \tag{6.11}$$

$$\begin{aligned} p_x = & \{d_7(s_7c_6c_5 + c_7s_5)\}\{c_3c_4(c_1c_2 - s_1s_2) - s_4(c_1s_2 + s_1c_2)\} + \{d_7(s_7s_5c_6 - c_7c_5)\}\{s_3(s_1s_2 - c_1c_2)\} \\ & + (d_7s_7s_6 + d_5)\{c_3s_4(s_1s_2 - c_1c_2) - c_4(c_1s_2 + s_1c_2)\} + \{-d_3(c_1s_2 + s_1c_2)\} \end{aligned} \tag{6.12}$$

$$p_y = \{d_7(s_7c_6c_5 + s_5c_7)\}\{c_3c_4(s_1c_2 + c_1s_2) + s_4(c_1c_2 - s_1s_2)\} + \{d_7(s_7s_5c_6 - c_7c_5)\}\{-s_3(s_1c_2 + c_1s_2)\}$$
$$+ (d_7s_7s_6 + d_5)\{-c_3s_4(s_1c_2 + c_1s_2) + c_4(c_1c_2 - s_1s_2)\}$$
(6.13)

$$p_z = d_7s_7s_3c_6c_5c_4 - d_7s_7s_5c_6c_3 + d_7s_7s_6s_4s_3 + d_7s_5s_3c_7c_4 - d_7c_7c_5c_3 + d_5s_4s_3 + d_1$$
(6.14)

where $c_i = \cos(\theta_i), s_i = \sin(\theta_i)$. From equation (6.3)-(6.14), the position and orientation of the 7-DOF redundant manipulator can be obtained and the exact value of these equations can be calculated if all the joint angles and link parameters are given. This is the solution to the forward kinematics.

6.3 Methods for determination of IK solutions

This chapter investigates the use of two artificial intelligence techniques to produce the solution to the inverse kinematics problem for a three joints upper arm kinematic chain.

6.3.1 LSSVM Architecture

The basic formulation of the standard LSSVM (Suykens and Vandewalle, 1999). for function estimation is briefly described in this section. Consider a given training set of N data points $\{x_k, y_k\}_{k=1}^{N}$ with input data $x_k \in R^N$ and output $y_k \in r$, where R^N the N-dimensional vector space and r is is the one-dimensional vector space. This study uses position in workspace as input (x) parameters of the LSSVM. The output of LSSVM is joint angle(y).

Following regression model is used.

$$y(x) = w^T\varphi(x) + b\,, \qquad (6.15)$$

Where the nonlinear mapping $\varphi(.)$ maps the input data into a higher dimensional feature space; $w \in R^n; b \in r$; w=an adjustable weight vector; b=the scalar threshold,

The following optimization problem is formulated:

Minimize: $\frac{1}{2}w^Tw + \frac{1}{2}\gamma\sum_{t=1}^{N}e_k^2$ (6.16)

subject to: $y(x) = (W^T\varphi(x_k)) + b + e_k$ k=1,……..,N (6.17)

where, e_t is the error variable at time t, where $\varphi(\,)$ is a nonlinear function mapping the input space into a higher dimensional space and γ is the regulation constant. The Lagrange function can be obtained as

$$L(W,b,e,\alpha)=\frac{1}{2}w^{T}w+\frac{1}{2}\gamma\sum_{i=1}^{N}e_i^2-\sum_{t=1}^{N}\alpha_i\left(w^{T}\varphi(x_i)\right)+b+e_i-y_i \quad (6.18)$$

where α_t are the Lagrange multipliers. The solution of the above Eq.(6.18) can be obtained by partially differentiating with respect to each variable

$$\frac{\partial L}{\partial w}=0\Rightarrow w=\sum_{k=1}^{N}\alpha_K\varphi(x_k)$$

$$\frac{\partial L}{\partial b}=0\Rightarrow\sum_{k=1}^{N}\alpha_K=0$$

$$\frac{\partial L}{\partial e_k}=0\Rightarrow\alpha_k=\gamma e_k \quad k=1,\ldots\ldots\ldots,N$$

$$\frac{\partial L}{\partial\alpha_K}=0\Rightarrow w^{T}\varphi(x_k)+b+e_k-y_k=0 \quad k=1,\ldots\ldots..,N \quad (6.19)$$

When the variables w and e are removed, the equation can be rewritten as a linear function group

$$\begin{bmatrix}0 & 1^{T}\\ 1_N & \Omega+\gamma^{-1}I\end{bmatrix}\begin{bmatrix}b\\ \alpha\end{bmatrix}=\begin{bmatrix}0\\ y\end{bmatrix} \quad (6.20)$$

Where $y=y_1 \ldots y_N$, $\alpha=[\alpha_1,\ldots\ldots\ldots..\alpha_N]$ and Mercer's theorem (Smola et al. 1998; Vapnik, 1998), is applied within the Ω matrix,

$$\Omega=\varphi(x_k)^{T}\varphi(x_l)=k(x_k,x_l), \qquad k,l=1,\ldots\ldots.N$$

Where k (x_k, x_l) is the kernel function. Choosing $\gamma>0$, ensures the matrix $\phi=\begin{bmatrix}0 & 1^{T}\\ 1 & \Omega+\gamma^{-1}I\end{bmatrix}$ is invertible. Then the analytical of α and b is given by

$$K(x_k,x_l)=\exp\left\{-\frac{(x_k-x_l)(x_k-x_l)^{T}}{2\sigma^2}\right\} \qquad k,l=1,\ldots\ldots\ldots\ldots\ldots N \quad (6.21)$$

Where σ is the width of radial basis function.

The resulting LSSVM model for joint angle prediction becomes then

$$\text{Joint angle}=\sum_{k=1}^{N}\alpha_K k(x,x_k)+b \quad (6.22)$$

The above described LSSVM has been adopted for prediction of joint angle

6.3.2 ANFIS Architecture

Previous chapter (chapter 3) presents the relevant methodology of ANFIS architecture. During training, a five layered ANFIS structure is constructed with one input, three hidden and one output. The Gaussian type of membership function (gaussmf) is used for input and linear type function is used for output. The number of correct outputs is noted till the error is minimized.

6.4 Results and discussions

With the help of comfort joint angle range as comfort posture and segment length, the kinematic equations are solved and hence trajectory can be achieved by moving each joint gradually to the determined position. A comfort work zone can be created by using equation 6.12, 6.13 and 6.14. Figure 6.4 shows the comfort work zone with hand reach positions (p_x,p_y and p_z).

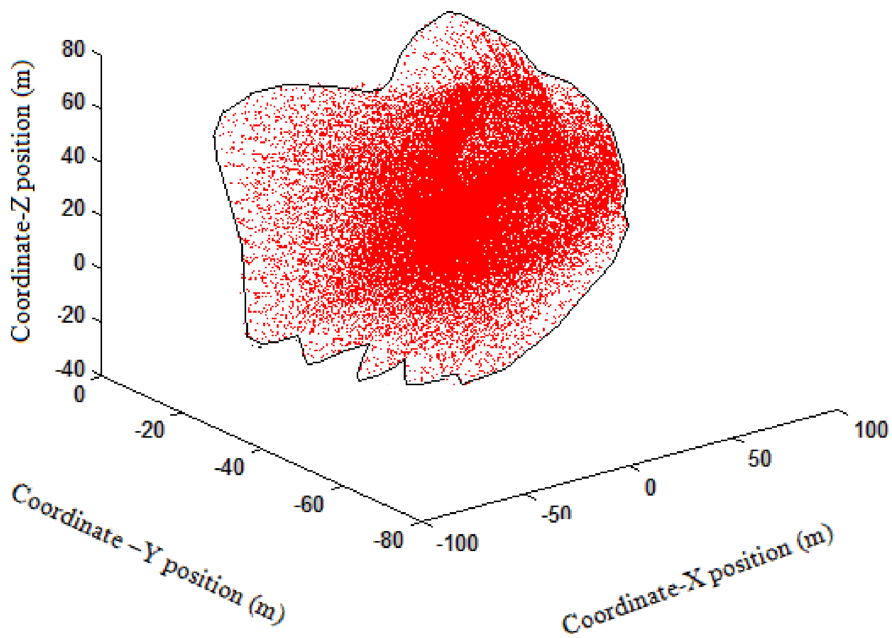
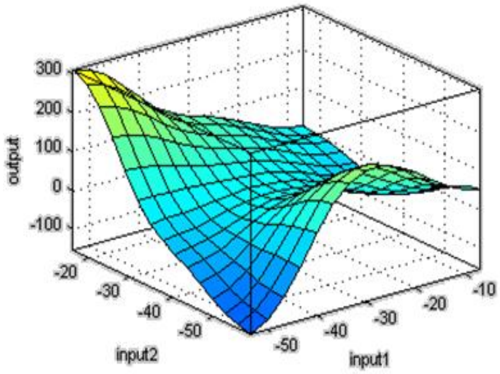


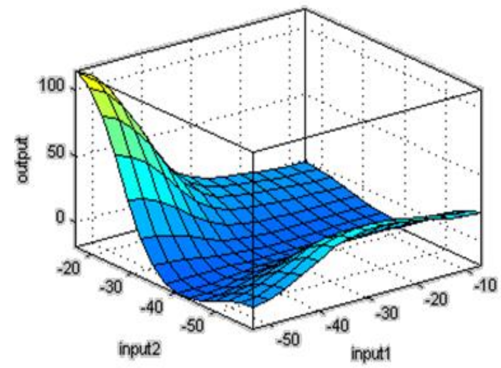
Figure 6.3 Workspace for 7-DOF redundant manipulator showing human arm extremity

As it is difficult to solve the nonlinear equation with the values of hand reach position(p_x,p_y and p_z) in order to find out the comfort joint angles($\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6$ and θ_7), in the proposed approach consider LSSVM and ANFIS model to obtain an IK solutions. Hand reach position that obtained from the forward kinematic relations are considered as input for LSSVM and ANFIS model and posture of upper arm in terms of joint angle (extracted from literature) as output in order to predict an improved set of joint angles. A sample of input-output data are trained in order to predict $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6$ and θ_7. Each of the networks carries seven different models with input p_x (input1), p_y

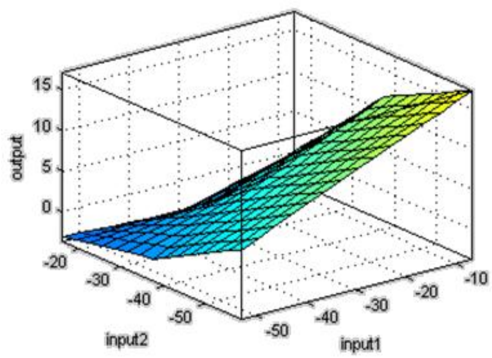
(input2) and $p_{z.}$ (input3) and output $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6$ and θ_7 respectively. In order to construct the model, dataset of 1600 training data and 400 data testing data was considered. Both ANFIS and LSSVM networks will be trained with position p_x,p_y and p_z as inputs and corresponding joint angles theta1, theta2, theta3, theta4, theta5, theta6 and theta7values as output. The matrix data1 contains the p_x,p_y and p_z- θ_1 values to train the first network. Similarly, for second network will be trained with all position values as input and corresponding θ_2 value as output and so on. It has been seen that the predicted joint angle falls within the isocomfort joint angle range. It has been seen from table 6.3 that in both the model the root mean square error have potential values that indicate that this solution is accurate for individual data and may be useful for future posture prediction system. Both model are able to map Cartesian coordinates of position point on comfort zone to healthy biomechanical configurations(joint angles).The surface plot in case of ANFIS as shown in figure.6.5 shows an uniform distribution of data and homogeneity in the training data. Therefore it has been confirmed that the solution is adequate for predicting a comfort posture with a healthy trajectory around the operator. Low residual value of LSSVM in comparison to ANFIS shows that LSSVM provides a better solution in comparison to ANFIS. In this study, the radial basis function is used as the kernel function of LSSVM. Figure 6.6 shows the residual for all seven angles which are nothing but the difference between the predicted output from the model and the actual output of joint angles obtained from literature. As the points are randomly spread around the horizontal axis, the prediction is found to be appropriate. Figure shows that the residual obtained from LSSVM model (red colour) are very close to the horizontal axis in comparison to the blue lines for ANFIS model which indicates LSSVM model shows less error in comparison to ANFIS model.



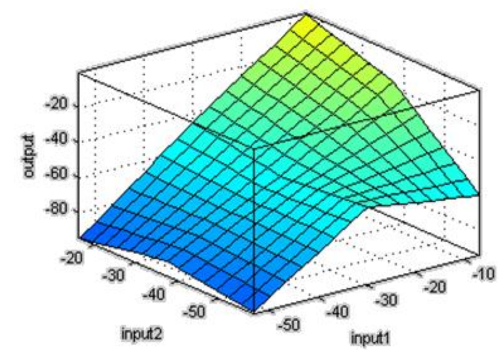
θ_1



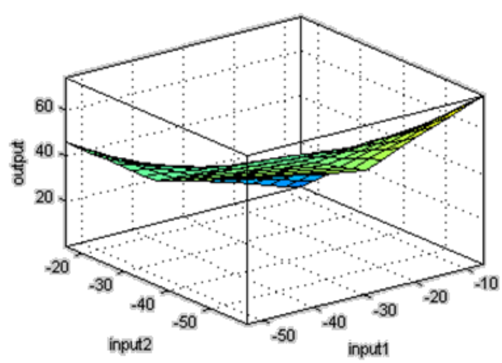
θ_2



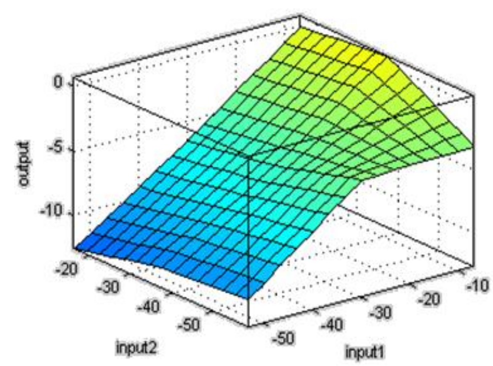
θ_3



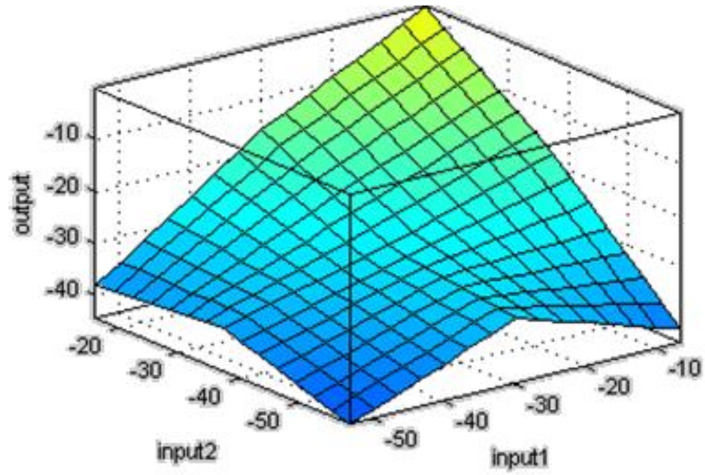
θ_4



θ_5



θ_6

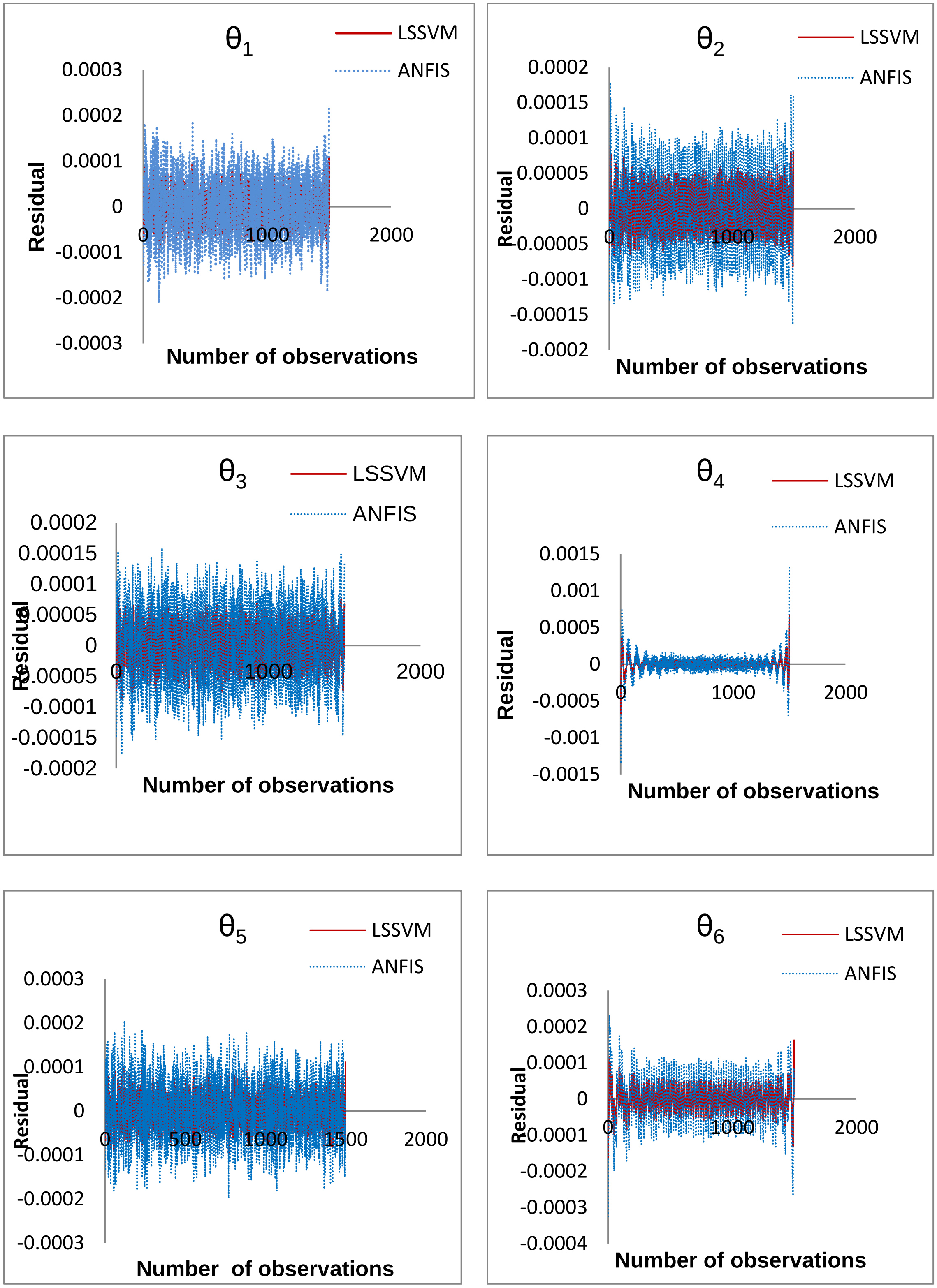


θ_7

Figure 6.4 Surface plot for $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6, \theta_7$

Table 6.3 Prediction comparison between LSSVM and ANFIS

	ANFIS		LSSVM	
	Training (RMSE)	Testing (RMSE)	Training (RMSE)	Testing (RMSE)
θ_1	0.006416	0.335284	0.000156	0.067134
θ_2	0.023065	0.20086	0.001387	0.015626
θ_3	0.006504	0.555197	0.003414	0.033452
θ_4	0.00158	0.591968	0.000818	0.234112
θ_5	0.002328	0.418890	0.000899	0.095139
θ_6	0.010064	1.14556	0.008165	0.332050
θ_2	0.001673	0.2986661	0.000891	0.043887


θ1
LSSVM
ANFIS
0.0003
0.0002
0.0001
0
-0.0001
-0.0002
-0.0003
Residual
0
1000
2000
Number of observations
θ2
LSSVM
ANFIS
0.0002
0.00015
0.0001
0.00005
0
-0.00005
-0.0001
-0.00015
-0.0002
Residual
0
1000
2000
Number of observations
θ3
LSSVM
ANFIS
0.0002
0.00015
0.0001
0.00005
0
-0.00005
-0.0001
-0.00015
-0.0002
Residual
0
1000
2000
Number of observations
θ4
LSSVM
ANFIS
0.0015
0.001
0.0005
0
-0.0005
-0.001
-0.0015
Residual
0
1000
2000
Number of observations
θ5
LSSVM
ANFIS
0.0003
0.0002
0.0001
0
-0.0001
-0.0002
-0.0003
Residual
0
500
1000
1500
2000
Number of observations
θ6
LSSVM
ANFIS
0.0003
0.0002
0.0001
0
-0.0001
-0.0002
-0.0003
-0.0004
Residual
0
1000
2000
Number of observations

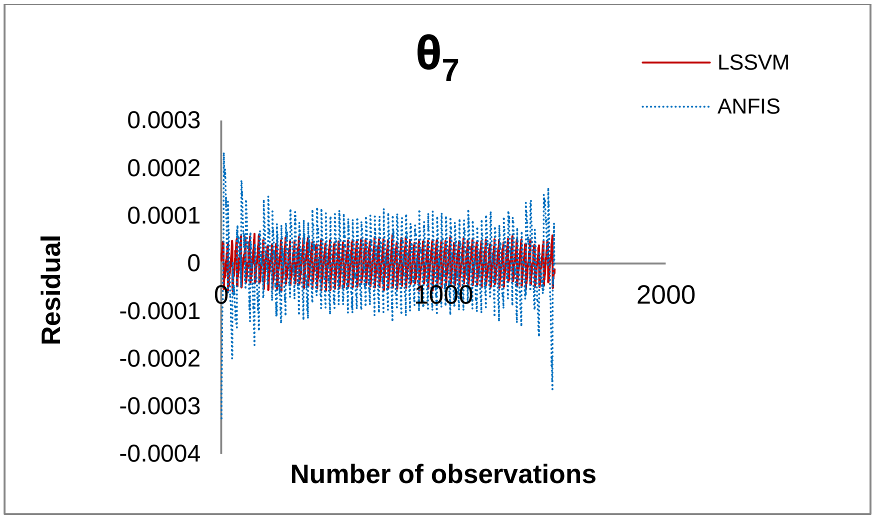


Figure 6.5 Residual plot for $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6, \theta_7$ through LSSVM and ANFIS

To ensure effective performance, the operator needs to work within a comfort work zone so that there is no interference during manual operation. Comfort posture also provides a healthy and safety work environment. In this study, an isocomfort joint posture has been considered from previous literature to create a comfort work zone. With the help of Indian anthropometric data and D-H notation, the proposed model helps to analytically generate three-dimensional isocomfort work zone by using forward kinematics for a range of isocomfort postures. Two intelligence techniques have been applied to predict comfort joint arm postures considering end position of hand in workspace.

The results of this study may be generalized or justified to a larger extent by considering more degrees of freedom resulting in complex situation to the link system. Therefore, only the upper extremity is considered for the analysis. The results show that the predicted joint angles are found within the isocomfort range. No significant difference between actual and predicted joint is observed in both the techniques as the root mean square error has low values. Table 6.4 shows LSSVM and ANFIS based root mean square error (RMSE) results.

6.5 Conclusions

This study predicts the comfort joint angles for human arm in sitting and standing postures. The study develops an inverse kinematics solution for 7-DOF kinematic chain model using ANFIS and LSSVM. The difference in actual and predicted joint angle with ANFIS and LSSVM model for 7-DOF kinematic chain model clearly depicts that the proposed LSSVM method performs better as minimum RMSE error is observed. The model is constructed considering hand end position as input and seven joint positions as output parameters in training and testing data with a smaller number of iteration steps. Hence, it is concluded that the trained LSSVM and ANFIS models can be utilized to solve complex, nonlinear and discontinuous kinematics equation of complex kinematic chain model for biomechanical studies in order to predict comfort work zone.

CHAPTER 7

EXECUTIVE SUMMARY AND CONCLUSIONS

7.1 Introduction

The present thesis involves detailed study on affective satisfaction of user, product's functional performance and comfort of the user to enhance the design process of product/machine/equipment/component. Affective satisfaction of user deals with the issues related to product's intangible characteristics that satisfy the users. Objective performance originates from the effectiveness of use whereas the comfort level of user is quantified through biomechanical and physiological perspective of human body during physical interaction with the product. Consideration of three criteria such as product performance in terms of usability, user satisfaction and comfort level generally enhances the design process. To deal with the complex operator-system interaction, the study outlines various approaches relevant to design phase of a product. The study also emphasizes on prediction of comfort level through biomechanical analysis of human body-product interaction. In order to meet the objectives, the methodology proposed here as follows:

1. An integrated approach is established that deals with subjective and objective design criteria of product with ergonomic consideration. In order to deal with subjective feelings associated with product, a questionnaire survey has been conducted. Customer driven approaches like QFD and factor analysis are considered in order to establish the relation between user requirements and design elements. Intelligence technique like ANFIS develops a relation between design parameters and customer satisfaction. The approach is described with the help of an office chair design.
2. The study also involves a biomechanical analysis as a measure of comfortness during physical interaction of user and product. To describe the biomechanical analysis, human-chair seat model with various parameters is considered as a case study. Present work develops a simple two-dimensional finite element model of human soft tissue with ischial tuberocity-seat with various seat material parameters, thicknesses of seat and different loading angle to predict stress at ischial tuberosity in order to provide guidelines to reduce occurrence of pressure ulcer. The analysis investigates maximum extent of stress in soft tissue muscle (at ischial tuberocity) on prolonged sitting in an office environment.
3. The study carries out various possible ways to choose a suitable ergonomically design product with most usability factors (design criteria) among a number of conflicting criteria.

4. As awkward posture is always associated with a measure of discomfort, the analysis covers the prediction of comfort posture with design of comfort work zone in order to place all materials, tools and equipment within the work envelope so that they are easily accessible by the operators.

7.2 Summary of findings

- A novel integrated approach using statistical and artificial intelligence techniques has been proposed in this thesis to handle effectively subjective and objective design characteristics. Customers' expectation from the product is extracted through a questionnaire survey. Data reduction technique like factor analysis has been applied to survey data to eliminate redundancy. The reduced customer requirements are translated into design characteristics using QFD. Through an artificial intelligence technique like adaptive neuro-fuzzy inference system, the nonlinear relationship between user satisfaction and design attributes can be successfully established. The prototype is compared with the data prescribed by Bureau of Indian Standard (BIS) for office chair. It is observed that some parameters are not within the range of BIS data. The variations are attributed to localization of sample data.
- A numerical approach based on simple two dimensional finite element seat-soft tissue model is proposed in the thesis to provide guidelines for the designers for analyzing the behavior of interaction of soft human tissue and cushion material and estimates maximum stress beneath the bony structure (ischial tuberocity). It can be deduced that the size of the affected zone as well as the stress is much larger for a rigid seat as compared to soft cushion. The cushion having elastic modulus of 20 kPa and density 40 kg/m^3 shows less stress distribution at ischial tuberosity in comparison to cushion having elastic modulus of 200 kPa and density 60 kg/m^3. The effect of sitting posture (tilting posture) from 0^0 to 30^0 has also been analyzed to study the influence of postural change on maximum stress at ischial tuberocity. It has been observed that only a fraction of total vertical load acts on ischial tuberosity due to postural change because change of posture transfers the load to those regions of body other than ischial tuberosity. Therefore, the muscles lying below ischial tuberosity relieves stress by distributing the stress toward thighs and waist. The stress at ischial tuberosity goes on increasing with sitting time. However, the stress becomes constant after

an interval of one and half hours of continuous sitting but the intensity of load causes significant influence on cell damage.

- The proposed MADM method in this work considers both subjective and objective weights of design attributes for selection of alternatives in an uncertain environment so that the decision maker facilitate with the objective information regarding the product as well as the uncertainity of human judgement on the product. In order to rank the alternatives with different weighting proportion, three MADM methods like TOPSIS, VIKOR and PROMETHEE have been used. In order to check the stability of ranking with respect to different weighted criteria, a sensitivity analysis has been carried out considering different proportion of attribute weights (subjective and objective). It is to be noted that the alternative designated as 2 is the first preference by all the methods even if the weighting proportion of subjective and objective weights vary.
- The proposed kinematic model of human arm makes it possible to evaluate analytically comfort work zone satisfying a comfort posture. Human arm with seven degrees of freedom is considered to generate a three dimensional workspace around operator. In order to avoid the physical constraint, an isocomfort joint angle range (Diffrientet al., 1985) is considered to determine the workspace. As it is difficult to solve complex inverse kinematic equations, this chapter explores two artificial intelligence techniques such as LSSVM and ANFIS model to predict upper arm comfort posture under a standing/sitting condition satisfying comfort work zone.

7.3 Contribution of research work

- Providing a novel integrated approach using statistical and artificial intelligence techniques, current methodology manages subjective and objective design criteria for product development with ergonomic consideration and provides a guideline to adopt this approach in any design phase of any product. Through an artificial intelligence technique like adaptive neuro fuzzy inference system, the model is able to develop a nonlinear relationship between customer satisfaction and design attributes.
- As the proposed design does not satisfy all prescribed limits regarding design elements of Bureau of Indian Standard (BIS), it has been suggested that the variations are attributed to localization of data collection. The standards should

be regularly reviewed and formulated in accordance with the technological development as well as localization effect of anthropometric parameters.

- The numerical analysis considering simple 2D finite element formulation provides insight into the problem and prescribes guidelines to avoid suffering from pressure sore to some extent. It also suggests the ways to reduce the stress on bony prominence causing cell death of muscle tissue during prolonged sitting in an office environment.
- Effect of changing posture suggests that change in posture transfers the load to those regions of body other than ischial tuberocity and relieves the muscles from the load below ischial tuberocity by distributing the stress towards thighs and waist. In order to make stress relaxed or reduce the direct load on fibers, either a postural change or a leisure time should be preferred after certain duration of sitting. It has been shown that use of right kind of foam for seat cushion and thickness can substantially reduce the stress level at ischial tuberosity.
- A novel multi attribute decision making (MADM) approach is proposed in the present work to choose a suitable alternative (office chair) considering both subjective and objective weights for design attributes in an uncertain environment.
- Sensitivity analysis shows that different weighting proportion for subjective and objective weights significantly influence in choosing the alternatives. It is to be noted that the alternative designated as 2 is the first preference by all the methods even if the weighting proportion of subjective and objective weights varies. The model demonstrates that the ranking of alternatives depends upon the weighting proportion of subjective and objective weights. However, different approaches lead to approximately same alternatives preference order for a given weighting proportions.
- The kinematic analysis of upper extremities allows the operator to have comfort work zone within which possible posture can be accepted to enable the operator to use their hands safely to perform the task. The proposed LSSVM and ANFIS models can produce solution to complex inverse kinematics problem to suggest the joint angles to reach at specified locations within a safe work zone.

7.4 Limitations of study

- The work has been limited to analyze only one performance i.e. sitting in office environment.
- Although numerical analysis shows the stress within muscle decreases with proper cushion thickness and postural changes, this work considers a simple 2D model to provide guidelines for the designers and analyze behavior of interaction of soft human tissue and cushion material. The study can be improved considering a model with 3D formulation.
- Contouring of the seat can potentially influence on pressure distribution at ischial tuberosity but this effect has not been considered in the present work.

7.5 Scope of future research

- The work can be extended to design of hand tools, machinery, vehicles and furniture with ergonomic consideration used in various work environments.
- The numerical approach considered in this work may be extended to dynamic analysis where vibrational effect can be analyzed in a moving vehicle.
- .Contouring of the seat can be considered to study its influence on pressure distribution at ischial tuberosity.

Bibliography

1. Abdel-Malek, K., Yu, W., Yang, J. and Nebel, K. (2004). A mathematical method for ergonomic-based design: placement. International Journal of Industrial Ergonomics, 34(5), 375-394.
2. Anderson, G. B. J., Murphy, R. W., Örtengren, R. and Nachemson, A. L. (1979). The influence of backrest inclination and lumbar support on lumbar lordosis. Spine, 4(1), 52-58.
3. Andreas, K., Mutlu, B., Forlizzi, J., Guastrin C. and Hodgins, J. (2007). Robust, low cost, non-intrusive sensing and recognition of seated postures. Proceedings of the 20th Annual ACM Symposium on User Interface Software and Technology, New Port, Rhode Island, USA, 7–10 October,149–158.
4. Armstrong, L. E., De Luca, J.P. and Hubbard, R. W. (1990).Time course of recovery and heat acclimation ability of prior exertional heat stroke patients. Medicine and Science in Sports and Exercise, 22(1), 36-48.
5. Avalle, M., Belingardi, G. and Montanini, R. (2001). Characterization of polymeric structural foams under compressive impact loading by means of energy-absorption diagram. International Journal of Impact Engineering, 25(5), 455-472.
6. Axelsson, J. R. C. (2000). Quality and ergonomics-towards successful integration. Doctoral Thesis, Dissertation No 616, Quality and Human Systems Engineering, Linkoping University, Linkoping.
7. Bellman, R. E. and Zadeh, L. A. (1970). Decision-making in a fuzzy environment. Management Science, 17(4), 141–164.
8. Bennett, J. L. (1984). Managing to meet usability requirements: establishing and meeting software development goals. Visual display terminals, Prentice-Hall, Englewood Cliffs, NJ, 161-184.
9. Bergqvist, U. O. and Knave, B. G. (1994). Eye discomfort and work with visual display terminals. Scandinavian Journal of Work, Environment and Health,20, 27-33.
10. Besharati, B., Luo, L., Azarm, S. and Kannan, P. K. (2006). Multi-objective single product robust optimization: An integrated design and marketing approach. Journal of Mechanical Design, 128(4), 884-892.

11. Bolstad, G., Benum, B. and Rokne, A. (2001). Anthropometry of Norwegian light industry and office workers. Applied Ergonomics, 32(3), 239-246.

12. Brans J. P., Mareschal, B. and Vincke, P. (1984). PROMETHEE: a new family of outranking methods in multi criteria analysis. Proceedings of Operational Research, Amsterdam, North Holland, 477-490.

13. Braun, W. J., Rebollar, R. and Schiller, E. F. (1996). Computer aided planning and design of manual assembly systems. International Journal of Production Research, 34(8), 2317-2333.

14. Bridger, R.S. (1995). Introduction to Ergonomics. McGraw-Hill, New York.

15. Briody, C., Duignan, B., Jerrams, S. and Tiernan, J. (2012). The implementation of a visco-hyperelastic numerical material model for simulating the behaviour of polymer foam materials. Computational Materials Science, 64, 47-51.

16. Buckle, P. W. and Devereux J. J. (2002). The nature of work-related neck and upper limb musculoskeletal disorders. Applied Ergonomics, 33, 207-217

17. Burri Jr, G. J. and Helander, M. G. (1991). A field study of productivity improvements in the manufacturing of circuit boards. International Journal of Industrial Ergonomics, 7(3), 207-215.

18. Carlsson, C. and Fullér, R. (1996). Fuzzy multiple criteria decision making: Recent developments. Fuzzy Sets and Systems, 78(2), 139-153.

19. Castellucci, H. I., Arezes, P. M. and Viviani, C. A. (2010). Mismatch between classroom furniture and anthropometric measures in Chilean schools. Applied Ergonomics, 41(4), 563-568.

20. Ceelen, K. K., Stekelenburg, A., Mulders, J. L. J., Strijkers, G. J., Baaijens, F. P. T., Nicolay, K. and Oomens, C. W. J. (2008). Validation of a numerical model of skeletal muscle compression with MR tagging: a contribution to pressure ulcer research. Journal of Biomechanical Engineering, 130(6), 061015(1-8).

21. Chaffin. D.B. 1999 Manual material-handling limits. In: Chaffin. DB. Andersson. G.B.J. Martin. B.J. (Eds.). Occupational Biomechanics. 3rd Edition. Wiley. New York, 315-354.

22. Chan, K. Y., Dillon, T. S., Kwong, C. K. and Ling, S. H. (2011, June). Using genetic programming for developing relationship between engineering characteristics and customer requirements in new products. IEEE International Conference of Industrial Electronics and Application (ICIEA 2011), Beijing, China, 526–531.

23. Chen, C. T. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment. Fuzzy sets and systems, 114(1), 1-9.
24. Chen, C. T., Lin, C. T. and Huang, S. F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. International Journal of Production Economics, 102(2), 289-301.
25. Chen, L. H. and Ko, W. C. (2008). A fuzzy nonlinear model for quality function deployment considering Kano's concept. Mathematical and Computer Modeling, 48(3), 581-593.
26. Chen, S. H. (1985). Ranking fuzzy numbers with maximizing set and minimizing set. Fuzzy sets and Systems, 17(2), 113-129.
27. Chen, S. J. J., Hwang, C. L., Beckmann, M. J. and Krelle, W. (1992). Fuzzy multiple attribute decision making: methods and applications. Springer-Verlag New York, Inc.
28. Chiaverini, S. (1997). Singularity-robust task-priority redundancy resolution for real-time kinematic control of robot manipulators. Robotics and Automation, IEEE Transactions on Systems, 13(3), 398-410.
29. Chow, W. W. and Odell, E. I. (1978). Deformations and stresses in soft body tissues of a sitting person. Journal of Biomechanical Engineering, 100(2),79-87.
30. Chuang, M. C., Chang, C. C. and Hsu, S. H. (2001). Perceptual factors underlying user preferences toward product form of mobile phones. International Journal of Industrial Ergonomics, 27(4), 247-258.
31. Cimino, A., Longo, F. and Mirabelli, G. (2009). A multi measure-based methodology for the ergonomic effective design of manufacturing system workstations. International Journal of Industrial Ergonomics, 39(2), 447–455.
32. Conkur, E. S. and Buckingham, R. (1997). Clarifying the definition of redundancy as used in robotics. Robotica, 15(5), 583-586.
33. Corlett, E. N., Madeley, S. J. and Manenica, I. (1979). Posture targetting: a technique for recording work postures. Ergonomics, 22 (3), 357-366.
34. Corlett, E. N. and Manenica, I. (1980). The effects and measurement of working postures. Applied Ergonomics, 11(1), 7-16.
35. Coulibaly, S., and Hua, Z. (2006). A scientific basis for the choice of scale in QFD. International Journal of Services and Operations Management, 2(2), 124-145.

36. Crenshaw, R. P. and Vistnes, L. M. (1987). A decade of pressure sore research. Journal of Rehabilitation Research and Development, 26(1), 63-74.
37. Dandavate, U., Sanders, E. B. N. and Stuart, S. (1996, October). Emotions matter: user empathy in the product development process. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 40(7), 415-418). SAGE Publications.
38. Das, B. and Grady, R. M. (1983). Industrial workplace layout designs: an application of engineering anthropometry. Ergonomics, 26(5), 433-447.
39. Das, B. and Sengupta, A. K. (1996). Industrial workstation design: a systematic ergonomics approach. Applied Ergonomics, 27(2), 157-163.
40. Dewangan, K. N., Owary, C. and Datta, R. K. (2010). Anthropometry of male agricultural workers of north-eastern India and its use in design of agricultural tools and equipment. International Journal of Industrial Ergonomics, 40(5), 560-573.
41. Diffrient, N., Tilley, A. R. and Harman, D. (1985).Human scale (Cambridge, MA: MIT Press).
42. Santos, D., I. J. A. L., Farias, M. S., Monteiro, B. G., Falcão, M. A. and Marcelino, F. D. (2011). Using participatory ergonomics to improve nuclear equipment design. Journal of Loss Prevention in the Process Industries, 24(5), 594-600.
43. Dursun Kaya, M., Samet Hasiloglu, A., Bayramoglu, M., Yesilyurt, H. and Fahri Ozok, A. (2003). A new approach to estimate anthropometric measurements by adaptive neuro-fuzzy inference system. International Journal of Industrial Ergonomics, 32(2), 105-114.
44. Ellegast, R. P., Kraft, K., Groenesteijn, L., Krause, F., Berger, H. and Vink, P. (2012). Comparison of four specific dynamic office chairs with a conventional office chair: impact upon muscle activation, physical activity and posture. Applied Ergonomics, 43(2), 296-307.
45. Fathallah, F. A. (2010). Musculoskeletal disorders in labor-intensive agriculture. Applied Ergonomics, 41(6), 738-743.
46. Falck, A. C., Örtengren, R. and Högberg, D. (2010). The impact of poor assembly ergonomics on product quality: a cost–benefit analysis in car manufacturing. Human Factors and Ergonomics in Manufacturing & Service Industries, 20(1), 24-41.

47. Ferguson-Pell, M.W. (1990). Seat cushions selection. Journal of Rehabilitation Research and Development, 2, 49-73.

48. Fredriksson, K., Bildt, C., Hägg, G. and Kilbom, Å. (2001). The impact on musculoskeletal disorders of changing physical and psychosocial work environment conditions in the automobile industry. International Journal of Industrial Ergonomics, 28(1), 31-45.

49. Fok, K. S. and Chou, S. M. (2010). Development of a finger biomechanical model and its considerations. Journal of Biomechanics, 43(4), 701-713.

50. Gauvali, M.K. and Boudolos, K. (2006). Match between school furniture dimensions and children's anthropometry. Applied Ergonomics, 37(6), 765–773.

51. Gefen, A., Gefen, N., Linder-Ganz, E. and Margulies, S. S. (2005). In vivo muscle stiffening under bone compression promotes deep pressure sores. Journal of Biomechanical Engineering, 127(3), 512-524.

52. Gefen, A., van Nierop, B., Bader, D. L. and Oomens, C. W. (2008). Strain-time cell-death threshold for skeletal muscle in a tissue-engineered model system for deep tissue injury. Journal of Biomechanics, 41(9), 2003-2012.

53. Gibson, R.F. (2012). Principle of Composite Material Mechanics, third edition. CRC Press, University of Nevada, Reno, USA.

54. Goonetilleke, R.S. and Feizhou, S. (2001). A methodology to determine the optimum seat depth. International Journal of Industrial Ergonomics. 27(4), 207–217.

55. Gragg, J., Yang, J. J. and Howard, B. (2012). Hybrid method for driver accommodation using optimization-based digital human models. Computer-Aided Design, 44(1), 29-39.

56. Grandjean, E. and Hünting, W. (1977). Ergonomics of posture-review of various problems of standing and sitting posture. Applied Ergonomics, 8(3), 135-140.

57. Groenesteijn, L., Vink, P., Loozc, M.D. and Krause, F. (2009). Effects of differences in office chair controls, seat and back rest angle, design in relation to tasks. Applied Ergonomics, 40(3), 362–370.

58. Grujicic, M., Pandurangan, B., Arakere, G., Bell, W. C., He, T. and Xie, X. (2009). Seat-cushion and soft-tissue material modeling and a finite element investigation of the seating comfort for passenger-vehicle occupants. Materials and Design, 30(10), 4273-4285.

59. Guan, S. S. and Lin, Y. C. (2001). A study on the color and style collocation of mobile phones using neural network method. Journal of the Chinese Institute of Industrial Engineers, 18(6), 84-94.
60. Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E. (2010) Multivariate Data Analysis, 7th ed., John Wiley and Sons, New York.
61. Hales, T. R. and Bernard, B. P. (1996). Epidemiology of work-related musculoskeletal disorders. The orthopedic clinics of North America, 27(4), 679-709.
62. Han, S. H. and Hong, S.W. (2003). A systematic approach for coupling user satisfaction with product design. Ergonomics, 46 (13-14), 1441-1461.
63. Han, S. H., Hwan Yun, M., Kim, K. J. and Kwahk, J. (2000). Evaluation of product usability: development and validation of usability dimensions and design elements based on empirical models. International Journal of Industrial Ergonomics, 26(4), 477-488.
64. Han, S. H., Kim, K. J., Yun, M. H., Hong, S. W. and Kim, J. (2004). Identifying mobile phone design features critical to user satisfaction. Human Factors and Ergonomics in Manufacturing and Service Industries, 14 (1), 15-29.
65. Harih, G. (2014).Decision support system for generating ergonomic tool-handles. International Journals of Simulation Modeling, 13 (1), 5-15.
66. Haslegrave, C. M. (1994). What do we mean by a ‘working posture? Ergonomics, 37(4), 781-799.
67. Helander, M. G. and Burri, G. J. (1995). Cost effectiveness of ergonomics and quality improvements in electronics manufacturing. International Journal of Industrial Ergonomics, 15(2), 137-151.
68. Hilton, M. F. and Whiteford, H. A. (2010). Associations between psychological distress, workplace accidents, workplace failures and workplace successes. International Archives of Occupational and Environmental Health, 83(8), 923-933.
69. Hingtgen, B. A., McGuire, J. R., Wang, M., & Harris, G. F. (2004, September). Quantification of reaching during stroke rehabilitation using unique upper extremity kinematic model. In Engineering in Medicine and Biology Society, 2004. IEMBS'04. 26th Annual International Conference of the IEEE, 2, 4916-4919.

70. Hobson, D. A. (1992). Comparative effects of posture on pressure and shear at the body-seat interface. Journal of Rehabilitation Research and Development, 29(4) 21-31.
71. Horiguchi, A. and Suetomi, T. (1995). A Kansei engineering approach to a driver/vehicle system. International Journal of Industrial Ergonomics, 15(1), 25-37.
72. Hong, S. W., Kim, K. J. and Han, S. H. (2002, September). Optimal balancing of product design features: A case study on mobile phones. Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting, 46(6), 700-704. SAGE Publications.
73. Hua, S. K., Lu, M. T. and Tzeng, G. H. (2014). Exploring smart phone improvements based on a hybrid MCDM model. Expert Systems with Applications, 41(9), 4401-4413.
74. Hu, B., Ma, L., Zhang, W., Salvendy, G., Chablat D. and Bennis F. (2011). Predicting real-world ergonomic measurements by simulation in a virtual environment. International Journal of Industrial Ergonomics, 41(1), 64-71.
75. Hunting, W., and Grandjean, T. L. E. (1981). Postural and visual loads at VDT workplaces. I. Constrained postures. Ergonomics, 24(12), 917–931.
76. Hwang, C.L. and Lin, M.J. (1987).Group Decision Making under Multiple Criteria: Methods and Applications, Springer, Berlin.
77. Isiklar G. and Buyukozkan G. (2007).Using a multi- criteria decision making approach to evaluate mobile phone alternatives, Computer Standards and Interfaces, 29(2),265-274.
78. Jahan, A., Ismail, M. Y., Mustapha, F. and Sapuan, S. M. (2010). Material selection based on ordinal data. Materials and Design, 31(7), 3180-3187.
79. Jang, J.R. (1991). Fuzzy modeling using generalized neural networks and Kalmman filter algorithm. Proceedings of Ninth National Conference on Artificial Intelligence, 762–767.
80. Jang, J.R.S. (1993). ANFIS: adaptive-network-based fuzzy inference system. Systems, Man and Cybernetics. IEEE Transactions on Systems, 23(3), 665–685.
81. Jayaram, U., Jayaram, S., Shaikh, I., Kim, Y. and Palmer, C. (2006). Introducing quantitative analysis methods into virtual environments for real-time and continuous ergonomic evaluations. Computers in Industry, 57(3), 283–296.

82. Jee, D. H. and Kang, K. J. (2000). A method for optimal material selection aided with decision making theory. Materials and Design, 21(3), 199-206.
83. Jeong, B.Y. and Park, K.S. (1990). Sex differences in anthropometry for school furniture design. Ergonomics, 33 (12), 1511–1521.
84. Jeya Girubha, R. and Vinodh, S. (2012). Application of fuzzy VIKOR and environmental impact analysis for material selection of an automotive component. Materials and Design, 37, 478-486.
85. Jiang, H. M., Kwong, C.K., Lp, W.H. and Wong, T.C. (2011). Modeling customer satisfaction for new product development using a PSO based ANFIS approach. Applied Soft Computing, 12(2), 726–734.
86. Jindo, T., and Hirasago, K. (1997). Application studies to car interior of Kansei engineering. International Journal of Industrial Ergonomics, 19(2), 105–114.
87. Jindo, T., Hirasago, K. and Nagamachi, M. (1995). Development of a design support system for office chair using 3-D graphics. International Journal of Industrial Ergonomics, 15(1), 49–62.
88. Jordan, P.W. (1998). Human factors for pleasure in product use. Applied Ergonomics, 29 (1), 25-33.
89. Jung, H.S. (2005). A prototype of an adjustable table and an adjustable chair for schools. International Journal of Industrial Ergonomics, 35(10), 955–969.
90. Jung, E. S., Kee, D. and Chung, M. K. (1992, October). Reach posture prediction of upper limb for ergonomic workspace evaluation. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 36(10), 702-706. SAGE Publications.
91. Jung, E. S., Kee, D. and Chung, M. K. (1995). Upper body reaches posture prediction for ergonomic evaluation models. International Journal of Industrial Ergonomics, 16(2), 95-107.
92. Jung, E. S., Shin, Y. and Kee, D. (2000).Generation of visual fields for ergonomic design and evaluation. International Journal of Industrial Ergonomics, 26(4), 445-456.
93. Khanam, C.N., Reddy, M.V., Mrunalini, A., 2006. Opinion of students on seating furniture used in class room. Journal of Human Ecology, 20(1), 15–20.
94. Kaur M., Mahajan, A. Singh, K. B. Kaur A. A. and Batra, A.P.S**.** (2011). Estimation of stature from upper arm length in north Indians - an anthropometric

study, Indian Journal of Fundamental and Applied Life Sciences, 1 (4), 151-154.

95. Kazmierczak, K., Neumann, W. P. and Winkel, J. (2007). A case study of serial-flow car disassembly: Ergonomics, productivity and potential system performance. Human Factors and Ergonomics in Manufacturing & Service Industries, 17(4), 331-351.

96. Kee, D. (2002). A method for analytically generating three-dimensional isocomfort workspace based on perceived discomfort. Applied Ergonomics, 33(1), 51-62.

97. Kee, D., Jung, E. S. and Chung, M. K. (1992). Iso response time regions for the evaluation of visual search performance in ergonomic interface models. Ergonomics, 35(3), 243-252.

98. Kingma, I. and van Dieën, J. H. (2009). Static and dynamic postural loadings during computer work in females: Sitting on an office chair versus sitting on an exercise ball. Applied Ergonomics, 40(2), 199-205.

99. Kosiak, M., Kubicek, W.G., Wilson, M., Danz, J.N., Kottke, F.J., 1958. Evaluation of pressure as a factor in the production of ischial ulcers. Archives of Physical Medicine and Rehabilitation, 39 (10), 623-629.

100. Kumar, A., Bhaskar, G. and Singh, J. K. (2009). Assessment of controls layout of Indian tractors. Applied Ergonomics, 40(1), 91-102.

101. Kuoppala, J., Lamminpaa, A. and Husman, P. (2008). Work health promotion, job well-being, and sickness absences-a systematic review and meta-analysis. Journal of Occupational and Environmental Medicine, 50(11), 1216-1227.

102. Kwong, C. K., Wong, T. C., & Chan, K. Y. (2009). A methodology of generating customer satisfaction models for new product development using a neuro-fuzzy approach. Expert Systems with Applications, 36(8), 11262-11270.

103. Lili, W., Tao, S., Zheng, Y. and Yixiong, L. (2010, June). The parametric design of office chairs based on ergonomics. In Computing, Control and Industrial Engineering (CCIE), 2010 International Conference, 1, 355-360. IEEE.

104. Lindegård, A., Karlberg, C., Wigaeus Tornqvist, E., Toomingas, A. and Hagberg, M. (2005). Concordance between VDU-users' ratings of comfort and

perceived exertion with experts' observations of workplace layout and working postures. Applied Ergonomics, 36(3), 319-325.

105. Linder-Ganz, E., Engelberg, S., Scheinowitz, M. and Gefen, A. (2006). Pressure–time cell death threshold for albino rat skeletal muscles as related to pressure sore biomechanics. Journal of Biomechanics, 39(14), 2725-2732.

106. Linder-Ganz, E. and Gefen, A. (2009). Stress analyses coupled with damage laws to determine biomechanical risk factors for deep tissue injury during sitting. Journal of Biomechanical Engineering, 131(1), 011003(1-13).

107. Linder-Ganz, E., Shabshin, N., Itzchak, Y. and Gefen, A. (2007). Assessment of mechanical conditions in sub-dermal tissues during sitting: a combined experimental-MRI and finite element approach. Journal of Biomechanics, 40(7), 1443-1456.

108. Lin, M. C., Wang, C. C., Chen, M. S. and Chang, C. A. (2008). Using AHP and TOPSIS approaches in customer-driven product design process. Computers in Industry, 59(1), 17-31.

109. Lin, R. and Kang, Y.Y. (2000). Ergonomic design of desk and chair for primary school students in Taiwan. Proceedings of the 4th International Conference on Universal Access in Human Computer Interaction: Coping with Diversity, 207–216.

110. Lin, Y. C., Lai, H. H. and Yeh, C. H. (2007). Consumer-oriented product form design based on fuzzy logic: A case study of mobile phones. International Journal of Industrial Ergonomics, 37(6), 531-543.

111. Lim, J. and Hoffmann, E. (1997). Appreciation of the zone of convenient reach by naive operators performing an assembly task. International Journal of Industrial Ergonomics, 19(3), 187-199.

112. Lucas, R. L. (1974, October). Human Factors in Industry-Getting the Point Across. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 18(4), 404-405. SAGE Publications.

113. Luczak, H., Volpert, W., Raeithel, A. and Schwier, W. (1987). Arbeitswissenschaft–Kerndefinition. Gegenstandskatalog, Forschungsgebiete, Eschborn: RKW, S, 59.

114. Liu, Y., Kiang, M. and Brusco, M. (2012). A unified framework for market segmentation and its applications. Expert Systems with Applications, 39(11), 10292–10302.

115. Lowe, A. and Lakes, R. S. (2000). Negative Poisson's ratio foam as seat cushion material. Cellular Polymers, 19(3), 157-168.
116. Ma, L., Zhang, W., Chablat, D., Bennis, F. and Guillaume, F. (2009). Multi-objective optimisation method for posture prediction and analysis with consideration of fatigue effect and its application case. Computers and Industrial Engineering, 57(4), 1235-1246.
117. Maire, M. and Ross-Motta, J, (2000), Work-related Musculoskeletal Disorders, Ecology research group, University of Oregon, [online]. US: Research alert. Available: http://www.cbs.state.or.us/external/imd/rasums/resalert/msd/html [assessed on 29 November 2012].
118. Mills, N. (2007). Polymer Foams Handbook, Engineering and Biomechanics Applications and Design Guide. Butterworth-Heinemann.
119. Maniya, K. and Bhatt, M. G. (2010). A selection of material using a novel type decision-making method: preference selection index method. Materials and Design, 31(4), 1785-1789.
120. Margaritis, S. and Marmaras, N. (2007). Supporting the design of office layout meeting ergonomics requirements. Applied Ergonomics, 38(6), 781-790.
121. Marras, W. S. and Schoenmarxlin, R. W. (1993). Wrist motions in industry. Ergonomics, 36(4), 341-351.
122. Menendez, C.C., Amick, B.C., Robortson, M., Bazzani, L., Derango, K., Roony, T. and Moore, A. (2012). A replicated field intervention study evaluating the impact of a highly adjustable chair and office ergonomics training on visual symptoms. Applied Ergonomics, 43(4), 639–644.
123. Mittal, R.K. and Nagrath, I.J. (2007). Robotics and Control. Tata McGraw-Hill, Delhi.
124. Moes, C. C. M. N. and Horvath, I. (2002). Using finite element model of human body for shape optimization of seats: optimization material properties. International Design Conference, Dubrovnik. May 14-17.
125. Mokdad, M. and Al-Ansari, M. (2009). Anthropometrics for the design of Bahraini school furniture. International Journal of Industrial Ergonomics, 39(5), 728-735.
126. Mokhlis, S. and Yaakop, A. Y. (2012). Consumer choice criteria in mobile phone selection: An investigation of malaysian university students. International Review of Social Sciences & Humanities, 2(2), 203-212.

127. Thariq, M. G., Munasinghe, H. P. and Abeysekara, J. D. (2010). Designing chairs with mounted desktop for university students: Ergonomics and comfort. International Journal of Industrial Ergonomics, 40(1), 8-18.
128. Mohanty, P. P. and Mahapatra, S. S. (2014). An integrated approach for designing office chair with ergonomic consideration. International Journal of Services and Operations Management, 17(2), 194-220.
129. Morag, I. (2007). Intel's incident-free culture: A case study. Applied Ergonomics, 38(2), 201-211.
130. Moreau, M. (2003). Corporate ergonomics programme at automobiles Peugeot-Sochaux. Applied Ergonomics, 34(1), 29-34.
131. Myers, R. H. (2000). Classical and modern regression with applications (Duxbury Classic). Duxbury Press, Pacific Grove.
132. Murray, I. A. and Johnson, G. R. (2004). A study of the external forces and moments at the shoulder and elbow while performing everyday tasks. Clinical Biomechanics, 19(6), 586-594.
133. Musa, A.I. (2011). Anthropometric evaluation and assessment of school furniture design in Nigeria: a case study of secondary schools in rural area of Odida, Nigeria. International Journal of Industrial Engineering Computations, 2(3), 499–508.
134. Nagamachi, M. (1995). Kansei engineering: a new ergonomic consumer-oriented technology for product development. International Journal of Industrial Ergonomics, 15(1), 3-11.
135. Nagamachi, M. (2002). Kansei engineering as a powerful consumer-oriented technology for product development. Applied Ergonomics, 33(3), 289-294.
136. Neumann, W. P., Winkel, J., Medbo, L., Magneberg, R. and Mathiassen, S. E. (2006). Production system design elements influencing productivity and ergonomics: A case study of parallel and serial flow strategies. International Journal of Operations & Production Management, 26(8), 904-923.
137. Noruzy, A., Hayat, A. A., Rezazadeh, A., Najafi, S. and Hatami-Shirkouhi, L. (2011). Factors influencing the productivity of knowledge workers: a case study from an Iranian Oil Company. International Journal of Productivity and Quality Management, 8(4), 459-479.

138. Nunes, I. L. (2009). FAST ERGO_X – a tool for ergonomic auditing and work-related musculoskeletal disorders prevention. WORK: A Journal of Prevention, Assessment, & Rehabilitation, 34(2), 133-148.
139. Odgen, R.W. (1997). Non-linear Elastic Deformations. Dover Publications, New York.
140. Opricovic, S. and Tzeng, G. H. (2002). Multi criteria planning of post-earthquake sustainable reconstruction. Computer-Aided Civil and Infrastructure Engineering, 17(3), 211-220.
141. Opricovic, S. and Tzeng, G. H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. European Journal of Operational Research, 156(2), 445-455.
142. Opricovic, S. and Tzeng, G. H. (2007). Extended VIKOR method in comparison with outranking methods. European Journal of Operational Research, 178(2), 514-529.
143. Pennestrì, E., Valentini, P. P. and Vita, L. (2005). Comfort analysis of car occupants: comparison between multibody and finite element models. International Journal of Vehicle Systems Modeling and Testing, 1(1), 68-78.
144. Peterson, N.C., 1976. The development of pressure sores during hospitalization. In: Kenedi, R.M., Cowden, J.M., Scales, J.T. (Eds.), Bedsore Biomechanics. Macmillan, London, 219-224.
145. Pressure ulcers prevalence, cost and risk assessment: consensus development conference statement e the National Pressure Ulcer Advisory Panel. Decubitus 2, May 2, 1989, 24-28.
146. Park, J. and Han, S. H. (2004). A fuzzy rule-based approach to modeling affective user satisfaction towards office chair design. International Journal of Industrial Ergonomics, 34(1), 31-47.
147. Park, J., Snell, W., Ha, S. and Chung, T. L. (2011). Consumers' post-adoption of M-services: Interest in future M-services based on consumer evaluations of current M-services. Journal of Electronic Commerce Research, 12(3), 165-175.
148. Park, M. Y., Kim, J. Y. and Shin, J. H. (2000). Ergonomic design and evaluation of a new VDT workstation chair with keyboard–mouse support. International Journal of Industrial Ergonomics, 26(5), 537-548.

149. Park, T. and Kim, K. J. (1998). Determination of an optimal set of design requirements using house of quality. Journal of Operations Management, 16(5), 569-581.
150. Peterson, N. F. (1997). Production system and individual mechanical exposure, Lic. Eng, Lund University. Lund. ISBN ISSN. 1104-1080.
151. Punnett, L. and Wegman, D. H. (2004). Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. Journal of Electromyography and Kinesiology, 14(1), 13-23.
152. Ragan, R., Kernozek, T. W., Bidar, M. and Matheson, J. W. (2002). Seat-interface pressures on various thicknesses of foam wheelchair cushions: a finite modeling approach. Archives of Physical Medicine and Rehabilitation, 83(6), 872-875.
153. Rajan, V. N., Sivasubramanian, K. and Fernandez, J. E. (1999). Accessibility and ergonomic analysis of assembly product and jig designs. International Journal of Industrial Ergonomics, 23(5), 473-487.
154. Rao, R. (2012). A note on "An alternative multiple attribute decision making methodology for solving optimal facility layout design selection problems". International Journal of Industrial Engineering Computations, 3(3), 519-524.
155. Rao, R. V. and Patel, B. K. (2010). A subjective and objective integrated multiple attribute decision making method for material selection. Materials and Design, 31(10), 4738-4747.
156. Rao, R. V. and Rajesh, T. S. (2009). Software Selection in Manufacturing Industries Using a Fuzzy Multiple Criteria Decision Making Method, PROMETHEE. Intelligent Information Management, 1(3), 159-165.
157. Ray, G. G., Ghosh, S. and Atreya, V. (1995). An anthropometric survey of Indian schoolchildren aged 3–5 years. Applied Ergonomics, 26(1), 67-72.
158. Reitenbach, E.F.R., Jochems, A.J., Molenbrock, J.F.M., Ball, R. and Eijk, D.J.V. (2009). User experience of office chairs and anthropometric of female Chinese and Hong Kong Chinese office and factory workers. The Ergonomics Open Journal, 2, 1–12.
159. Resnick, M. L. and Zanotti, A. (1997). Using ergonomics to target productivity improvements. Computers and Industrial Engineering, 33(1), 185-188.
160. Suykens, J. A. and Vandewalle, J. (1999). Least squares support vector machine classifiers. Neural Processing Letters, 9(3), 293-300.

161. Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology, 15(3), 234-281.

162. Schmidtke, H., 1989. Arbeitsplatze und arbeitsra¨ume in werkstatt und betrieb. In: Brokmann, W. (Ed.), Arbeitsgestaltung in Production und Verwaltung. Wirtschaftsverlag Bachem, Cologne.

163. Schnauber, H. (1986). Ergonomics and productivity as reflected in a new factory. In Trends in ergonomics/human factors III, Karwowski Ed., Elsevier Science Publishers, 459-465.

164. Schrodt, M., Benderoth, G., Kühhorn, A. and Silber, G. (2005). Hyperelastic description of polymer soft foams at finite deformations. Technische Mechanik, 25(3-4), 162-173.

165. Shabshin, N., Zoizner, G., Herman, A., Ougortsin, V. and Gefen, A. (2010). Use of weight bearing MRI for evaluating wheel chair cushions based on internal soft tissue deformations under ischial tuberocities. Journal of Rehabilitation Research and Development, 47 (1), 31-42.

166. Shanian, A. and Savadogo, O. (2006). TOPSIS multiple-criteria decision support analysis for material selection of metallic bipolar plates for polymer electrolyte fuel cell. Journal of Power Sources, 159(2), 1095-1104.

167. Shimizu, Y. and Jindo, T. (1995). A fuzzy logic analysis method for evaluating human sensitivities. International Journal of Industrial Ergonomics, 15(1), 39-47.

168. Siefert, A., Pankoke, S., and Wölfel, H. P. (2008). Virtual optimization of car passenger seats: Simulation of static and dynamic effects on drivers' seating comfort. International Journal of Industrial Ergonomics, 38(5), 410-424.

169. Shackel, B. (1984). The concept of usability. Visual display terminals: Usability issues and health concerns, Prentice-Hall, Englewood Cliffs, NJ, 45-87.

170. Shikdar, A. A. and Das, B. (1995). A field study of worker productivity improvements. Applied Ergonomics, 26(1), 21-27.

171. Silver-Thron, M. B. and Childress, D.S. (1996). Parameter analysis using finite element method to investigate prosthetic interface stresses for persons with trans-tibial ampulation. Journal of Rehabilitation Research and Development, 33(3), 227-238.

172. Singh, B., Kaur, M., Kaur, J., Singh, M. and Batra, A.P.S., (2013). Estimation of stature from forearm length in north indians - an anthropometric study. International Journal of Basic and Applied Medical Sciences, 3 (1), 201-204.
173. Sobeih, T., Salem, O., Genaidy, A., Abdelhamid, T. and Shell, R. (2009). Psychosocial factors and musculoskeletal disorders in the construction industry. Journal of Construction Engineering and Management, 135(4), 267-277.
174. Sugeno, M., and Kang, G. T. (1988). Structure identification of fuzzy model. Fuzzy Sets and Systems, 28(1), 15-33.
175. Takagi, T. and Sugeno, M. (1985) .Fuzzy identification of systems and its applications to modeling and control. Systems, Man and Cybernetics, 15(1), 116–132.
176. Tang, C.Y., Chan, W. and Tsui, C.P., (2010). Finite element analysis of contact pressures between seat cushion and human buttock-thigh tissue, Journal of Engineering, 2(9), 720-726.
177. Tang, C.Y. and Tsui, C.P. (2006). Method of Modeling Muscular Tissue with Active Finite Elements. U. S. Patent, the Hong Kong Polytechnic University, Kowloon (HK).
178. Tewari, V. K. and Prasad, N. (2000). Optimum seat pan and back-rest parameters for a comfortable tractor seat. Ergonomics, 43(2), 167-186.
179. Thakurta,K.,Koester,D.,Bush,N.,Bachle,S.,1995.Evaluating short and long term seating comfort,in:SAE Technical paper series 950144(Troy,Mi:Society of Automotive Engineers),33-37.
180. Todd, B. A. and Thacker, J. G. (1994). Three dimensional computer models of the human buttocks, in Vivo, Journal of Rehabilitation Research and Development, 31(2), 111-119.
181. Tzeng, G. H., Lin, C. W. and Opricovic, S. (2005). Multi-criteria analysis of alternative-fuel buses for public transportation. Energy Policy, 33(11), 1373-1383.
182. Tzeng, G. H., Tsaur, S. H., Laiw, Y. D. and Opricovic, S. (2002). Multi criteria analysis of environmental quality in Taipei: public preferences and improvement strategies. Journal of Environmental Management, 65(2), 109-120.
183. Vergara, M. and Page, A. (2000). System to measure the use of the backrest in sitting-posture office tasks. Applied Ergonomics, 31(3), 247-254.

184. Verver, M. M., Van Hoof, J., Oomens, C. W. J., Wismans, J. S. H. M. and Baaijens, F. P. T. (2004). A finite element model of the human buttocks for prediction of seat pressure distributions. Computer Methods in Biomechanics and Biomedical Engineering, 7(4), 193-203.
185. Verver, M. M., De Lange, R., van Hoof, J. and Wismans, J. S.H.M. (2005). Aspects of seat modelling for seating comfort analysis. Applied Ergonomics, 36(1), 33-42.
186. Vignais, N. and Marin, F. (2014). Analysis of the musculoskeletal system of the hand and forearm during a cylinder grasping task. International Journal of Industrial Ergonomics, 44(4), 535-543.
187. Vink, P., Koningsveld, E. A. and Molenbroek, J. F. (2006). Positive outcomes of participatory ergonomics in terms of greater comfort and higher productivity. Applied Ergonomics, 37(4), 537-546.
188. Veryzer, R. W. (1995). The place of product design and aesthetics in consumer research. Advances in Consumer Research, 22, 641-645.
189. Vos, G. A., Congleton, J. J., Steven Moore, J., Amendola, A. A. and Ringer, L. (2006). Postural versus chair design impacts upon interface pressure. Applied Ergonomics, 37(5), 619-628.
190. Wang, K. C. (2011). User-oriented product form design evaluation using integrated Kansei engineering scheme. Journal of Convergence Information Technology, 6(6), 420-438.
191. Wang, X. (1999). A behavior-based inverse kinematics algorithm to predict arm prehension postures for computer-aided ergonomic evaluation. Journal of Biomechanics, 32(5), 453-460.
192. Wang, Y. C. and Lakes, R. (2002). Analytical parametric analysis of the contact problem of human buttocks and negative Poisson's ratio foam cushions. International Journal of Solids and Structures, 39(18), 4825-4838.
193. Wang, M. J. J., Wang, E. and Lin, Y. C. (2002). The anthropometric database for children and young adults in Taiwan. Applied Ergonomics, 33(6), 583-585.
194. Wang, X. and Verriest, J. P. (1998). A geometric algorithm to predict the arm reaches posture for computer-aided ergonomic evaluation. The Journal of Visualization and Computer Animation, 9(1), 33-47.

195. Weiman, N. (1982, October). Integrating Human Factors into Product Development within Industry. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 26(8), 731-732. SAGE Publications.
196. Westgaard, R. H. and Aarås, A. (1984). Postural muscle strain as a causal factor in the development of musculo-skeletal illnesses. Applied Ergonomics, 15(3), 162-174.
197. Wu, C.F.J., Hamada, M., 2000.Experiments: Planning, Analysis and Parameter Design Optimization, Wiley-India, New Delhi.
198. Yang, S. M., Nagamachi, M. and Lee, S. Y. (1999). Rule-based inference model for the Kansei Engineering System. International Journal of Industrial Ergonomics, 24(5), 459-471.
199. Yoon, K. P. and Hwang, C. L. (1995). Multiple attribute decision making: an introduction, 104, Sage Publications.
200. Yu, P. L. (1973). A class of solutions for group decision problems. Management Science, 19(8), 936-946.
201. Yue ZL (2011). Deriving decision maker's weights based on distance measure for interval-valued intuitionistic fuzzy group decision making. Expert System Application, 38(9), 11665-11670.
202. Zhao, J. and Badler, N. I. (1994). Inverse kinematics positioning using nonlinear programming for highly articulated figures. ACM Transactions on Graphics (TOG), 13(4), 313-336.
203. Zadeh, L. A. (1975).The concept of a linguistic variable and its application to approximate reasoning. Information Sciences, 8 (3), 199–249.

APPENDIX

List of Publications

International Journals (Published)

1. **Mohanty, P. P.,** Mahapatra, S. S. (2014). A finite element approach for analyzing the effect of cushion Type and thickness on pressure ulcer. International Journal of Industrial Ergonomics, 44(4), 499-509.
2. **Mohanty, P. P.,** Mahapatra, S. S. (2014). An integrated approach for designing office chair with ergonomic consideration. International Journal of Services and Operations Management. 17(2), 194-220.
3. **Mohanty, P. P.,** Mahapatra, S. S. (2013). Design of office chair: A quality function deployment approach. Advanced Materials Manufacturing and Characterization. 3(2), 520-523.

International Journal (Communicated)

1. **Mohanty, P.P.,** Mahapatra, S. S. (2014). A novel multi-attribute decision making approach for selection of appropriate product conforming ergonomic considerations. Behavior and Information Technology (Under review).

International Conferences

1. **Mohanty, P. P.,** Mahapatra, S. S. (2013). Seating comfort in office environment: numerical analysis on human soft tissue and seat cushion. Third International Conference on Production and Industrial Engineering (CPIE 2013) held on 29-31 March at National Institute of Technology, Jalandhar.
2. **Mohanty, P. P.,** Mahapatra, S. S. (2013). A finite element analysis for stress distribution in muscle tissue of buttock for different cushion thickness. Second International Conference on Industrial Engineering (ICIE 2013) held on 20-22 November 2013 at National Institute of Technology, Surat.
3. **Mohanty, P. P.,** Mahapatra, S. S. (2014). Application of MADM method for selecting ergonomically designed office chair. 1st International Conference on Mechanical

Engineering: Emerging Trends for Sustainability (ICMEETS-2014) held on 29th-31st January 2014 at National Institute of Technology, Bhopal.

4. **Mohanty, P. P.,** Mahapatra, S. S. (2014). A compromise solution by VIKOR method for ergonomically designed product with optimal set of design characteristics", Second Annual International Conference on Material proceedings and Characterization held on 8th-9th March 2014 at GRIET, Hyderabad.

.