MATHEMATICAL MODELING FOR ESTIMATING ERGONOMIC COMPATIBILITY OF PASSENGER CARS USING FUZZY APPROACH

Ph.D. Thesis

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Mathematical Modeling for Estimating Ergonomic Compatibility of Passenger Cars using Fuzzy Approach

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Dedicated to Late Prof. Awadhesh Bhardwaj

DECLARATION

I, **Ashish Dutta (2013RME9070)** declare that this thesis titled "**Mathematical Modeling for Estimating Ergonomic Compatibility of Passenger Cars using Fuzzy Approach**" and the work presented in it, are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at Malaviya National Institute of Technology, Jaipur.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this university or any other institution, this has been clearly stated.
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CERTIFICATE

This is to certify that the thesis entitled **"Mathematical Modeling for Estimating Ergonomic Compatibility of Passenger Cars using Fuzzy Approach"** being submitted by **Ashish Dutta (2013RME9070)** is a bonafide research work carried out under my supervision and guidance in fulfillment of the requirement for the award of the degree of **Doctor of Philosophy** in the Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur, India. The matter embodied in this thesis is original and has not been submitted to any other University or Institute for the award of any other degree.

Place: Jaipur
Date:

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ABSTRACT

High economic growth and motorization have resulted in unacceptable numbers of road accidents. Driving is a complex task involving sharp sensory perception, visual acuity, hand limb coordination, and prompt motor reflexes. Ergonomics in the design of a car can enhance safety and render mental and physical wellbeing.The ergonomic needs should be focused during the product development phase. Previous researches focus mainly on few ergonomic aspects like reach capabilities or comfortable seat or vibration analysis. The same may form the part of assessment criteria but does not comprehensively define the Ergonomic Compatibility of a car.

The present research aims at developing a methodology for comprehending the varied and vague Voice of Customers (VoC) to mathematically prioritizing the ergonomic attributes and a mathematical model for quantifying the ergonomic compatibility of a car. Twenty ergonomic attributes that enhance safety, decrease passenger fatigue, increase driver alertness, and reduce chances of an accident; were identified from literature review and were ratified in Indian scenario by discussions with car users and automobile dealers. The VoC about these attributes was captured from consumer survey based on Fuzzy Kano Model. The results of the survey were integrated with Quality Function Deployment (QFD) to develop a novel framework "***House of Ergonomics Deployment (HED)***" to prioritise these ergonomic attributes. These priorities were compared with the priorities obtained from Fuzzy Analytic Hierarchy Process (FAHP). The rankings by both these methods do not show significant differences (±2 ranks) for 18 out of the 20 attributes.

Subsequently, the twenty identified attributes were grouped into three major factors: Overall Safety Factor (8 attributes); Musculoskeletal/ Reach Factor (6 attributes); and Compatible Man Machine Interface/ Comfort Factor (6 attributes). For any particular brand of car, the attribute score and factor score can be determined based on the features present in the car. The mathematical model has been developed by applying Mamdani Fuzzy Inference system for combining the factor scores. The

output of the model is the ergonomic index (score) of that car (in the range of 1 to 100) and it reflects the ergonomic compatibility of that car.

In general, this research provides a novel method for assessing the ergonomic compatibility of a car, which can be used by the car manufacturers and automobile designers during the product development phase, for improving the ergonomic appeal of a car and to stay ahead in the competition. The prospective buyers can use this model for selecting a car by using the ergonomic index (or compatibility) as a benchmark for comparison among the various models of car. The methodology developed in this research may apply to other products and services as well.

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List of Abbreviations

ABS	Anti-lock Braking System
AHP	Analytic Hierarchy Process
AI	Absolute Importance
AW	Absolute weight
BLIS	Blind Spot Information System
CD	Consumer Dissatisfaction
CI	Consistency Index
COG	Centre of Gravity
CR	Consistency Ratio
CS	Consumer Satisfaction
DAI	Direct user Attribute Importance
ESC	Electronic Stability Control
FAHP	Fuzzy Analytic Hierarchy Process
FIS	Fuzzy Inference System
GPS	Global Positioning System
HED	House of Ergonomics Deployment
MCDM	Multiple Criteria Decision Making
MF	Membership Function
MOM	Mean of Maximum

MoRTH	Ministry of Road Transport & Highways
MSD	Musculoskeletal Disorders
NHTSA	National Highway Traffic Safety Administration (of US)
NIOSH	National Institute for Occupational Safety and Health
OWAS	Ovako Working posture Assessment System
PE	Participatory Ergonomics
QFD	Quality Function Deployment
RDI	Repetitive Driving Injury
REBA	Rapid Entire Body Assessment
RI	Random Index
RULA	Rapid Upper Limb Assessment
SD	Standard Deviation *(σ)*
SMILD	Satisfied (S), Must be (M), Indifferent (I), Live with it (L), and Dissatisfied (D)
TFN	Triangular Fuzzy Number
TRIZ	Theory of Inventive Problem Solving
TSK	Takagi–Sugeno–Kang
VoC	Voice of Customers
WA	Weighted Average
WMSD	Work-related Musculoskeletal Disorder

Chapter: 1.
Introduction

1. 1 Ergonomics and its need in product design

In all modern product design, ergonomics plays an important role. Ergonomics is indispensable in all aspects of design. According to International Ergonomics Association, Ergonomics is the understanding of interactions among humans and other elements of a system. Ergonomics focuses on an objective oriented and rationally designed system consisting of humans and their environment (Helander, 1997). The perspective of ergonomics is holistic in nature and differentiates it from other areas such as cognitive psychology and human movement science, which fails to provide a comprehensive view (Brewer and Hsiang, 2002). Ergonomics considers various aspects of the person like physical, physiological, psychological (Dul et al., 2012). In ergonomics, scientific principles are applied for designing the product / work place by considering the shape and sizes of people and their physical power and restrictions. Ergonomics studies the human posture during performing a job. Ergonomists amalgamates various principles related to industrial engineering, anthropometry (dimension of the humans), bio mechanics (muscular activity) and psychology. The application of ergonomics to product development leads to maximizing the safety, efficiency and comfort of the user. Hence it significantly reduces the errors during the accomplishment of the job.

1. 2 Driving: An essential activity in the modern era

Rapid economic development has made driving a crucial activity. Driving involves taking quick decisions based on road and traffic conditions. It necessitates evasive maneuvering by using steering and braking techniques and simultaneously controlling skid risks. Driving is a complex task involving sharp sensory perception, visual acuity, hand limb coordination, prompt motor reflexes and speed of response.

Alertness, proper seating position and uninterrupted vision are of prime importance for safe driving.

Car is the most important utility vehicle owing to its versatile use. Now a day, people drive the car not only within the city limits but also use the car to travel to distant places, driving hundreds of miles. The city roads are overcrowded and have many pot-holes and most of the cross country roads are not in proper shape for comfortable driving. This makes driving unsafe and tiring. Sitting on a car seat is different from sitting on a chair. Driving has much higher level of fatigue than working on a desk. As compared to sitting on a chair, during driving, arms are held higher (for operating the steering wheel), legs are more extended and foot are inclined on the floor (for operating the accelerator, clutch and brake pedals). Also, the body suffers vibrations (which may be violent when travelling on a bumpy road), side movements (while making a turn) and sudden jerks (while accelerating or decelerating). These causes discomfort to the lower back, upper back and neck. Drivers suffer from foot cramps, lumbar pain, stiff neck, sore shoulders and have headaches, eye strain and mental stress. This is referred as repetitive driving injury (RDI) and is a form of work-related musculoskeletal disorder (WMSD).

1. 3 Road accidents and fatalities: The adverse face of driving

Transportation in India has been rapidly evolving for the past few decades due to a high rate of economic growth. Though two-wheelers still provide the most common personal transportation mode, cars are increasingly becoming the travel mode of choice in both urban and rural areas. However, the traffic environment is adverse due to growing motorization fueled by increasing urbanization and has resulted in unacceptably high numbers of road accidents and fatalities. The number of motor vehicles on roads are increasing exponentially and due to heavy traffic, road accidents occur frequently, sometimes even with serious / tragic outcomes. The most important causes of the road accident are high speed, obstruction in vision and fatigue. Even experienced drivers suffer from severe injuries during accidents due to incorrect sitting posture, unadjusted car seats, non-use of safety belt, absence or poor quality of airbags, improper use of brakes, etc.

In 2015, India signed the Brasilia declaration as a step to halve the number of deaths and injuries from road accidents by 2020, but so far, the reduction is not substantial. As per the Ministry of Road Transport & Highways, Government of India (MoRTH) report, 'Road accidents in India', in 2017; 464910 road accidents claimed 147913 lives out of which adults in the productive age group of 18–60 years accounted for 87.2%. Light vehicles category comprising of cars, jeeps, and taxis were second most prone to accidents (after two-wheelers) with a share of 24.5% in total accidents and 21.1% in total fatalities.

1. 4 Car ergonomics: A step towards safe and comfortable driving

With the economic development and expanding city limits, more and more people are taking up driving and number of cars on road is increasing day by day. This has made the city roads overcrowded and growing traffic congestion have increased the driving time. Driving on a crowded road induces more fatigue and escalates the risk of accidents. Hence, ergonomics has multifarious implications for car design and its need is increasing with time.

Car ergonomics have long term implications in terms of posture and musculoskeletal disorders. The lower back i.e. the lumbar region has a natural concave curve, when a person is standing, leading to proper pressure distribution on the spinal discs. When a person sits, this natural concave curve straightens which leads to varying pressure distribution on the spinal discs. This straightening of the spinal cord in the lumbar region may cause tension and pain in the neck, shoulder and back muscles, and sometimes even leads to misalignment of vertebrae. The spinal discs in this posture are unable to withstand the vibrations. Therefore the lumbar should be properly supported and the backrest should be properly reclined so that the pressure on the spinal discs is reduced and the back muscles are relaxed. Ergonomically suitable car designs can achieve maximum mental and physical wellbeing during driving.

A truly ergonomic car not only makes the driving safe and comfortable for its occupants and driver but also adds to the security of the other passer by vehicles. Ergonomic car reduces the fatigue of the passengers and drivers and makes driving a pleasure and leaves the passengers in a better mood to perform the tasks after reaching their destinations. Considering ergonomics during car design can significantly reduces driving errors and reduces number of accidents and fatalities. There are numerous features which contribute towards an ergonomic car. Car manufacturers and designers continue to work on them but exploring the various functional requirements of drivers and passengers is often undone. Taking into account the voice of the customers and assimilating them during car design can help in developing better ergonomically compatible cars which would augment the focus and attention of the driver and comfort of the passengers. This would also aid in reducing drivers' fatigue which is one of the main reason for the fatal accidents on the road.

1. 5 Structure of this thesis

This thesis is structured into eight chapters as described below:

Chapter 1 – Introduction: This research work commences with providing an introduction to the work and discusses the need of ergonomics in product design. It also discusses the risks associated with driving and how ergonomic designs of a passenger car could be a step towards safe and comfortable driving.

Chapter 2 – Literature Review, Research Gap and Aim of this Research: This chapter assesses the existing knowledge base and review of extant literature in the field of automobile engineering in terms of ergonomic features of a car and the techniques used for product design in automobile industry. On basis of this literature review, the research gap was identified and the need for a new research was established. This chapter concludes with the aim of this research.

Chapter 3 – Methodology: The main aim of this research is to develop a model for ergonomic compatibility of a passenger car. It is not easy to define ergonomic compatibility because it is an ambiguous and complex zone. Fuzzy logic was used in various steps of this research. Complete methodology of this research has been dealt in this chapter and all the essential equations have been derived. All the steps have been discussed in details along with the reasoning for selecting a particular method.

Chapter 4 – Attribute Identification and Survey: This chapter deals with the first step of this research i.e. identification of major attributes. Detailed review of the available literature was done for this purpose followed by observation and discussions and capturing the Voice of the Customers (VoC) about the identified attributes using fuzzy Kano survey.

Chapter 5 – Framing HED and Comparing Priority of Attributes using FAHP: The results of the survey has been analysed in this chapter. After analysis of the result, a new framework "House of Ergonomics Deployment" (HED) was developed in this chapter which prioritises the identified ergonomic attributes of a passenger car. These priorities were then compared with the priorities obtained by using fuzzy AHP. Comparison of the ranks obtained by both the methods was done at the end of this chapter.

Chapter 6 – Formulation of Mathematical Model using Fuzzy Approach: This chapter deals with the formulation of a mathematical model using Mamdani Fuzzy Inference System (FIS). The priorities of the attributes obtained by from HED were used for this purpose. The inputs or scores were fuzzified and defuzzified using Mamdani FIS and a crisp output was obtained. This output (in the range 1 to 100), is the final ergonomic score (or index) of the car.

Chapter 7 – Results and Discussions: The result obtained from the new framework House of Ergonomics Deployment and the result of the fuzzy model based on Mamdani FIS has been discussed in this chapter. Limitations of both the models have also been discussed. The major limitation of HED is the small sample size (100). The limitation of the fuzzy model is the inherent features of all FIS models. The effectiveness of both the models has also been discussed in this chapter.

Chapter 8 - Conclusions: The major benefits of this research have been portrayed in this chapter. This research can be used by the prospective buyers of a car who can compare the ergonomic score and ergonomic attributes of one model of car with another and satisfy their desire to get better ergonomic features at the least cost. The automobile designers and manufacturers can also use this model for assessing and improving the ergonomic attributes of a car. The Federal government can motivate research for understanding the potential limitations of passenger cars and evolving essential safety and accident mitigation measures. The methodologies explained in this research can be applied to other products and services as well that present a similar design challenge to designers and manufacturers.

Chapter: 2.

Literature Review, Research Gap and Aim of this Research

The critical determinant of success for any product is the consumers' perception about the product and the benefits offered by it. The product design phase should focus on all the features and aspect of the product and develop a product that is capable of meeting consumers' requirements and desires. Addressing only few features and functional requirements during product development phase, has detrimental effect in the long run, both to manufacturers and the users.

In this research, review of the literature was done to identify various ergonomic attributes of a car, the ongoing research on various aspects of a car, and also to find out the methodologies adopted by other researchers to elicit the customer's requirements in various fields. The objective of literature review was also to identify the research gap in this area, identify the methodologies used for product design, and develop a sustainable model for assessing car ergonomics.

2. 1 Literature review about ergonomic features of a car

With so many attributes important for safe and comfortable driving, navigating the automobile market is complex for both buyers and manufacturers. Various researches have been made regarding seat design, reach capabilities, comfort and safety features of a car.

Kolich and Taboun (2002) have evaluated seat comfort based on physiological technique (electromyography) and subjective questionnaire (responses to prolonged driving). El Falou et al., (2003) have evaluated driver discomfort during car driving using surface electromyography to study muscle activity. Reed, Parkinson and Chaffin (2003) have discussed the reach capability of the driver based on SAE recommended practice and given a new method of modeling it. Verbeek et al. (2012) suggested that lower back pain can be reduced by overcoming the awkward postures. Jamroz and Smolarek (2013) have discussed the factors causing driver fatigue and have identified the causes of accidents caused by driver fatigue.

Jiaxing, Fard, and Jazar (2014) have discussed the various factors affecting seating comfort and have analyzed the seat with geared links for adjustment of seat height.

Wu, Rakheja, and Boileau (1999) have investigated the distribution of contact pressure and forces between seated human subjects and a visco-elastic seat under vertical vibration. The pressure data is analysed to illustrate the influence of magnitude and frequency of vibration excitations on the maximum ischium pressure. Naa et al. (2005) have studied the application of body pressure distribution measurements for the prediction of the driver's posture and analyses of the change of body pressure distribution with time.

Mohamed and Yusuff (2007) have discussed the passenger car's ergonomics and internal dimensions and comfort of passengers. Grujicic et al. (2010) have investigated the main causes for driving fatigue using musculoskeletal modeling and simulation methods using a model of a prototypical adjustable car seat and a musculoskeletal model of a seated human.

Kovacevic et al. (2010) have discussed the impact of anthropometric measurements on ergonomic driver posture and safety. Tamrin et al. (2014) have studied the risk factors associated with musculoskeletal disorders prevalent in male Malaysian bus drivers. De Carvalho and Callaghan (2015) have examined the posture of the spine and the discomfort during prolonged simulated driving using five levels of lumbar supports. Peng, Wang, and Denninger (2017) have investigated the effect of the height of seat and the driver's anthropometric dimensions.

Brown, Lee, and McGehee (2001) have discussed the collision warning systems for avoiding collisions. Jerome et al. (2002) have analyzed the effect of in-vehicle devices (e.g., cell phones, navigation systems, radios, etc.) on the performance of driver and safety against accidents. The use of these devices during driving is on rise. Haq et al. (2013) have given an overview of some safety features in an automobile design for the mitigation of accidents and prevention of injuries. Yadav and Goel (2008) have discussed about quality improvement target planning based on customer satisfaction for product development in automotive industry.

From the literature survey, it was apparent that the major ergonomic attributes under consideration by the researchers are seat adjustments, comfort and fatigue reduction, reach capabilities of the controls, safety devices for accident mitigation and injury reduction, and the like. These attributes relates to enhancing safety, improving reach capabilities and fatigue reduction and comfort factors.

2. 2 Literature review about various techniques used for product design

Various techniques and analytical tools are used in the field of product development to elicit the feature that imparts consumer satisfaction.

Shen, Tan and Xie (2000) and Tan and Shen (2000) have integrated Kano's model in Quality Function Deployment (QFD) to understand VoC and for innovative product development. Marsot (2005) have applied QFD as a vector for integrating ergonomics into hand tool design. Lee, Sheu and Tsou (2008) have applied QFD implementation based on fuzzy Kano model. Lee and Huang (2009) have applied fuzzy approach to modify Kano's two-dimensional questionnaires. Kuo, Wu and Shieh (2009) have integrated environmental considerations in QFD using fuzzy logic. Hashim and Dawal (2012) have integrated Kano model and QFD to improve workstation design in terms of ergonomics and users need.

Zhang, Yang and Liu (2014) have integrated customer satisfaction needs with QFD, and then applied Theory of Inventive Problem Solving (TRIZ) and fuzzy decision making approach for ergonomic product design. Yeh and Chen (2014) have combined Kano model, QFD, and Grey Relational Analysis for improving the quality of service imparted in the nursing homes. Turisova and Sinay (2017) have discussed the challenges faced by the developers in designing a product that would be acceptable as well as sufficiently attractive. They have used analytical Kano model to measure the product attractiveness. Sun et al. (2018) have proposed a Function-Task-Behavior framework for restating the design process. Gupta and Shri (2018) have studied the customer requirements of corrugated industry using Kano model that have facilitated the decision making process.

Choedon and Lee (2018) have used Kano Model and Analytic Hierarchy Process (AHP) in their study about evaluating, improving, and classifying the customers' service requirements in mobile application regarding tourism activities.

Haber, Fargnoli, and Sakao (2018) have improved the QFD for Product Service Systems using Kano model. Fuzzy AHP (FAHP) method was also integrated to assess the parameters and their uncertainty. Materla, Cudney, and Antony (2019) have made a systematic literature review of application of the Kano model in the healthcare industry and have revealed the customers' requirements related to improving service quality. Mu and Nicola (2019) have used AHP (MCDM approach) for developing a model for rank and tenure decisions for faculty evaluation in academia for higher-education administrators. Qu et al. (2019) have evaluated the requirements of smart manufacturing systems by integrating fuzzy Kano model and FAHP.

From the review of literature, it was apparent that techniques like Kano model, QFD, AHP and Fuzzy approach have been used by many researchers either singly or jointly to get an insight about consumer's preferences and derive conclusions regarding product design.

2. 3 Literature review about techniques used for design in automobile industry

A combination of various tools has also been in research in the automobile industry. Khalid and Helander (2004) have proposed a framework to establish customer needs in product design for present and future automobile devices. They have used a semantic differential technique to find preferences on product attributes, relating to holistic design, functional design, and product styling. Miller et al. (2005) have applied QFD to vehicle side doors with the objective to optimize customer comfort when opening and closing the door. Xu et al. (2009) have given analytical Kano model for finding out the needs of the customer for the dashboard in automotive design which incorporated preferences of customers in the design of the product, with the best possible trade-off between satisfaction of customer and capacity of a manufacturer.

Yadav et al. (2013) have prioritised the aesthetic attributes of a car using QFD and Kano model. They have allowed fuzziness in VoC. Helander et al. (2013) have investigated the emotional intent of car buyers and designers and found that car owners also values emotional design features along with functionality. Hence car designers should consider such features during the design of cars. Strayer and Fisher (2016) have developed a model (SPIDER) which finds out the cognitive processes that are affected when the driver's attention is diverted.

Park, Ebert, and Reed (2015) have predicted driving posture using a statistical model and have also shown the effect of age. Karali, Gyi, and Mansfield (2017) have designed a questionnaire for the survey of elderly drivers in comparison to younger. Velagapudi and Ray (2017) have developed and tested a questionnaire regarding comfortable motorcycle seat.

From the review of the literature, it was evident that many researchers have used questionnaire to find out the VoC. Kano model continues to be one of the powerful tools to get an insight about the likes and dislikes of the consumers. It has been modified by various researchers and has been used jointly with other tools. QFD and AHP are also widely used tools to uncover customers' preferences. Fuzzy approach has been employed by various researchers to address the ambiguity in customer needs.

2. 4 Research gap

From the review of the extant literature, it was observed that most of the research focused only on a few aspects of a car. It was hard to find a study that could provide an exhaustive list of features, necessary for safe and comfortable driving. Even with countless ongoing research in the field of car ergonomics, it was not possible to bring into light any research that has attempted to assess the ergonomic compatibility of a car. Assessing the car ergonomics necessitates a comprehensive list of features with their priorities clearly drawn out.

Generally, for optimizing the workplace design, ergonomists normally use Rapid Entire Body Assessment (REBA) score, Rapid Upper Limb Assessment (RULA) score, Ovako Working posture Assessment System (OWAS), Job Strain Index and/ or National Institute for Occupational Safety and Health (NIOSH) lifting equation. These may be applied to assess some ergonomic aspects of a car like reach capabilities but fails to provide an overall picture about car ergonomics.

The ongoing research regarding car ergonomics mainly focuses on comfortable seat or on reach capabilities or on vibration analysis or on safety features of a car. The same forms the part of assessment criteria but does not comprehensively define car ergonomics. Even though research in all aspects of improving the features of a car is ongoing but evidence for prioritising the important attributes of a passenger car could not be made. Moreover, most of the research were carried outside India and did not cater the specific requirements of customers in Indian subcontinent.

From the literature review, it was also not possible to uncover a comprehensive methodology as how to quantify the ergonomic compatibility of a car. The extant literature did not provide any evidence of a mathematical model for quantifying car ergonomics.

2. 5 Need for this research

The modern cars come with different levels of safety and comfort features. Each car manufacturer focuses on different aspect and offer different options. These differences cause a wide variation of prices. Due to the different degree of various features provided in the different brands and models of car, it becomes mystifying for the consumers to compare various cars and select a car best suiting his needs and budget. Moreover, the automakers have geared up their innovation cycles and are analyzing the upgrades needed in the existing cars. Newer features are being added to the upcoming models. Many features provided by the car manufacturers are not of much use to many consumers. These superfluous features may not have much relevance in terms of driver/ passenger safety and comfort but adds to price of the cars. Addition of new features has price implications. This further causes a perplexity among the prospective buyers.

The decision of a consumer to purchase a particular car is not only be guided by its physical appearance or engine related technical competence or price but also by presence of various essential ergonomic features and fitness for its use. Some consumers are not knowledgeable to identify all the essential features about car ergonomics and compare them across the brands.

There are various feature of a car which are essential and contributes towards ergonomic compatibility. Safety and safety devices are a major factor that contributes to the ergonomic compatibility. Clear and uninterrupted vision during forward movement, rear movement and during parking is another essential feature. Comfortable and proper posture of all the passengers including the driver is of major concern. Cars have primary controls (clutch, gear, brake, steering), secondary controls (head light, turn indicators, seat belt, wipers, wind screen, window pane, doors and boot space opening and closing) and ancillary controls (AC and entertainment features). These controls need to be operated during driving. Reach capabilities of all the control and accessories plays an important role in deciding the ergonomic compatibility. Due to reach space constraint, all the controls have to be positioned perfectly. Body posture and stress during operating various controls, disturbing or irritating elements, focus of light and proper vision needs to be considered.

The ergonomic compatibility of a car needs to address all the essential features, like musculoskeletal/ reach factors, compatible man-machine interface/ comfort factors and overall safety factors. These features augment the security and aids in reducing fatigue of passengers.

Even though the technological advances in the automobile industry are generally advantageous to both consumers and manufacturers, but at times it may exhibit disadvantages or show evidence of lack of acceptance by consumers. The onset of a new technological environment in the automobile industry, therefore, necessitates major implications for conducting successful market research and for achieving its proper application. Identifying the major ergonomic features and making them available at competitive price, is the need of the time.

From manufacturers view, two factors are associated with the inclusion of any feature:

(i) The cost to be incurred, and

(ii) The benefit to be derived.

The decision to include any attribute can be supported by the automobile designers only after assessing the benefits imparted by that attribute.

Due to these reasons, prioritisation of the attributes is essential. Prioritisation necessitates establishing the relative importance of a set of attributes. All manufacturers have predefined corporate strategic planning and product differentiation strategies, so it becomes necessary that the attributes are prioritised**.** Prioritising is also necessary because it may not be feasible for the manufacturers to address all the potential attributes simultaneously due to budgetary constraints and availability of time.

For helping the prospective customers in selecting a car and manufactures in product development, it was important to identify and prioritise major ergonomic attributes in Indian context. For assigning some kind of ranking (i.e. placing a set of attributes in order from most desirable to least) and prioritising (i.e. calculating the relative merit of the attributes of a set) the ergonomic attributes of a car, it was felt necessary to address the VoC, especially in the Indian scenario. It was also felt necessary to develop a mathematical model for quantifying car ergonomics, which will provide a benchmark for comparing cars.

2. 6 Aim of this research

This research reflects consumer and manufacturer conditions in India's emerging automobile marketplace. The aims of the present research are:

*(i) To develop a novel framework **"House of Ergonomics Deployment (HED)",** for prioritising the ergonomic attributes of a passenger car, and*

*(ii) To develop a **"Mathematical Model"** to determine the ergonomic compatibility (or index) of a car.*

The present research aims at comprehending the varied and vague VoC with regards to car ergonomics; identifying major ergonomic attributes that might have the maximum potential for safe and comfortable driving; creating a framework for prioritising the identified ergonomic attributes and developing a mathematical model for estimating the ergonomic compatibility of a passenger car.

In the first step of this research, major ergonomic needs were identified through literature survey, and were ratified in Indian scenario, through observation, direct discussion, and interview with car users and dealers. The needs were then converted to major ergonomic attributes. These attributes were then mathematically prioritised by using VoC.

For capturing the VoC about the identified ergonomic attributes, only the owners of sedan cars were chosen because the low price hatch back manufacturers believes in price wars by providing only the functional features. The general population in India drives low-priced and smaller vehicles because of having restricted disposable income. Often there is a tradeoff between price and safety. Many such vehicles lack safety features with basic models doesn’t have any airbags or anti-lock braking system (ABS). This leads to a higher chance of injury in the event of a crash.

After identifying and prioritising the major ergonomic attributes of the car, a mathematical model based on Fuzzy inference system (FIS) has been developed. First the attributes were grouped in major ergonomic categories or factors. Then attribute scores and factor scores for a particular model of a car were calculated and then the factor scores are fed into the model. The output of the model is in the form of ergonomic index of that car (in the range of 1 to 100) and it reflects the ergonomic compatibility of that car.

The methodology developed in this research may be applicable to other products and services as well, which pose similar design problems.

Chapter: 3.
Methodology

3. 1 Ergonomic compatibility of a passenger car: An ambiguous zone

It is a complex task to define and quantify the ergonomic compatibility of a passenger car. The first and foremost reason is the various factors that together contribute towards ergonomics and the second reason is that human response is varied. Moreover human response varies from person to person as well as from time to time. Thus the situation becomes complex and the uncertainty in the form of ambiguity creeps in. Ambiguity is the mother of complexity. According to the Compatibility Principle, the complexity and the imprecision are correlated and add.

To deal with this kind of uncertainty and information granularity, Dr. Lotfi A. Zadeh proposed Fuzzy Logic (Zadeh, 1973, 1978). There is a profound correlation between Complexity and Fuzziness. As the complexity of a task (problem), exceeds a certain threshold, the system becomes fuzzy. Fuzzy Logic provides a method to deal with imprecision and information granularity. It provides a mode enabling appropriate human reasoning capabilities. This is the strength of the Fuzzy logic system.

Whereas, the traditional binary set theory describes events which are crisp, i.e. which either do or do not occur, Probability theory is used to explain the chance if an event will occur.

The theory of fuzzy logic is based upon membership functions. If uncertainty is due to imprecision, indistinctness or similar reasons, then variable is fuzzy and is characterized by a membership function. The fuzzy sets are useful because they can model uncertain or ambiguous real life data. The strength of fuzzy logic system is shown in the *Fig. 3.1*.

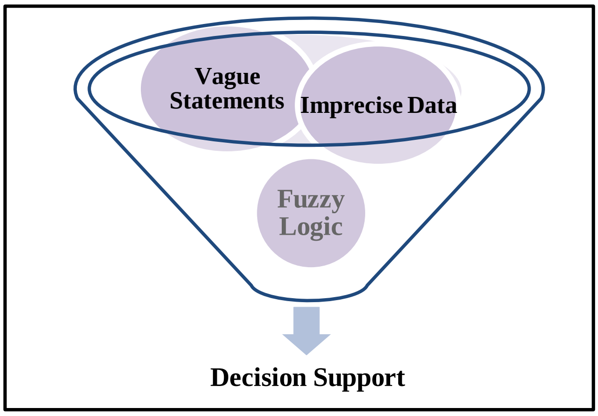

Fig. 3.1 Fuzzy logic system

3. 2 Major steps of this research

In the present research for developing a comprehensive methodology for prioritising the attributes which determines the ergonomic compatibility of a car, the first step was to identify the various stated and unstated safety and comfort needs of the users of a car and translate them into ergonomic attributes.

In the automotive world, people expect big new innovations, so cars need to evolve to include those expectations. Even the most mundane aspects of automotive functionality are being addressed by new technologies but the manufacturers are focussing on features like driving safety, comfort, driver assistance, and process control systems. It is an established fact that safety is always a major issue in the automobile industry and the technological features which contribute to driver safety are often a key element for drawing customer's focus.

Automobile manufacturers also capitalize on the idea of passenger satisfaction and comfort. The growth pattern of the automotive industry globally is based on *'Innovation'* and the same is also being realised gradually in developing economies like India.

In the present research, only those features which enhance safety, augments user satisfaction, provide fatigue-free driving, and aid in increasing the alertness of driver were considered.

The important ergonomic needs of the driver and passengers were identified from literature review. Subsequently, personal interaction was conducted with three dealers of major car manufacturers located in Jaipur city and the features of the upcoming models of car were discussed and ratified, especially in the Indian scenario. Discussions and interview was also conducted with sedan car users. The identified ergonomic needs were further discussed with seven automobile engineers and academicians and were categorized into twenty (20) ergonomic attributes which contribute towards safe and fatigue-free driving and aids in increasing the alertness of driver.

After identifying the major ergonomic attributes, the need was felt for establishing the relative importance of the attributes and to prioritize them.

Prioritisation of these attributes was a multi-criteria decision-making (MCDM) problem and for analysis of such problems, pair-wise comparisons techniques are generally used. These techniques are based on establishing priorities and involve huge effort when many attributes need to be compared. This is because every attribute is to be compared with each other; thereby leading to an increase in the number of pair-wise comparisons. It is not possible for any decision maker to make a large number of comparisons and that too consistently. For comparing *(n)* attributes, the number of pair-wise comparisons would be [$n \times (n\text{-}1)/2$], which for 20 attributes will be 190. Also, this method fails to reflect human thinking effectively and is very time-consuming. To overcome these issues, the need for developing a new model based on the VoC was felt necessary.

The stated and unstated requirements about these attributes in terms of VoC were captured from consumer survey based on Fuzzy Kano Model. The respondents of the survey gave their opinion on each attribute. They were informed that the survey was for academic purposes only and informed consent was obtained from each of them.

The results of the survey were integrated with Quality Function Deployment (QFD) to develop the new framework "***House of Ergonomics Deployment (HED)***", for prioritising the attributes of a car. QFD and Kano model are originally about Quality, but here they were modified for application in ergonomic attributes. HED determines attribute weights and prioritises the ergonomic attributes. These priorities were compared with the priorities obtained from Fuzzy AHP. These steps are shown in *Fig. 3.2*.

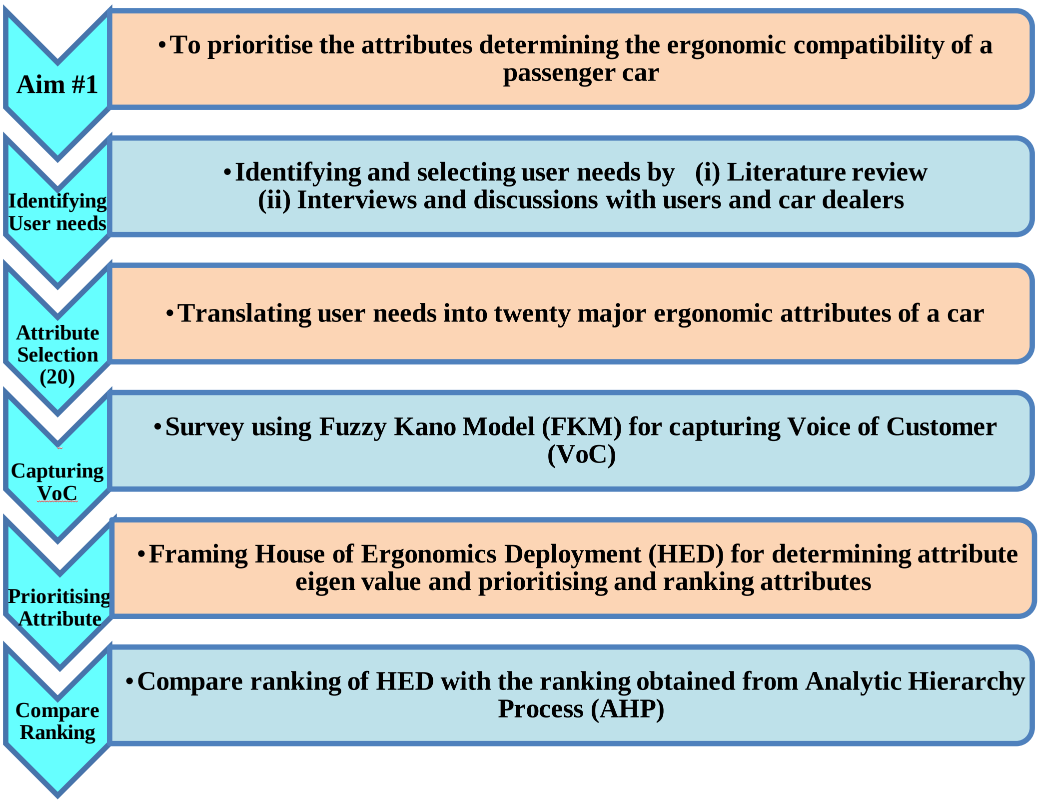

Fig. 3.2 Steps for prioritising the attributes determining the ergonomic compatibility of a car.

In the second step, the identified attributes were grouped into three major factors, based on their cause and effect:

(i) *Overall Safety factor:* The attributes which determines the safety during driving, helps in avoiding the chances of an accident or reduces the injury in case of an accident, were classified under this group.

(ii) *Musculoskeletal/ Reach factor:* The attributes which have a bearing on the posture of body during driving or while reaching for a control and if improper may lead to musculoskeletal trouble, were classified under this group.

(iii) Compatible Man-Machine Interface/ Comfort factor: The attributes which makes driving fatigue-free and easy and helps in maintaining proper ambience during driving, were classified under this group.

Then, for any particular brand of car, the attribute score and factor score is determined based on the features present in the car. These factor scores are combined by applying Mamdani FIS using MATLAB, to arrive at a final ergonomic score of the car. The steps are detailed in the following section. The major steps are shown in Fig. 3.3.

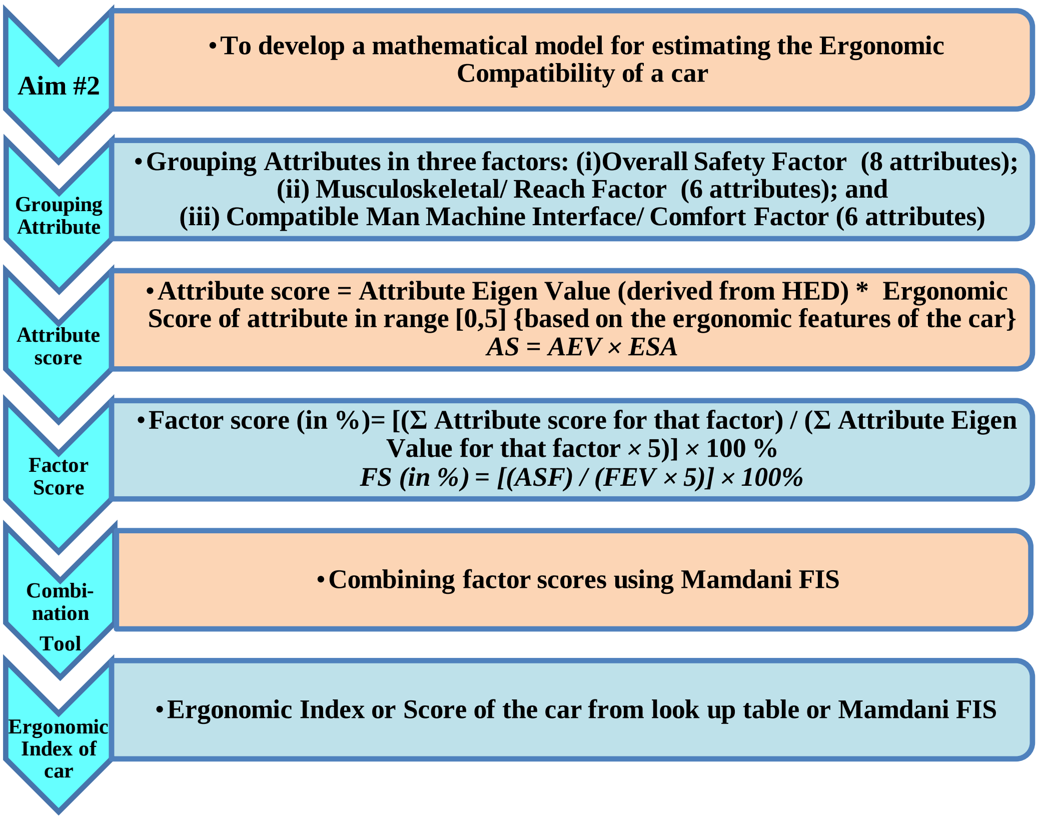

Fig. 3.3 Steps for developing a mathematical model for estimating the ergonomic compatibility of a passenger car.

3. 3 Kano's model

Kano's model allows insights into the dynamics of consumer preferences about the product features. Kano et al., (1984) gave a method for capturing the user responses to questionnaires onto his model. In this research, this model is used to concentrate on characteristic ergonomic features, instead of concentrating only on user needs. The Kano Categories as used in this research are:

- Attractive ergonomic features (A)
- One-dimensional ergonomic features (O)
- Must-be ergonomic features (M)
- Indifferent ergonomic features (I)
- Reverse ergonomic features (R)

These Kano Categories are shown in the *Fig. 3.4*.

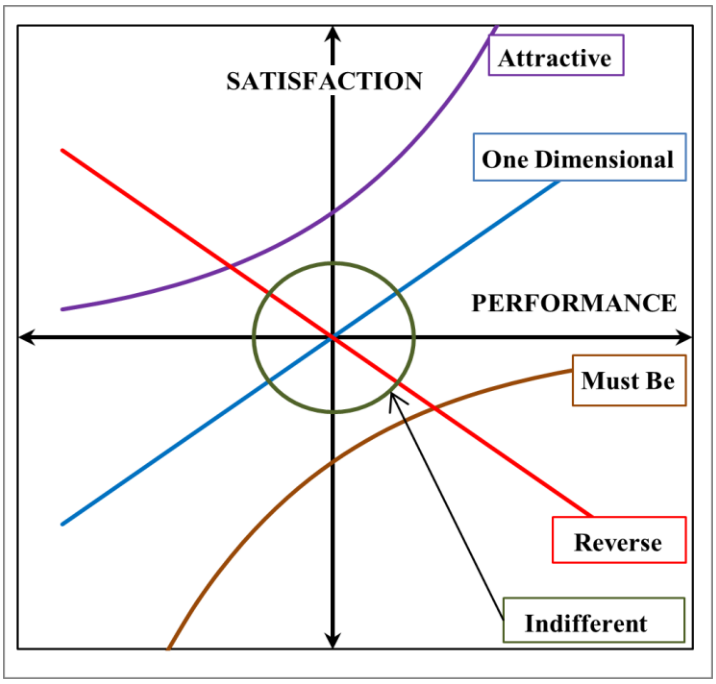

Fig. 3.4 Various categories of attributes used in Kano model.

3. 4 Quality Function Deployment (QFD)

QFD is a well-planned methodology that defines consumer's needs or requirements and interprets them into detailed strategies to manufacture products to satisfy those requirements. Wasserman (1993) have proposed a decision model which prioritizes the design requirements during QFD. Armacost et al. (1994) have prioritised the requirements of consumers in QFD and have given an AHP framework in an industrialized housing application. Khoo and Ho (1996) have provided a framework of a fuzzy QFD. Fung, Popplewell, and Xie (1998) have proposed a hybrid system based on the principles of QFD, AHP and fuzzy set theory. Chan, Kao, and Wu (1999) have shown the consistency of QFD with

MCDM for finding the relative importance of customer needs. Wang (1999) have proposed a fuzzy approach for prioritising the design requirements in QFD for a car design. Kwong et al. (2011) have proposed a fuzzy group decision-making method by integrating consensus ordinal ranking and fuzzy weighted average method for prioritising engineering characteristics in QFD.

3. 5 House of Ergonomics Deployment (HED): Integration of Kano model and QFD

In this research, the original QFD matrix has been modified to House of Ergonomics Deployment (HED) which defines the effect of each attribute on customer satisfaction and also prioritises all the identified ergonomic attributes. The general layout of the HED matrix is shown in *Fig. 3.5*.

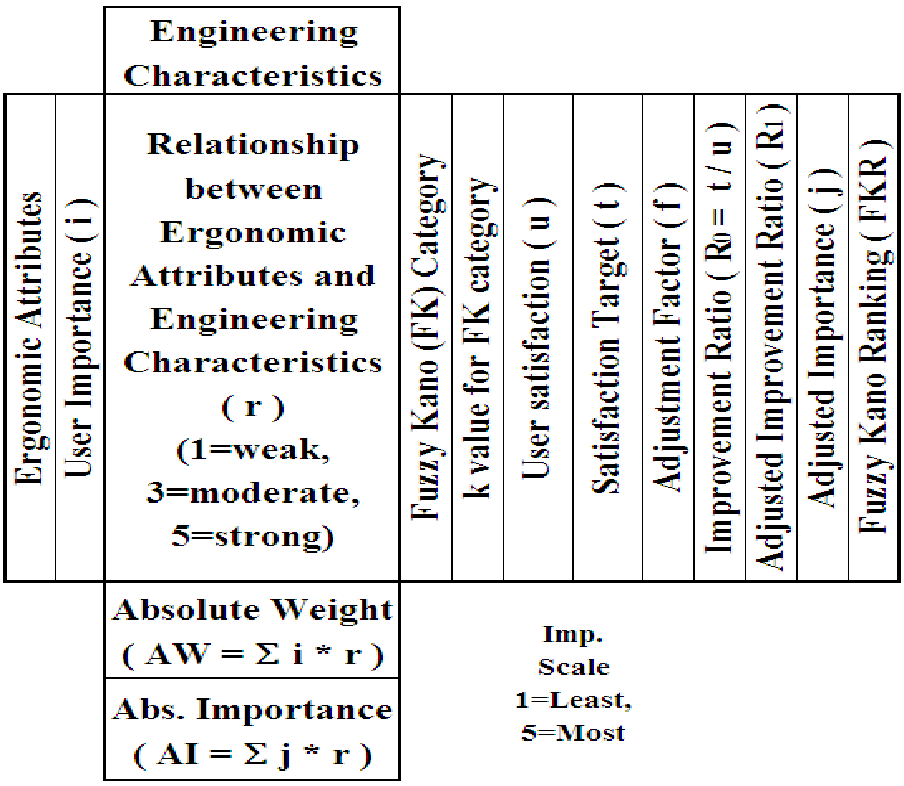

Fig. 3.5 General layout of the HED matrix.

Data was collected through Kano model based questionnaire. In the questionnaire, respondents could specify their choices, with two given conditions. In the first condition, he imagines that the desired ergonomic criterion is existing or adequate. In the second condition, he imagines that the desired ergonomic criterion is missing or inadequate. Various options under each condition were:

"Must be (M), Satisfied (S), Live with it (L), Indifferent (I) and Dissatisfied (D)".

The strength of deservedness is given by M> S> L> I> D.

By merging the two responses and by using Kano's evaluation table, the ergonomic attributes were designated as "*A: Attractive; O: One-dimensional; M: Must be; I: Indifferent; R: Reverse; Q: Questionable*". Kano's evaluation table is shown in *Table 3.1*.

TABLE 3.1 KANO EVALUATION TABLE

Functional form of question	**Dysfunctional form of question**				
	S	***M***	***I***	***L***	***D***
Satisfied (S)	Q	A	A	A	O
Must be (M)	R	I	I	I	M
Indifferent (I)	R	I	I	I	M
Live with it (L)	R	I	I	I	M
Dissatisfied (D)	R	R	R	R	Q

Any attribute categorizing as Reverse category was to be rejected, but no such attribute appeared in this research. The four main categories, viz. "*Attractive, One Dimensional, Must Be and Indifferent*", were considered further in the research. These four categories were separated into two conditions: good and bad. It was explained by Berger et al. (1993) that the coefficients of consumer satisfaction (CS) and dissatisfaction (CD) are quantitative estimates of satisfaction and dissatisfaction of the consumer by fulfilling or not fulfilling his requirement.

$$\text{Consumer satisfaction } (CS) = (O + A) / (O + A + I + M) \qquad (1\text{ a})$$

$$\text{Consumer dissatisfaction } (CD) = (O + M) / (O + A + I + M) \qquad (1\text{ b})$$

The coefficients, *CS* and *CD* reflect how closely an attribute influences satisfaction or dissatisfaction, if absent. These values lie between 0 & 1. CS value approaching 1 indicates a higher influence on satisfaction level and vice versa. CD value approaching 1 (i.e.-1) indicates that customer dissatisfaction is high if the attribute is absent.

From the survey, the raw user importance was obtained which is the sum of the product of count of Kano category and the corresponding *k-value* of the Kano category. The *k-value* for each Kano category was defined by Chaudha et al. (2011) as 1.5, 1, 0.5 and 0 for A, O, M, and I category, respectively.

$$\text{Raw user importance} = (1.5\times A + 1.0\times O + 0.5\times M + 0\times I) \tag{2}$$

The value of user importance, *(i)* is the normalized value of raw user importance in the range [1,5].

The mean value of the satisfaction derived from an attribute (on the scale of 1 to 5) by driving their own car as indicated by the respondents during the survey [*part (c) of each question*] represents User satisfaction *(u)*. Similarly, the mean value of the essentiality of an attribute (on the scale of 1 to 5) as indicated by the respondents [*part (d) of each question*], defined the Target expectation *(t)*. The ratio of Target expectation *(t)* to User satisfaction *(u)* gives Improvement ratio *(R_0)*:

$$\text{Improvement ratio } (R_0) = (t) / (u) \tag{3}$$

Adjustment factor *(f)* as proposed by Tontini (2007) was used in HED:

$$\text{Adjustment factor } (f) = \max([CS], [CD]) \tag{4}$$

Adjusted improvement ratio (R_1), as proposed by Chaudha et al. (2011), was used in the HED:

$$\text{Adjusted Improvement ratio } (R_1) = (1 + f)^k \times R_0 \tag{5}$$

In HED, *(R_0)* represents the desired degree of increase in customer satisfaction and (R_1) tells us *'What'* should be done to achieve the desired degree of customer satisfaction. Adjustment Importance *(j)* is the product of the adjusted improvement ratio *(R_1.)* and user importance *(i)*.

$$Adjustment\ importance\ (j) = i \times R_1. \quad (6)$$

Adjustment Importance *(j)* indicates the relative importance of the attributes and was used to prioritise the identified ergonomic attributes.

The relationship between the ergonomic attributes and various engineering characteristics were considered in the *relationship* section of HED. This section of HED is the *'How'* list, where relationships between an ergonomic attribute and the engineering characteristics were determined. These interrelationships indicate the connection between *'What'* and *'How'*. The value of relationship rating *(r)* used was *1* for weak, *3* for medium and *5* for a strong relationship. In HED, just below the relationship section, is the *Absolute* section. In this section, Absolute Weight (*AW*) and Absolute Importance (*AI*) are calculated by using the following equations:

$$Absolute\ Weight\ (AW) = \Sigma\ (i \times r) \quad (7)$$

$$Absolute\ Importance\ (AI) = \Sigma\ (j \times r) \quad (8)$$

where; r = relationship rating, i = user importance and j = adjustment importance

3. 6 Introducing fuzziness in the Kano model

Traditional Kano model captures VoC only in the crisp form. Lee and Huang (2009) have discussed that the questionnaire designed traditionally reflects the result in two value logic. The feelings of some respondents for some attributes were not crisp sets, as ergonomic features cannot be considered crisp. To investigate people's opinions accurately, the fuzzy logic was used. In the questionnaire, respondents could specify their choice (crisp) / choices (fuzzy).

Suppose for an ergonomic attributes, a respondent who is very clear about his liking may respond to:

Functional form of question F = {1 0 0 0 0} or {0 1 0 0 0}, and

Dysfunctional form of question N = {0 0 0 1 0} or {0 0 0 0 1},

{S M I L D} respectively.

Then, the attribute as per the Kano evaluation table will be:

F = {1 0 0 0 0} & N = {0 0 0 1 0} => A

F = {1 0 0 0 0} & N = {0 0 0 0 1} => O

F = {0 1 0 0 0} & N = {0 0 0 1 0} => I

F = {0 1 0 0 0} & N = {0 0 0 0 1} => M

Now for the same attributes, if a respondent is not very clear about his liking, he may give fuzzy response to:

Functional form of questions F = {0.3 0.7 0.0 0.0 0.0}, and

Dysfunctional form of question N = {0.0 0.0 0.0 0.3 0.7},

{S M I L D} respectively.

Then the fuzzy Kano calculation for this attribute is shown in *Fig. 3.6*.

$$\begin{Bmatrix} 0.3 \\ 0.7 \\ 0.0 \\ 0.0 \\ 0.0 \end{Bmatrix} \begin{Bmatrix} 0.0 & 0.0 & 0.0 & 0.3 & 0.7 \end{Bmatrix} = \begin{Bmatrix} 0.00 & 0.00 & 0.00 & 0.09 & 0.21 \\ 0.00 & 0.00 & 0.00 & 0.21 & 0.49 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \end{Bmatrix}$$

$$= \begin{Bmatrix} \underline{0.49} & \underline{0.21} & \underline{0.09} & \underline{0.21} & \underline{0.00} \\ \mathbf{M} & \mathbf{O} & \mathbf{A} & \mathbf{I} & \mathbf{R} \end{Bmatrix}$$

Must be Attribute

Fig. 3.6 Fuzzy Kano calculations.

Attributes are counted only above thresh hold value of 0.4 and in the case of a tie for the first position, the order is M>O>A>I.

3. 7 *Comparison method: MCDM using Analytic Hierarchy Process (AHP)*

MCDM is a tool for decision-making, which involves quantitative and qualitative factors. AHP, proposed by Saaty (1980), is a procedure for analyzing complex-decision problems, in which the problem is structurally decomposed into a hierarchy of sub-problems. AHP deals with human subjectivity numerically.

Ho, Lai, and Chang (1999) have minimized inconsistency over the group and individual preferences in an integrated group decision-making system. Askin and Dawson (2000) have given a mathematical programming model for capturing customer preferences.

The method of MCDM in AHP depends on the pair-wise comparisons. The relative importance of various elements is evaluated by the decision-maker by making pair-wise comparisons. These evaluations are converted to numerical values (weights or priorities), which are used to calculate a score for each alternative (Saaty, 1980). The priorities are decided by computing the eigen-vector of a pair-wise comparison matrix. AHP is also useful when different elements of the decision are difficult to quantify or compare, or where decision makers have different perspectives or specializations. Priority or numerical weight is calculated for each element of the hierarchy, which permits the comparison of diverse elements in a rational and dependable manner. For determining the degree to which a decision-maker was consistent in his responses, the consistency index is calculated. AHP is very useful where the problems are complex and involves human judgments and perceptions, and whose decisions have a long-term impact. These potentials of AHP distinguish it from other MCDM techniques and hence preferred.

Let the alternatives are $\{A_1, A_2, ..., A_n\}$, then the pair-wise comparisons matrix, $A = [a_{ij}]$ is the preference of a decision maker between all the pairs of alternatives (A_i versus A_j, for all $i, j = 1, 2, .., n$; where n is the total number of alternatives). The preferences generally vary from *1/9, 1/7, 1/5, …, 5, 7, and 9*. (with *1 = same importance, 3 = weekly more important, 5 = moderately more important, 7 = strongly more important and 9 = absolutely more important and reciprocals are* *for inverse comparison*), hence the element $a_{ij} = 1$, if i equals j and $a_{ij} = 9^{-1}, 7^{-1}, \ldots, 7, 9$ otherwise (Gold and Awasthi, 2015).

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12}\ldots\ldots & a_{1n} \\ 1/a_{12} & 1\ldots\ldots & a_{2n} \\ \vdots & \vdots & \vdots \\ 1/a_{1n} & 1/a_{2n}\ldots\ldots & 1 \end{bmatrix} \quad (9)$$

In this research, the number of attributes was 20, so the number of pair-wise comparisons would be 190 (19×20/2). It is not possible for any decision maker to make 190 comparisons and that too consistently. Moreover, the evaluation is subjective and qualitative in nature, so it is very hard to assign exact numerical values to the pair-wise comparison judgments and express the preferences using exact numerical values. Also, when comparing many alternatives in a pair-wise fashion, the vagueness of linguistics and expressing them in numbers, causes inconsistency. Even though a certain valve of inconsistency is allowed, perfect consistency is very difficult to achieve. Moreover, this process is very time-consuming when large numbers of alternatives are considered. In that case, the pair-wise comparisons matrix, A can be replaced by matrix W, which is the ratio of the weights of the alternatives.

The element (a_{ij}) in above matrix is the estimate the ratio of the weights of the alternatives (w_i / w_j). Hence, instead of pair-wise comparison matrix A [shown in equation (9)], the matrix of ratios of weights of attributes W [shown in equation (10)], can be used in AHP. In this matrix W, the element (a_{ij}) is the estimate the ratio of the weights of the alternatives (w_i / w_j), as proposed by Alonso and Lamata (2006). So matrix A can be represented as:

$$W = [w_i/w_j] = \begin{bmatrix} w_1/w_1 & w_1/w_2\ldots\ldots & w_1/w_n \\ w_2/w_1 & w_2/w_2\ldots\ldots & w_2/w_n \\ \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2\ldots\ldots & w_n/w_n \end{bmatrix} \quad (10)$$

Every ratio in this matrix is positive, and so it has positive eigen-values. After the pair-wise comparisons are made by the individual, group priority vectors are generated by aggregating the individual judgments. Once, the aggregate judgment matrix of all the pair-wise comparisons is obtained, the consistency is determined by using the eigen value λ_{max} to calculate the consistency index *(CI)*. The relation for *CI* as given by Saaty, (1980), for a matrix size *(n)* is as follows:

$$CI = (\lambda_{max} - n) / (n-1) \quad (11)$$

The consistency of judgment is verified by calculating consistency ratio *(CR)*

$$CR = CI / RI \quad (12)$$

Here, Random Index (*RI*) is the average value of *CI* for randomly generated pair-wise comparison matrices using the Saaty scale. The value of *RI* depends on the number of criteria *(n)* being compared, as shown in *Table 3.2*.

TABLE 3.2 RANDOM INDEX (*RI*) (SAATY, 1980)

Size (n)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

If the matrix *A* is represented as the ratio of the weights of the alternatives, then it will be absolutely consistent with *A=W*.

Then, $a_{ij} \cdot a_{jk} = a_{ik}$ (for all i, j, k)

and, the principal eigen value $(\lambda_{max}) = n$,

and, the consistency index $(CI) = 0$.

Often the decision maker is not absolutely consistent (which generally occurs even with the professionals comparing many alternatives in a pair-wise fashion), then the comparison matrix *A* is a perturbation of the consistent case.

In the non-consistent case, “$\lambda_{max} > n$”.

A threshold for consistency has been set which should not be exceeded. The matrix is considered to be consistent enough only if $CR < 0.1$. If $CR \geq 0.1$, then the comparison matrix needs to be improved.

3. 8 Introducing fuzziness in the AHP (FAHP)

Even though AHP is a very efficient method of capturing the knowledge of the decision makers, yet the traditional AHP fails to reflect the human thinking effectively and does not account for the uncertainty.

Kwong and Bai (2003) have used fuzzy AHP with an extent analysis approach for determining the importance weights for product planning of a hair dryer design. Chen, Chen, and Lin (2004) have given a method for determining and revising the customer’s priority based on new customer surveys using a fuzzy logic inference and have demonstrated it for car redesign. Nepal, Yadav, and Murat (2010) have used fuzzy AHP to prioritise attributes in the planning of product development. Mardani, Jusoh, and Zavadskas (2015) have found that many fuzzy multi decision-making (FMCDM) techniques have been used for selecting the optimal alternative.

Fuzzy AHP (FAHP) carries out AHP in fuzzy conditions and addresses imprecise and vague judgments and provides an effective solution when dealing with varied human responses. It enables the valuable human experience and real-life situations to be incorporated into decision making which is difficult, if not impossible, to deal with the classical approach.

In this research, the survey results were based on human responses, so Fuzzy AHP was considered more appropriate and was used to prioritize the identified attributes. To compare the ranks of all 20 attributes, FAHP method with Triangular Fuzzy Numbers (TFN) and scale similar to Saaty's (1980) was used.

Let us consider a fuzzy set $\tilde{N}$, and if an element x is a member of this fuzzy set $\tilde{N}$, then the TFN is represented as (l, m, u), where parameter (l) is the minimum possible value, (m) is the most likely value and (u) is the maximum possible value associated with the fuzzy event (Nagoorgani and Begam, 2010). From the survey result, the minimum, maximum and most likely (i.e. mean) value were calculated.

The curve describing the fuzzy set by assigning each element a degree of membership or a corresponding membership value is known as Membership Function (MF). The horizontal axis represents the input variable (x), and the vertical axis represents the equivalent membership value $\mu_{\tilde{N}}(x)$ of (x). The MF of Ñ is shown in *Fig. 3.7*.

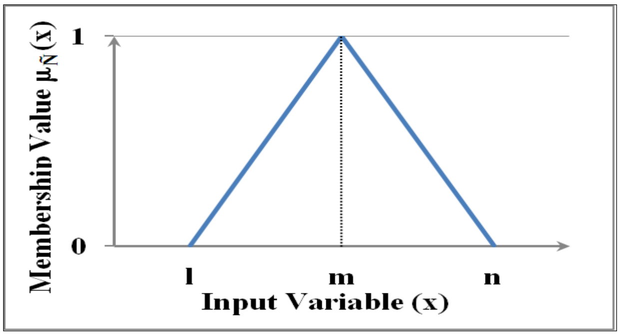

Fig. 3.7 Triangular Fuzzy Number (TFN)

After the rankings are made by all the individual decision makers (i) for all the attributes (j), weights can be generated by aggregating the individual judgments. Let us denote that the judgment provided by the expert (i) on element (j) as w_{ij}. The aggregate judgment all the respondents $(r=100)$ on element (j), is given by

$$\widetilde{w_j} = (l_j, m_j, u_j) \tag{13}$$

where, $l_j = Min\{w_{ij}\}$,

$$m_j = \frac{1}{r}\sum_{i=1}^{r} w_{ij} \quad \text{and,}$$

$$u_j = Max\ \{w_{ij}\}$$

$$The\ MF\ of\ this\ TFN,\ \ \mu_{\tilde{w}}(x) = \begin{Bmatrix} \frac{x-l}{m-l},\ \ l \leq x \leq m \\ \frac{u-x}{u-m},\ \ m \leq x \leq u \\ 0,\ otherwise \end{Bmatrix} \qquad (14)$$

To obtain the crisp value w_j, for the triangular fuzzy number (TFN) $\widetilde{w_j} = (\ l_j\ , m_j\ , u_j)$, the graded mean integration representation for defuzzification as proposed by Chen and Hsieh (1999, 2000) and Chen and Wang (2006) was used and the value of (w_j) is:

$$w_j = \left\{\frac{l_j + (4 \times m_j\ ) + u_j}{6}\right\} \qquad (15)$$

3. 9 Developing a mathematical model: Calculation of attribute score and factor scores

Attribute Eigen Value (AEV): In the House of Ergonomics Deployment (HED), adjusted importance value for each attribute was calculated. The attribute eigen value is normalised value of adjusted importance in the range [0, 1], such that:

$$\Sigma\ (AEV) = 1$$

Ergonomic Score of the Attribute (ESA): For a particular model and variant of car, the ergonomic score for each attribute is the degree of fulfillment of that ergonomic attribute by that car. This is based on sub classification of each attribute. To determine the degree of fulfilment of any attribute by any car, each of the twenty ergonomic attributes was further classified into subcategories based on the analysis of the latest features of car, literature reviews and discussions with the car dealers. Presence or absence of these features forms the basis for determining the ergonomic score of attribute. Ergonomic score for an attribute can take only whole numbers values in the range [0,5], where 0 means no fulfillment and 5 means maximum fulfillment.

Attribute score (AS): The product of attribute eigen value (AEV) and ergonomic score of attribute gives Attribute score:

$$\textit{Attribute score} = \textit{Attribute Eigen Value} \times \textit{Ergonomic Score of the attribute} \qquad (16)$$

$$AS = AEV \times ESA$$

Factor eigen value: The attributes were grouped into three main ergonomic factors. The sum of the attribute eigen values (AEV) for each of the factors is found out and this sum is denoted as Factor eigen value (FEV).

$$\textit{For each factor, } \Sigma\,(AEV) = FEV$$

The sum of FEV for all factors, $\Sigma\,(FEV) = 1$.

Attribute score for a factor (ASF): The sum of the attribute score (AS) for each of the factors is found out. This sum is denoted as Attribute score for a factor (ASF).

$$\textit{For each factor, } \Sigma\,(AS) = ASF$$

Factor score (FS): The Factor score (FS) in % is calculated for all the three factors as:

$$FS\ (in\ \%) = \left[\frac{(\Sigma\ Attribute\ score\ for\ a\ factor)}{(\Sigma\ Attribute\ Eigen\ Value\ for\ that\ factor) \times (5)}\right] \times 100\ \%$$

$$FS\ (in\ \%) = \left[\frac{(ASF)}{(FEV)\times(5)}\right] \times 100\ \% \qquad (17)$$

3. 10 Combination of factor scores: Fuzzy logic integration using FIS

In this research, the human response about the ergonomic attributes and factor scores are complex and are considered to be fuzzy because fuzzy logic is reasonably precise in mimicking the human expertise.

A fuzzy rule-base model or fuzzy inference engine performs fairly accurate reasoning, quite similar to primitive human brain. Fuzzy logic provides a method to deal with imprecision and information granularity. It provides a mode for enabling appropriate human reasoning capabilities. The variable is fuzzy, if there is uncertainty due to imprecision, indistinctness or similar reasons. The fuzzy sets can model uncertain or ambiguous real life data. There is also a correlation between complexity and fuzziness, i.e. as the complexity of a task (problem), exceeds a certain threshold, the system becomes fuzzy. Even though only some particular aspects of natural language can be represented by the fuzzy sets, yet fuzzy logic is one of the most practical ways to mimic human expertise. The theory of fuzzy logic is based upon membership functions. The ergonomic factor scores or inputs are fuzzified using fuzzy rule based models for function approximation.

Various researchers have used fuzzy logic for ergonomic evaluation and studies. Gurcanli and Mungen (2009) have given a Mamdani model for assessing the risks of construction site workers, by using inadequate and uncertain data. Beriha et al. (2012) have assessed the risks and safety parameters using Mamdani Fuzzy Inference System (FIS) and have predicted different severity of accidents in an uncertain environment. They have used fuzzy logic to map input and output for building inference engine for predicting accidents and for improving safety. Rivero et al. (2015) have performed ergonomic evaluation and assessed the risk of workers using fuzzy logic and RULA method in hardware stores during the packing process. Wang (2015) have studied the features of membership functions in Mamdani FIS which affects the relations between input and output variables. Debnath et al. (2016) have formulated a Sugeno type FIS to assess the occupational risk in construction industries which is based on various parameters using inadequate data or imprecise information.

Fuzzy inference systems maps given input(s) to output(s) using fuzzy logic and offers a basis for making decisions (Ross, 2010). Membership functions (MFs) describe all the information about the fuzzy sets and are important in defining any fuzzy logic system. MFs indicate the relation between the points of input space to a membership value. The input space is called the universe of discourse and it has every possible values of input to a fuzzy system. The members of fuzzy sets have different degree of membership in the range 0 to 1 and MFs represent this graphically. The universe of discourse (i.e. input) is plotted on x-axis and the corresponding level of membership on y-axis. A fuzzy logic system has four main parts, viz. Fuzzification, Rule base, Fuzzy inference and Defuzzification.

- *Fuzzification*: Fuzzification is an interface which converts the crisp classical data into fuzzy data or MFs so that comparison can be done with the rules in the rule base. MFs are generally continuous, normal and convex functions and can be symmetrical or asymmetrical. Mostly simple MFs are used because while working in fuzzy environment, any complex function does not improve the precision.

- *Rule base*: The set of rules comprises Rule base, which are a set of linguistic statements illustrating how a decision should be taken by the FIS about categorizing an input or calculating an output. The general form of Fuzzy rules is: *If (input1 is MF1) and/ or (input2 is MF2) and/ or ….Then (output is output MF)*.

- *Fuzzy Inference System*: FIS is a mechanism to evaluate which rules will be relevant in a particular condition for deciding the output i.e. the fuzzy output is derived by the combination of the MFs and the control rules. The commonly used fuzzy inference models are discussed in the following section.

- *Defuzzification*: Defuzzification interface converts the fuzzy conclusions into crisp output and display it into a look up table. Based on the input, the output is determined from the lookup table. Various techniques for defuzzification of output distribution are smallest of maximum, mean of maximum (MOM), largest of maximum, weighted average (WA), bisector of area and centre of gravity (COG) (also called centroid of area).

Fuzzy inference is the method of drawing output from a given input using fuzzy logic. This gives a basis by which evaluation can be made. Fuzzy rules are a set of linguistic statements that illustrate how the FIS should finalize regarding classifying an input or controlling an output. The two standard and commonly used Fuzzy Inference models are:

- *Non additive rule models* (e.g. Mamdani), or
- *Additive rule models* (e.g. Takagi–Sugeno–Kang TSK model or Tsukamoto model or Kosko standard additive model)

The designing of both the FIS is same but the crisp output is generated in different ways for both the FIS. The comparison of Sugeno and Mamdani FIS has been performed for many applications by various researchers (Jain and Soni, 2015; Kamboj and Kaur, 2013; Kaur and Kaur, 2012; Shleeg and Ellabib, 2013).

In Mamdani FIS, the inputs may be crisp or fuzzy numbers, but it uses rules whose consequents are fuzzy sets. The fuzzy sets obtained from the consequent of each *If-Then* rule are aggregated through the combination operator and the fuzzy set so obtained is defuzzified to find the system output. The advantages of the Mamdani FIS are that it is (i) Accepted widely, (ii) Intuitive, and (iii) Suits well to human input.

In Sugeno FIS, the inputs are combined linearly as the consequent of each *If-Then* rule. A weighted linear aggregation of the consequents yields the output. The output MFs can either be linear or constant. The final crisp output is found by using a weighted mechanism. The Sugeno FIS is more consistent with optimization and adaptive techniques and is efficient computationally. It is appropriate for mathematical analysis and ensures continuity of the output surface.

The difference between both the FIS is in the way the defuzzification happens. Mamdani FIS gives an output that is a fuzzy set. The output of Sugeno FIS is either constant or a linear mathematical expression. For illustration, let in Mamdani FIS: *If A is S_1, and B is S_2, then C is S_3 (where, S_1, S_2, S_3 are fuzzy sets),* *but in Sugeno FIS: If A is S_1 and B is S_2 then $C = aS_1 + bS_2 + c$ (linear expression), where a, b and c are constants.*

The method of deciding the parameters of polynomial is not simple in Sugeno FIS and the method for determining the output fuzzy sets is complex in comparison to Mamdani FIS. So, Mamdani FIS is more popular and has wide spread acceptance. Haman and Geogranas (2008) have also found that the output of Mamdani FIS has better expressive power and interpretability than Sugeno FIS because the consequents of the rules in Sugeno are not fuzzy. Thus, Mamdani FIS is used in this research.

The fuzzy sets from the consequent of each rule are combined through the aggregation operator and the resulting fuzzy set is defuzzified to yield the output of the system. This is shown in *Fig. 3.8.*

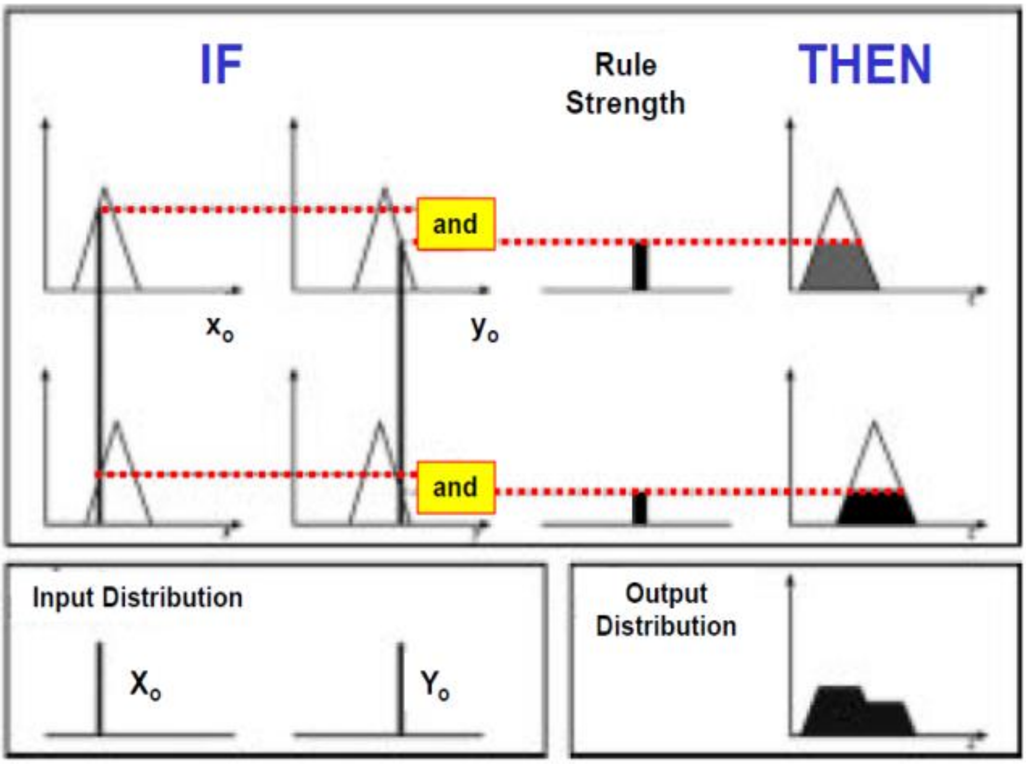

Fig. 3.8 Mamdani FIS.

After the aggregation, there is a fuzzy set for each output variable which is then defuzzified. Defuzzification of output distribution is shown in the *Fig. 3.9*.

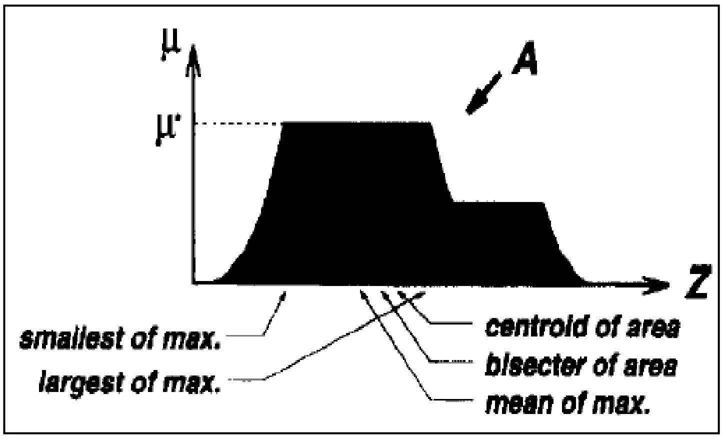

Fig. 3.9 Defuzzification.

Chapter: 4.
Attribute Identification and Survey

Practically cars should be so designed so as to maximize user satisfaction and fatigue-free driving while taking care of ergonomic and safety feature. In this research, it was important to identify the various stated and unstated ergonomic needs of the user of a car. The stated and unstated requirements about the ergonomic needs of a car were collected through observations, direct discussions or interviews with users and car dealers, surveys, field reports, literature surveys etc.

4. 1 Literature review for attribute identification

The prime reason for an ergonomic car design is the realization of an effective man-machine interface which permits driver and passengers to harmoniously and safely operate all functions in all situations without interfering with the focus of driver. Stevens (2000) has discussed about vehicle instrumentation, human-machine interface aspects of safety and relevant codes and guidelines.

Koppel et al. (2008) found that for new vehicle purchase process, consumers consider safety-related factors (e.g., advanced braking systems, airbags, stability etc.) as more important than other factors (e.g. price, reliability, route navigation systems, air-conditioning, automatic transmission etc).

Klarin et al. (2009, 2011) have discussed about the automobile interior where the foot controls are located and have stressed on anthropometric data for designing passenger vehicles ergonomically. They have also discussed about modeling the space that drivers occupies using anthropometric measurements and have given a design for the space behind the windscreen, the position of the steering wheel and the position of the foot controls.

Hurwitz et al. (2010), found that the vehicles equipped with a rear-view camera and sensor system-based parking aid, have reduced the chances of crashes during backing, particularly when paired with an appropriate sensor system.

Vrkljan and Anaby (2011) studied the importance attributed by the customers to various features while purchasing a vehicle and found that safety and reliability were the most desired, whereas design and performance had the lowest rating.

Intelligent adaptations and fitments can be of great help to all drivers. Kim et al. (2012) have conducted a study about in-car navigation systems and route guidance modality for driver navigation and found that a combination of auditory and haptic modalities should be designed for drivers for improved task performance. Adding more modalities (like visual) could increase the strain of drivers in form of visual distraction and cognitive load. The navigation system should be easy to program and should give turn-by-turn audible directions, so as to conveniently guide the driver towards the destination without the trouble of reading road signs and fear of getting lost. It should provide road and route information systems, real-time traffic congestion on each route, the distance of destination according to the route chosen, the shortest route, the fastest route etc., thus enabling a driver to select the route, accounting for road type, traffic and distance. It should also memorize the path followed if travelled to the destination earlier. The system memory can be programmed to store a list of favourite destinations and the required destination can be selected by the driver to conveniently guide him.

Selander, Bolin, and Falkmer (2012) compared the driving errors made by young and old drivers during manual and automatic gear shift driving. Based on this study, he recommended that automatic transmission may be a method for safe driving. Under left-hand drive conditions, the automatic transmission reduces the left hand and left leg functioning needs of the drivers and reduces the stress of driving. This feature could be very effective during driving in busy city traffic.

Sivakumar and Krishnaraj (2013) have proposed various safety technologies like electronic stability control (ESC), lane departure warning, collision warning with automatic braking, blind-zone warning, emergency brake assist, adaptive headlights etc. that are important for safe driving.

Sewall, Borzendowski, and Tyrrell (2014) investigated what drivers thought about their vision at night and examined the effect of glare. They found that drivers' judgments about the disabling effects of oncoming headlights could be systematically inaccurate.

US National Highway Traffic Safety Administration (NHTSA) (2007) has reported that beam patterns, aim, colour, optical design and mounting height of headlamp in vehicles coming from the opposite direction have crucial roles in determining the amount of light reaching the eyes of drivers that may make some objects invisible to them. Glare is unavoidable in night driving so a proper balance between visibility and glare needs to be made. Cars offering auto-dimming rear-view and side mirrors help to minimise glare while driving after dark. Cars that can automatically switch between high and low beams, as needed to maximise visibility, could help to prevent blinding the drivers from the glare of oncoming traffic. Anti-glare adaptations on the windshield and rear view mirrors and improved headlight designs could be of great help for drivers. Vision enhancement systems using infrared sensor along with head-up display technology may also be of great advantage to the drivers, especially during night driving.

Hung and Yazdanifard (2015) studied the preferences of Malaysian consumer about vehicle safety and found that apart from airbags and anti-lock braking system (ABS); four other safety features that were considered important by the consumers were ESC, traction control, blind spot information system (BLIS) and collision warning with auto brake system.

Karali, Gyi, and Mansfield (2017) analyzed the driving performance, musculoskeletal symptoms, vehicle seat adjustments, access to controls, ingress & egress, and found that adjusting the headrest, seat height, turning their head and body to reverse, lifting the bonnet and opening/closing the boot was problematic for many drivers.

Lal et al. (2017) reported that in the cars fitted with brake assist technologies, when an obstruction approaches too close to the car, first the driver is warned and then 20% to 40% of braking capacity is applied automatically. If still, the driver does not respond, the emergency brake assist is activated which applies 100% of braking power.

Cicchino (2017) analysed the police-reported backing crash incidence in 22 U.S. states during 2009–2014 and found that rearview cameras are effective in reducing the backing crash incidence. With age, the joint flexibility declines and the cervical (neck) flexion decreases. This leads to restricted rotation of neck and trunk during motion of the car in the reverse gear. Camera fitment with back and side clearance indicators minimises the awkward posture by reducing the forces and pressures on the neck and trunk. A rear-view camera with audible warnings can help reduce the twisting of the neck and upper body. Side camera focussing on the blind spots along the side of the vehicle can help in manoeuvring the turns safely. Multiple cameras showing the 360-degree view around the car can be another option. Blind-spot warning technology that uses cameras and sensors to detect vehicles or other obstacles near the car and alerts the driver with a visual warning signal followed by an alarm will be a better choice. These systems also give an alert when backing out of a parking space. Cars with self-parking feature that automatically moves the car into the parking space by simply pressing a button (the driver only needs to control the brake pedal and change gears) may be another alternative.

As per the MoRTH report; in 2017, maximum numbers of road accidents were recorded between 6:00 PM to 9:00 PM, accounting for 18.4% of the total accidents. The glare from an oncoming vehicle might be the possible reasons. The maximum accidents (9.2%) occurred in the month of May, which might have some relation with the heat and humidity of pre-monsoon season. Accidents due to the usage of mobile during driving comprised 1.8% of the total accidents. Glare prevention glass and mirror, efficient air conditioning with humidity control and blue tooth connectivity for cell phone and audio could possibly cut down the number of such unfortunate incidences.

The objective of the research was partially addressed through literature review but in order to ratify the identified problems and their possible solution, from the perspective of the Indian drivers, Participatory Ergonomics (PE) was considered to be the most effective method. Other methods like driving simulation test and experimental field drive test were not feasible due to high associated risks and limited resources.

4. 2 Participatory ergonomics

Actively involving persons in developing and implementing their workplace changes is referred as participatory ergonomics (PE). PE actively involves those who will be part of the system being designed and they are brought into the product development process as participants (Noro and Imada, 1991). PE gives encouraging results for identifying and reducing the work-related risk factors (Wilson and Haines, 1997). PE interventions have a positive impact on many factors such as musculoskeletal symptoms, reducing injuries and workers' compensation claims (Rivilis et al., 2008). Gyi, Sang, and Haslam (2013) used PE to assess musculoskeletal health in drivers and made interventions to raise awareness about the same. They were successful in alleviating management's responsiveness towards musculoskeletal symptoms amongst business drivers. Rasmussen et al. (2017) explored the feasibility of a participatory ergonomics in the incidence of low back pain among workers. Burgess-Limerick (2018) has found that PE programs have effectively reduced the incidence of occupational musculoskeletal disorders by redesigning the manual tasks.

The ergonomic attributes identified through literature survey, were ratified through observations, direct discussions with users, in-depth interviews with car dealers, field reports, etc. To have a better understanding of the problems of drivers, a pilot study was conducted on 30 persons who frequently drive a car. Discussion was initiated with open-ended general questions about their family life, health conditions, followed by questions regarding their driving experience like since how long they are driving, what they feel about driving, etc. They were asked to identify perceived risk factors and problems faced during driving. They were requested to suggest adaptations which will permit better and harmonious interface between the driver (and passengers) with the car and technological modifications that may improve the safety, comfort and focus of drivers. Majority of them reported that they were experiencing some problems like low back pain, parking in narrow parallel space, twisting of the trunk during driving in reverse gear, etc. The major driving risks reported were glare during night driving, inability to press brake under emergency situations, continuously shift gear under heavy traffic conditions, maintaining a safe distance from the vehicle in front, detecting vehicles coming from back and from blind spot, making right turn (left-hand drive is mandatory in India), etc. They also proposed some solutions and adaptations to their problems. Some of the respondents had met minor accidents in past, the reasons for which were also discussed and the service stations, where they took their cars for repairing, were noted.

Subsequently, discussions were held with service station employees where accident hit cars were brought for repair. These employees had vital experience and their understanding of the possible reasons for the accident was discussed. They reported that increased traffic, inability to press brake under emergency situations and glare from an oncoming vehicle during night driving were the most important causes. Information was sought from the car dealers regarding upcoming features of a car, which will address these problems and could provide ease of driving. The needs were further discussed with automobile engineers and with teaching faculties of engineering colleges. The discussions were carefully noted and later analysed by the researcher himself.

It was found that the attributes which enhance safety, augments user satisfaction, provide fatigue-free driving and aids in increasing the alertness of driver are considered to be most important features by manufacturers and consumers. Hence, the identified ergonomic attributes were the needs related to primary controls (viz. steering, gear, clutch, brake), secondary controls (viz. headlight, turn indicators, seat belt, wipers), ancillary controls (viz. AC and entertainment features), and features related to the safety and comfort of the passengers and the driver, reach capabilities of the controls, clear and uninterrupted vision, etc. This information was used to develop a questionnaire about the ergonomic features of a car. Photographs showing inappropriate ergonomic aspects for a subject of height 1.54 m sitting in a typical car are shown in *Fig. 4.1*.

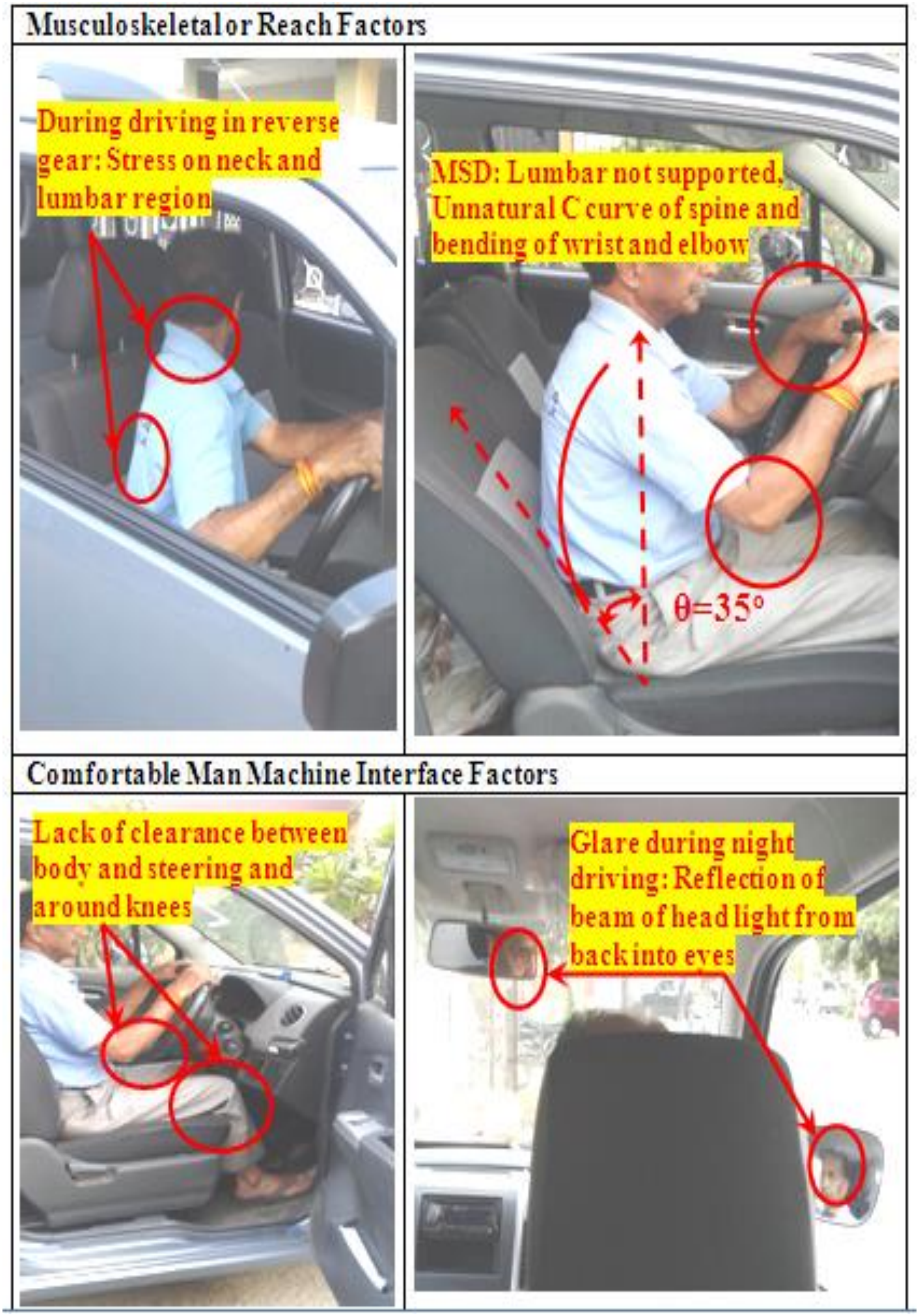

Fig. 4.1 Photographs showing inappropriate ergonomic features in a typical car.

4. 3 *Identifying the ergonomic attributes of a car and categorising them in ergonomic factors*

The identified ergonomic needs of a passenger car were classified into twenty (20) major ergonomic attributes. These attributes were categorised into three main ergonomic factors based on their cause and effects: Overall Safety factor, Musculoskeletal/ Reach factor and Compatible Man-Machine Interface/ Comfort factor. These are:

1) *Overall Safety factor* ***(8 attributes: a_1 to a_8)***

- Efficient **A**ir **B**ags (front, side and curtain) [AB]
- **B**rake **A**ssist with automatic emergency brake [BA]
- **F**atigue **D**etection sensor [FD]
- **H**illy **T**errain driving support [HT]
- Faster retractable **S**eat **B**elts [SB]
- **G**PS **N**avigation and assistance [GN]
- **S**ensor for **H**ead light intensity and auto dimmer [SH]
- **R**ain sensing wipers and **F**og lights [RF]

2) *Musculoskeletal/ Reach factor* ***(6 attributes: a_9 to a_{14})***

- Two-axis **A**djustable power **S**teering [AS]
- **C**amera for motion in reverse gear and side and back clearance **I**ndicators [CI]
- **D**oor locking sensors and **C**ontrol of doors and child lock near driver [DC]
- **F**requently used controls on **S**teering [FS]
- Effortless engine **B**onnet, fuel tank and **T**runk (dickey) operations [BT]
- Compatible driver **S**eat with three-axis **A**djustments and comfortable passenger seats [SA]

3) *Compatible Man-Machine Interface/ Comfort factor* ***(6 attributes: a_{15} to a_{20})***

- **A.C.** air circulation, cooling efficiency and humidity control [AC]
- **A**utomatic **T**ransmission (no clutch and gear lever) [AT]
- **S**ufficient head, knee and leg space for **D**river and passengers [SD]
- Effective shock absorbers and **V**ibration **D**amping [VD]
- **E**fficient sound proofing system & blue tooth **C**ompatibility for phone and audio streaming [EC]
- **G**lare **P**revention glass and mirror [GP]

All these factors contribute toward safe and fatigue-free driving and aids in increasing the alertness of driver. The prime reason of an ergonomic car design is the realization of an effective man-machine interface which permits driver and passengers to harmoniously and safely operate all functions in all situations without interfering with the focus of driver. These attributes and their corresponding effects on driver and passengers are shown in *Table 4.1*.

TABLE 4.1 EFFECTS OF ERGONOMIC ATTRIBUTES ON DRIVER AND PASSENGERS

Attribute name	Effect on driver and passengers
Efficient Air Bags (front, side and curtain) [AB]	Safety during accident
Brake Assist with automatic emergency brake [BA]	Prevention of accidents
Fatigue Detection sensor [FD]	Avoiding accidents by fatigue detection
Hilly Terrain driving support [HT]	Safe driving in hilly terrains and avoids accident
Faster retractable Seat Belts [SB]	Safety during accident
GPS Navigation and assistance [GN]	Avoiding accidents by suggesting least crowded route
Sensor for Head light intensity and auto dimmer [SH]	Avoiding accidents during night driving
Rain sensing wipers and Fog lights [RF]	Avoiding accidents during rainy and foggy weather
Two-axis Adjustable power Steering [AS]	Arms should be in a relaxed position when holding the steering wheel. Adjustable design for extremes of anthropometrical range.
Camera for motion in reverse gear and side and back clearance Indicators [CI]	Twisting of trunk and neck during reverse motion and during parking is risky
Door locking sensors and Control of doors and child lock near driver [DC]	All controls should be close to the driver's seat so that body should not be stretched to reach them. Reaching out may be awkward and is especially hazardous while driving. Safe for children and old passengers.
Frequently used controls on Steering [FS]	All controls should be close to the driver's seat so that body should not be stretched to reach them. Reaching out may be awkward and is hazardous while driving

Attribute name	Effect on driver and passengers
Effortless engine Bonnet, fuel tank and Trunk (dickey) operations [BT]	Bonnet, fuel tank and trunk operations should not strain the body by twisting, leaning forward and other awkward postures.
Compatible driver Seat with three-axis Adjustments and comfortable passenger seats [SA]	The body is relaxed and fatigue is minimized. Most of the MSD are associated with improper seat design and adjustments. Adjustable design for extremes of anthropometrical range
A.C. air circulation, cooling efficiency and humidity control [AC]	Thermal comfort increases driver's alertness even at extreme ambient temperatures. Minimizing fatigue at extreme temperatures
Automatic Transmission (no clutch and gear lever) [AT]	Minimizing driver's fatigue by avoiding the need to change gear under heavy traffic
Sufficient head, knee and leg space for Driver and passengers [SD]	Sufficient workspace and ability to change posture when required and feeling of spaciousness
Effective shock absorbers and Vibration Damping [VD]	Minimizing fatigue on bad roads and significantly increasing driver's alertness and safety
Efficient sound proofing system and blue tooth Compatibility for phone and audio streaming [EC]	Quieter interiors and acoustic comfort reduces driver's fatigue. Easy call answering without affecting alertness
Glare Prevention glass and mirror [GP]	Safe and glare free night driving and reduced fatigue

4. 4 Fuzzy Kano survey

The fuzzy Kano questionnaire was developed from the responses of direct user contact and all relevant suggestions regarding ergonomic attributes were included in the questionnaire. The questionnaire was discussed and tested with academicians, engineers and car dealers and modified at each level and the final questionnaire was developed which contained the 20 ergonomic attributes. Then the VoC about these ergonomic attributes was captured from a consumer survey. The questionnaire was either administered personally or sent by email only to the sedan car user within India. Participants were informed that the survey was for academic purposes only and informed consent was obtained from each of them.

The questionnaire had 20 questions; one for each attributes. Each question has 4 parts: (A), (B), (C) and (D). In part (A) and (B) of each question, the respondent was required to specify his choice, under a given conditions. In part (A), as a condition, he imagines that the desired criterion was existing or adequate. He selects one of the following responses:

"1. I am satisfied (S)

2. It must be that way (M)

3. I am neutral (Indifferent) (I)

4. I can live with it that way (L)

5. I am dissatisfied (D)"

The strength of deservedness of the response is given by M>S>L>I>D. In part (B), as the second condition, he imagines that the desired criterion was missing or inadequate. Again, he selects one of the above answers. In part (A) and (B), if a respondent was not sure about any one response, then he might give multiple choices in terms of percent liking. This induces the fuzziness in the responses, which was then defuzzified before further analysis. By combining the response to part (A) and part (B) of each question as indicated by each respondent and by using the Kano evaluation table, each ergonomic attribute was categorized into 5 standard Kano categories. Then for each attribute, the numbers of responses given in favour of each category were counted and on the basis of the maximum count, the attribute was categorized as "*Attractive (A), One Dimensional (O), Must Be (M), and Indifferent (I) ergonomic features*".

In part (C) of each question, each respondent was required to indicate the level of satisfaction (on the scale of 1 to 5) derived from his own car, for that particular attribute. The mean value of this satisfaction represents User satisfaction (u) for that attribute.

In part (D), each respondent was required to indicate the essentiality of that attribute on a scale 1 to 5 (*1 for minimum or not required feature and 5 for most essential feature*). The mean value of this represents Target expectation (t).

The complete survey questionnaire is placed at *Appendix I.*

A sample question from the survey questionnaire is shown in the *Fig. 4.2*.

1(A) If a car is having efficient airbags of 3 types (front, side and curtain), what is your opinion?

1(B) If a car is not having efficient airbags of 3 types (front, side and curtain), what is your opinion?

1I Status of airbags in your own car?

1(D) Essentiality of airbags in a car?

Fig. 4.2 Sample question from the survey questionnaire.

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Chapter: 5.

Framing HED and Comparing Priority of Attributes using FAHP

The survey questionnaire was sent to about 100 subjects through email. 63 responses were received from email, out of which 8 were rejected due to incompleteness or more of indifferent categorization of attributes. Additionally, direct one to one survey was carried out with 50 subjects, out of which 5 were rejected for the above-mentioned reasons. Thus finally responses from 100 respondents (55 from mail and 45 direct) were analyzed. The respondents varied in the profession, age, and sex. While some of the respondents were engineers with a deeper understanding about of the car, many others were businessmen, chartered accountants and so on. The respondents were in age group of 30 to 58 years (mean = 44.24 years, standard deviation=8.03). The responses of the entire 100 respondents were computerized and analyzed using SPSS 16.0 and MS Excel software. The Reliability Statistics Cronbach's Alpha value for part (d) of the survey questionnaire was 0.683, which is more than 0.6. This indicates satisfactory internal consistency reliability that is the questionnaire was reliable for use in this study. The responses to part (d) of the questionnaire are shown in *Appendix II.*

5. 1 Framing House of Ergonomics Deployment (HED)

As the first step, the fuzzy responses were defuzzified using matrix multiplication method. 22 respondents, who were surveyed personally, expressed their responses to one or more questions as fuzzy sets. All the responses received through mail were crisp sets. All the ergonomic attributes were categorized in four Kano categories: "*Must be (M), Attractive (A), One-dimensional (O) and Indifferent (I)*". Must-be attribute must be provided otherwise customers will be dissatisfied. Attractive attribute gives immense satisfaction to the customers if provided, but its absence does not cause dissatisfaction. For One-dimensional attributes, the customer's satisfaction is directly proportional to the attribute. Indifferent category means attribute does not affect user satisfaction at all.

The numbers of fuzzy Kano category (A, O, M and I) for each attribute as expressed by the respondents were calculated from the survey data. The User importance (*i*), User satisfaction (*u*), Target expectation (*t*) and Adjustment Factor (*f*) for each attribute were expressed by the users during the survey. Adjusted improvement ratio (R_1) and Adjustment Importance (*j*) were calculated and the ergonomic attributes were prioritised. These values are shown in *Table 5.1*.

These values were further used to frame House of Ergonomics Deployment (HED). In HED, (R_1) tells us '*What'* should be done to achieve the desired degree of customer satisfaction. In the *relationship* section of HED, the relationship between the ergonomic attributes and various engineering characteristics were considered. The engineering characteristics considered in this research were Indian standards, raw material quality, sensor quality and fidelity, weight, dimensions and also the cost. Engineering characteristics are important to meet the Ergonomic attributes. Obviously, there are some limitations like technical competence, adapting with present scenario and environment, but meeting user satisfaction is the prime objective. This section of HED is the '*How'* list.

In HED, just below the relationship section, is the *Absolute* section. Absolute weight, AW prioritizes specific characteristics that are crucial in designing an ergonomic car on the basis of user importance. Absolute Importance, AI indicates how the ergonomically compatible car can be designed on the basis of the results of the Kano model. Cost is the most important characteristic to meet the user's expectations. Sensor Quality is the next important criteria whereas weight is the least important criteria. The absolute results prioritise the technical requirement for improving the process of ergonomic design. Thus, interrelationship was established showing the connection between 'What' and 'How'. All these values were used to frame the House of Ergonomics Deployment (HED) as shown in *Appendix III*.

TABLE 5.1 FUZZY KANO CATEGORY AND FUZZY KANO RANKING OF ATTRIBUTES

Attribute acronym	Numbers of attribute 'A'	Numbers of attribute 'O'	Numbers of attribute 'M'	Numbers of attribute 'I'	Σ = (O+A+I+M)	Raw user importance (RUI) = 0.5*M +1*O +1.5*A	User importance (i) = (Normalised RUI, range [1,5])	CS= (O+A) / (O+A+I+M)	CD= (O+M) / (O+A+I+M)	Fuzzy Kano category	k value for FK category	User satisfaction (u)	User satisfaction target (t)	AF (f)= max (CD,CS)	Improvement ratio (R_o)	Adj. improvement ratio (R_1)	Adjusted importance (j)	Fuzzy Kano ranking (FKR)
AB	**47**	18	23	12	100	**100.0**	**5.00**	0.65	0.41	**A**	1.5	2.62	4.22	0.65	1.61	3.41	**17.07**	**2**
BA	**32**	11	25	19	87	71.50	1.96	0.49	0.41	**A**	1.5	1.25	3.36	0.49	2.69	4.91	9.62	7
FD	**38**	12	10	34	94	74.00	2.23	0.53	0.23	**A**	1.5	1.03	2.37	0.53	2.30	4.36	9.73	6
HT	31	19	**36**	13	99	83.50	3.24	0.51	0.56	**M**	0.5	2.69	2.43	0.56	0.90	1.13	3.65	16
SB	20	20	**25**	22	87	**62.50**	**1.00**	0.46	0.52	**M**	0.5	2.28	1.87	0.52	0.82	1.01	1.01	20
GN	**40**	17	29	14	100	91.50	4.09	0.57	0.46	**A**	1.5	2.64	3.57	0.57	1.35	2.66	10.88	4
SH	**31**	18	23	27	99	76.00	2.44	0.49	0.41	**A**	1.5	1.83	2.95	0.49	1.61	2.95	7.19	10
RF	26	24	**37**	12	99	81.50	3.03	0.51	0.62	**M**	0.5	2.51	3.13	0.62	1.25	1.59	4.80	13
AS	**36**	12	26	26	100	79.00	2.76	0.48	0.38	**A**	1.5	2.21	3.55	0.48	1.61	2.89	7.98	9
CI	15	21	**40**	21	97	63.50	1.11	0.37	0.63	**M**	0.5	2.54	2.40	0.63	0.94	1.21	1.34	19
DC	20	28	**49**	3	100	82.50	3.13	0.48	0.77	**M**	0.5	3.38	3.68	0.77	1.09	1.45	4.53	15
FS	27	17	**32**	22	98	73.50	2.17	0.45	0.50	**M**	0.5	2.70	2.47	0.50	0.91	1.12	2.43	18
BT	25	28	**37**	10	100	84.00	3.29	0.53	0.65	**M**	0.5	3.39	2.42	0.65	0.71	0.92	3.02	17
SA	35	**35**	21	9	100	98.00	4.79	0.70	0.56	**O**	1.0	2.84	3.48	0.70	1.23	2.08	9.98	5
AC	**37**	18	17	28	100	82.00	3.08	0.55	0.35	**A**	1.5	2.32	3.72	0.55	1.60	3.09	9.53	8
AT	**53**	10	16	17	96	97.50	4.73	0.66	0.27	**A**	1.5	1.92	4.45	0.66	2.32	4.94	**23.37**	**1**
SD	27	28	**38**	6	99	87.50	3.67	0.56	0.67	**M**	0.5	2.96	3.25	0.67	1.10	1.42	5.20	11
VD	21	32	**38**	9	100	82.50	3.13	0.53	0.70	**M**	0.5	2.77	3.28	0.70	1.18	1.54	4.83	12
EC	19	**37**	30	14	100	80.50	2.92	0.56	0.67	**O**	1.0	3.13	3.03	0.67	0.97	1.62	4.72	14
GP	**37**	23	21	18	99	89.00	3.83	0.61	0.44	**A**	1.5	2.50	4.35	0.61	1.74	3.54	**13.56**	**3**

HED brought out the unstated needs and desires of the consumers concerning safety and comfort features of a car in terms of various categories. The 9 attributes of the Attractive category excites consumers more and hence their ranking is higher (1^{st} to 10^{th} rank except for 5^{th}). The 9 attributes of the Must-be category are basic needs and hence their ranking is lower (11^{th} to 20^{th} rank except for 14^{th}). The 2 attributes of One-dimensional category are the performance needs and have an intermediate ranking (5^{th} and 14^{th} rank). The priorities calculated in HED indicted that automatic transmission (no clutch and gear lever) [AT] is the most preferred attribute; efficient airbags (front, side and curtain) [AB] comes at 2^{nd} priority and glare prevention glass and mirrors [GP] occupy the 3^{rd} place.

5. 2 Comparing priority of attributes using FAHP

In this research, AHP was used for multi-criteria decision-making to compare the ranks of all 20 attributes. Since, the number of attributes were 20, so the number of pair-wise comparisons would be 190 (=19×20/2). It is not possible for any decision maker to make 190 comparisons and that too consistently. Hence, instead of pair-wise comparison, matrix of ratios of weights of attributes was used in AHP.

The weights used in weight matrix were Triangular Fuzzy Number (TFN), where *l = least value, m = mean value and u = upper value* of Direct Attribute user Importance (DAI) for each attribute as obtained from survey (in response to part (d) of the questionnaire). This is shown in *Appendix II.*

Using equation 15,

$$\textit{Crisp (defuzzified) value of weights, } w_j = \left\{ \frac{l_j + (4 \times m_j) + u_j}{6} \right\}$$

Once, the aggregate and defuzzified judgment of all the respondents was obtained, the matrix of ratios of weights of attributes *W* was calculated. The crisp (defuzzified) value of weights and weight matrix used in the FAHP calculation is shown in *Fig. 5.1*.

Attributes	AB	BA	FD	HT	SB	GN	SH	RF	AS	CI	DC	FS	BT	SA	AC	AT	SD	VD	EC	GP
Crisp Values (w_j)	4.15	3.24	2.41	2.45	2.08	3.55	2.97	2.92	3.53	2.43	3.62	2.48	2.61	3.65	3.48	4.13	3.17	3.19	2.85	4.23

1.00	1.28	1.72	1.69	1.99	1.17	1.40	1.42	1.17	1.70	1.15	1.67	1.59	1.14	1.19	1.00	1.31	1.30	1.45	0.98
0.78	1.00	1.34	1.32	1.56	0.91	1.09	1.11	0.92	1.33	0.90	1.31	1.24	0.89	0.93	0.78	1.02	1.02	1.14	0.77
0.58	0.74	1.00	0.98	1.16	0.68	0.81	0.83	0.68	0.99	0.67	0.97	0.92	0.66	0.69	0.58	0.76	0.76	0.85	0.57
0.59	0.76	1.02	1.00	1.18	0.69	0.83	0.84	0.69	1.01	0.68	0.99	0.94	0.67	0.71	0.59	0.77	0.77	0.86	0.58
0.50	0.64	0.86	0.85	1.00	0.59	0.70	0.71	0.59	0.85	0.57	0.84	0.80	0.57	0.60	0.50	0.66	0.65	0.73	0.49
0.86	1.09	1.47	1.45	1.71	1.00	1.20	1.21	1.00	1.46	0.98	1.43	1.36	0.97	1.02	0.86	1.12	1.11	1.24	0.84
0.72	0.92	1.23	1.21	1.43	0.84	1.00	1.02	0.84	1.22	0.82	1.20	1.14	0.81	0.85	0.72	0.94	0.93	1.04	0.70
0.70	0.90	1.21	1.19	1.40	0.82	0.98	1.00	0.83	1.20	0.81	1.18	1.12	0.80	0.84	0.71	0.92	0.92	1.02	0.69
0.85	1.09	1.46	1.44	1.70	1.00	1.19	1.21	1.00	1.45	0.98	1.42	1.35	0.97	1.02	0.85	1.12	1.11	1.24	0.83
0.59	0.75	1.01	0.99	1.17	0.69	0.82	0.83	0.69	1.00	0.67	0.98	0.93	0.67	0.70	0.59	0.77	0.76	0.85	0.57
0.87	1.12	1.50	1.48	1.74	1.02	1.22	1.24	1.02	1.49	1.00	1.46	1.39	0.99	1.04	0.88	1.14	1.14	1.27	0.86
0.60	0.77	1.03	1.01	1.19	0.70	0.84	0.85	0.70	1.02	0.69	1.00	0.95	0.68	0.71	0.60	0.78	0.78	0.87	0.59
0.63	0.81	1.08	1.07	1.26	0.74	0.88	0.90	0.74	1.07	0.72	1.05	1.00	0.72	0.75	0.63	0.83	0.82	0.92	0.62
0.88	1.13	1.51	1.49	1.76	1.03	1.23	1.25	1.03	1.50	1.01	1.47	1.40	1.00	1.05	0.88	1.15	1.15	1.28	0.86
0.84	1.07	1.44	1.42	1.67	0.98	1.17	1.19	0.98	1.43	0.96	1.40	1.33	0.95	1.00	0.84	1.10	1.09	1.22	0.82
1.00	1.28	1.71	1.68	1.99	1.17	1.39	1.42	1.17	1.70	1.14	1.67	1.58	1.13	1.19	1.00	1.31	1.30	1.45	0.98
0.76	0.98	1.31	1.29	1.52	0.89	1.07	1.08	0.90	1.30	0.87	1.28	1.21	0.87	0.91	0.77	1.00	0.99	1.11	0.75
0.77	0.98	1.32	1.30	1.53	0.90	1.07	1.09	0.90	1.31	0.88	1.29	1.22	0.87	0.92	0.77	1.01	1.00	1.12	0.75
0.69	0.88	1.18	1.16	1.37	0.80	0.96	0.98	0.81	1.17	0.79	1.15	1.09	0.78	0.82	0.69	0.90	0.90	1.00	0.67
1.02	1.31	1.75	1.73	2.04	1.19	1.43	1.45	1.20	1.74	1.17	1.71	1.62	1.16	1.22	1.02	1.34	1.33	1.48	1.00

Fig. 5.1 Crisp (defuzzified) value of weights and weight matrix of attributes used in Fuzzy AHP

$$\textit{Principal eigen-value } (\lambda_{max}) = n = 20,$$

$$\textit{Consistency Index } (CI) = (\lambda_{max} - n) / (n - 1) = 0$$

Random Index (*RI*) is the average value of *CI* and its value depends on the number of criteria or attributes (*n*) being compared.

The values of RI for $n > 15$ were proposed by Alonso and Lamata (2006).

For (n = 20), the value of RI = 1.6341.

Consistency of judgment calculated using Consistency Ratio (CR) = CI / RI = 0;

A matrix is considered to be consistent enough only if CR = CI / RI < 0.10.

In this research, $CR = 0$, indicates absolute consistency. This is because the matrix used for AHP calculation was represented as ratio of the weights of the alternatives (*W*), and so it was absolutely consistent with $A = W$.

In this case: $a_{ij} \times a_{jk} = a_{ik}$ *(for all i, j, k)*

Using the normalized eigenvectors obtained for the attributes from FAHP calculation, the ranking of the attributes was made. Glare Prevention glass and mirror [GP] comes to be the most preferred attribute followed by efficient Air Bags (front, side and curtain) [AB] and Automatic Transmission (no clutch and gear lever) [AT]. This ranking was different from that obtained from HED. The FAHP result and comparison with fuzzy Kano rank are shown in *Table 5.2*.

TABLE 5.2 FAHP RESULT AND RANK COMPARISION WITH FUZZY KANO RANKS (HED RANKS)

FAHP Result		Rank comparison	
Attribute acronym	**Normalized eigen vector**	**FAHP**	**Kano (HED)**
AB	0.065660	**2**	**2**
BA	0.051304	9	7
FD	0.038215	19	6
HT	0.038847	17	16
SB	0.032935	20	20
GN	0.056159	6	4
SH	0.046975	12	10
RF	0.046237	13	13
AS	0.055948	7	9
CI	0.038530	18	19
DC	0.057321	5	15
FS	0.039270	16	18
BT	0.041381	15	17
SA	0.057849	4	5
AC	0.055104	8	8
AT	0.065449	**3**	**1**
SD	0.050142	11	11
VD	0.050459	10	12
EC	0.045181	14	14
GP	0.067033	**1**	**3**

λ_{max} =	20.000000009552
n (no. of attributes)=	20.000000000000
CI = (λ_{max} - n)/(n-1) =	0.000000000503
RI (for n = 20) =	1.634100000000
CR = CI / RI =	0.000000000308

Chapter: 6.
Formulation of the Mathematical Model using Fuzzy Approach

For a particular brand and variant of a car, each of the three ergonomic factors gets the Factor Score (FS) in % on the scale of 1 to 100, which forms the input for the model. These inputs are fuzzified using fuzzy rule based models for function approximation.

For this research purpose, Mamdani FIS has been used because it is well suited to human inputs and has wide spread acceptance. These inputs or scores are fuzzified and defuzzified using Mamdani FIS and a crisp output was obtained. This output is the final ergonomic score of the car.

6. 1 Calculation of attribute eigen value, sub-classification within each attribute and factor eigen value.

The House of Ergonomics Deployment (HED) gave the adjusted importance value of all the attributes which forms the basis for prioritising the attributes. The Attribute Eigen Value (AEV) for each attributes is calculated by normalizing the adjusted importance value in the range [0 , 1].

The twenty ergonomic attributes were further classified into subcategories based on the discussions with the car dealers, analyzing the latest trend, literature reviews and interviews and survey with the car users. The sub classification forms the guidelines for finding ergonomic score of attribute. Presence of each sub classified feature yields 1 mark up to a maximum of 5 marks which indicates complete fulfillment of that attribute by that model of car. Complete absence of the feature yields 0 marks. So, Ergonomic Score of Attribute (ESA) can take only whole numbers values in the range [0 , 5].

The product of Attribute Eigen Value (AEV) and Ergonomic Score of Attribute (ESA) gives Attribute Score (AS) *(eqn 16)*.

The 20 attributes were grouped into three main ergonomic categories or factors, based on the cause and effect of the attributes. The factors are:

- Overall Safety Factor (8 attributes)
- Musculoskeletal/ Reach Factor (6 attributes)
- Compatible Man Machine Interface/ Comfort Factor (6 attributes)

The sum of the attribute score for each of the three factors is found out. Similarly, the sum of the attribute eigen values for each of the three factors is found out. Then the Factor score (FS) in % is calculated for all three factors *(eqn 17)*.

The ranking of attributes, their eigen value and factor eigen values are shown in *Table 6.1*.

The sub classification for each attribute, which forms the basis for finding ergonomic score of attribute, is shown in *Table 6.2*.

The generalized data sheet for calculating the three FS (in %) is shown at *Appendix IV*.

TABLE 6.1 RANKING OF ATTRIBUTES AND EIGEN VALUES

Attribute number	Attribute	Kano category	Adjusted importance	Attribute Eigen Value (AEV) #	Attribute ranking	Factor name	Factor Eigen Value (FEV) $
1	Efficient Air Bags (front, side and curtain) [AB]	A	17.07	0.111	2	*Overall Safety Factor*	**0.415**
2	Brake Assist with automatic emergency brake [BA]	A	9.62	0.062	7		
3	Fatigue Detection sensor [FD]	A	9.73	0.063	6		
4	Hilly Terrain driving support [HT]	M	3.65	0.024	16		
5	Faster retractable Seat Belts [SB]	M	1.01	0.007	20		
6	GPS Navigation and assistance [GN]	A	10.88	0.070	4		
7	Sensor for Head light intensity and auto dimmer [SH]	A	7.19	0.047	10		
8	Rain sensing wipers and Fog lights [RF]	M	4.80	0.031	13		
9	Two-axis Adjustable power Steering [AS]	A	7.98	0.052	9	*Musculoskeletal/ Reach Factor*	**0.191**
10	Camera for motion in reverse gear and side and back clearance Indicators [CI]	M	1.34	0.009	19		
11	Door locking sensors and Control of doors and child lock near driver [DC]	M	4.53	0.029	15		
12	Frequently used controls on Steering [FS]	M	2.43	0.016	18		
13	Effortless engine Bonnet, fuel tank and Trunk (dickey) operations [BT]	M	3.02	0.020	17		
14	Compatible driver Seat with three-axis Adjustments and comfortable passenger seats [SA]	O	9.98	0.065	5		
15	A.C. air circulation, cooling efficiency and humidity control [AC]	A	9.53	0.062	8	*Compatible Man Machine Interface/ Comfort Factor*	**0.397**
16	Automatic Transmission (no clutch and gear lever) [AT]	A	23.37	0.151	1		
17	Sufficient head, knee and leg space for Driver and passengers [SD]	M	5.20	0.034	11		
18	Effective shock absorbers and Vibration Damping [VD]	M	4.83	0.031	12		
19	Efficient sound proofing system and blue tooth Compatibility for phone and audio streaming [EC]	O	4.72	0.031	14		
20	Glare Prevention glass and mirror [GP]	A	13.56	0.088	3		

 # Σ (AEV) = 1 and $ Σ (FEV) = 1.

TABLE 6.2 SUB-CLASSIFICATION FOR EACH OF THE TWENTY ATTRIBUTES

Attribute	Factor name	Sub classification of each of twenty attributes. (Guidelines for finding ergonomic score of attribute)
AB	*Overall Safety Factor*	Driver airbag, Front passenger airbag, Dual stage airbags, Side airbag, Curtain airbag
BA		Anti-Lock Braking System, Electronic Stability Program, Electronic Brake-force Distribution, Brake Assist, Radar sensors
FD		FD using time or distance driven, FD using path traversed, FD using camera of cell phone, FD using fixed camera, FD using combination of response (full score)
HT		Four Wheel drive, Traction control System, Hill decent control, Limited slip differential, Cruise control
SB		Rear three-point seatbelt, Child Seat Anchor Points, Seat Belt Warning, Pretensioners on front seats, Electronically controlled Faster retractable seatbelt
GN		Route guidance, Shortest route, Real time traffic info, Fastest route, Memorize destinatn
SH		Headlight off reminder, Sensor for head light intensity, Auto dimmer, Adjustable Cluster Brightness, Projector type and Cornering head lights
RF		Rain-sensing wipers, All time Running Lights, Fog Lamps Front and Back, Rear Wiper, Defogger
AS	*Musculoskeletal / Reach Factor*	Leather wrapped soft grip, Power steering, Tilt adjustment, Telescopic adjustment, Steering collapsible in emergency
CI		Parking Assistance, Camera on reverse motion, Rear Clearance Sensors, Side Clearance Sensors, Voice warnings.
DC		Remote Central Locking, Child Safety Lock, Door locking sensors, Door Ajar Warning, Engine immobilizer
FS		Music control, Cell phone control, AC controls, Light control, GPS Navigation control
BT		Press button opening of bonnet, Pneumatic lift of bonnet, Press button opening of trunk, Pneumatic lift of trunk, Press button operation of fuel tank
SA		Driver seat with two-axis adjustments, Driver seat with third-axis adjustments, Electrically Adjustable Head-rests on all seats, Rear Passenger individual Adjustable seats with Lumbar Support, Ventilated Seats
AC	*Compatible Man Machine Interface/ Comfort Factor*	AC with Automatic Climate Control, Cooling within 2 minutes, Humidity control, Rear AC, Differential A.C. air circulation and temperature difference up to 2^0 Celsius.
AT		Smooth automatic transmission (score based on efficiency)
SD		Comes out of car without bending head (for a person of height 185 cm), Clearance between knees and steering when seat is at extreme back (for a person of height 185 cm), Clearance between knees and steering when seat is at extreme front (for a person of height 155 cm), Sufficient leg space for all passengers.
VD		Efficient Vibration Damping (score based on efficiency)
EC		Sound proofing of external noise, Integrated music system, Display screen for rear passengers, Bluetooth compatibility for phone, BT compatibility for audio streaming
GP		Night glare prevention glass, Anti-glare internal mirrors, Anti-glare rear view mirrors, Electrically adjustable rear view mirrors, Retractable rear view mirrors

6. 2 *Model for ergonomic compatibility of car using Fuzzy Inference Systems (FIS)*

The three factor score forms the input for the model. One of the key elements of the model is the designing of fuzzy inference system. For designing the model using Mamdani FIS, various features were decided, which are detailed as under:

Membership function (MF): Mamdani FIS uses membership functions for both input and output data. Membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. It is a function that specifies the degree to which a given input belongs to a set or is related to a concept. The input space is referred to as the universe of discourse. The features of membership function affect the relations between input and output variables, and hence needs to be selected carefully. For designing of Mamdani FIS, various features of input and output Membership functions (MFs) which were to be decided were:

- Type of MFs: Triangular, Gaussian or any other,
- Number of MFs for each of 3 input data and the output data,
- Amount of the overlap between the MFs, and
- Standard deviations, in case Gaussian MFs are used.

Type of MFs: For the three inputs which are ergonomic categories or factors, (safety, reach and comfort); continuous, symmetrical and convex MFs have been used. Since input was from human interaction and survey, the rules of statistics were inbuilt. Guassian functions are the closest representation of human responses and all the human responses generally follow normal distribution. Moreover, Gaussian functions are smooth, non zero at all points, have concise notation, and so Gaussian MFs were the obvious choice for representing the input fuzzy sets.

For output function, both Gaussian and Triangular MF were tried, but there was no marked difference in result. But the advantage of Gaussian MF is that it is smooth and nonzero at all points. For the sake of uniformity, Gaussian MF was used for both input and output MF. In a fuzzy environment, any complex function does not improve precision. The two parameters on which a symmetric Gaussian function depends are standard deviation *(σ)* and centre or mean *(c)*, and is defined as:

$$f\ (x;\sigma,c) = \ e^{-\frac{(x-c)^2}{2\sigma^2}} \tag{18}$$

Number of MFs: When deciding about the number of MF within the input space (universe of discourse), it was found that less number of MFs fails to provide sufficient output response from a small input change and the system response becomes slow, whereas, too many MFs leads to the use of different rule consequents for small changes in input, which results in large changes in output. Since input was human response and three categories of each input can easily be perceived, so three number of input MF were used. For output, five numbers of MF were used for finer distribution and proper overlap in the model.

Amount of the overlap: The membership functions should be overlapped. The basic principle of overlap is that every point in input space should relate to at least one but at most two MFs. The point of maximum truth of MFs should be different. For any point within the overlap, the summation of truths should be less than or equal to 1.

The point of maximal truth of either MF should not be crossed during overlap. Each membership function should overlap only with the closest neighboring membership functions. For obtaining monotonous and continuous input-output relation, the input membership functions should be symmetrically and completely overlapped by the neighbouring membership functions, whereas the output MFs should be distributed over the entire range of output space.

Standard deviations: To ensure that each MF overlap only with the closest neighboring MF, standard deviation *(σ)* of input MF was taken as *16.66* (so that $3\sigma = 50$) for each of two half and one complete MFs, and standard deviation of output MF was taken as *8.33* (so that $3\sigma = 25$), for each of two half and three complete MFs.

The salient features of the MFs used in the Mamdani FIS model for the three input factors (or variable) and the output variable are summarized in the *Table 6.3*.

TABLE 6.3 SALIENT FEATURES OF THE MF'S OF THE VARIABLES

Variable (Input /Output)	Membership Function			
	Number	**Name**	**Type & SD (σ)**	**Mean**
Input variable: Overall Safety Factor	3	1. Poor 2. Good 3. Excellent	Gaussian (σ = 16.66)	1. 0 2. 50 3. 100
Input variable: Musculoskeletal/ Reach Factor	3	1. Stressful 2. Moderate 3. Easy	Gaussian (σ = 16.66)	1. 0 2. 50 3. 100
Input variable: Compatible Man Machine Interface/ Comfort Factor	3	1. Lo 2. Med 3. Hi	Gaussian (σ = 16.66)	1. 0 2. 50 3. 100
Output variable: Ergonomic Compatibility (using Mamdani FIS)	5	1. Poor 2. Bad 3. Average 4. Good 5. Excellent	Gaussian (σ = 8.33)	1. 0 2. 25 3. 50 4. 75 5. 100

For designing Mamdani FIS other important features to be decided were:

- Rules
- Defuzzification

Rules: There are three input variables i.e. ergonomic factors: Overall Safety factor, Musculoskeletal/ Reach factor and Compatible Man-Machine Interface/ Comfort factor. Each input variable has three membership functions associated with it. Hence, twenty seven rules *(3×3×3)* have been framed which forms the rule base. Corresponding to each rule, an output MF has been defined. Some examples of rules are shown below:

- If Safety is *Poor (1)* and Reach is *Easy (3)* and Comfort is *High (3)* then Ergonomic Compatibility is *Good (4)*.
- If Safety is *Good (2)* and Reach is *Easy (3)* and Comfort is *Low (1)* then Ergonomic Compatibility is *Average (3)*.

- If Safety is *Excellent (3)* and Reach is *Moderate (2)* and Comfort is *Medium (2)* then Ergonomic Compatibility is *Good (4)*.

The complete rule base is shown in *Table 6.4*.

TABLE 6.4 RULE BASE FOR MAMDANI FIS

If Safety is	and Reach is	and Comfort is	then Ergonomic Compatibility is
Poor (1)	Stressful (1)	Low (1)	Poor (1)
Poor (1)	Stressful (1)	Medium (2)	Poor (1)
Poor (1)	Stressful (1)	High (3)	Bad (2)
Poor (1)	Moderate (2)	Low (1)	Poor (1)
Poor (1)	Moderate (2)	Medium (2)	Bad (2)
Poor (1)	Moderate (2)	High (3)	Average (3)
Poor (1)	Easy (3)	Low (1)	Bad (2)
Poor (1)	Easy (3)	Medium (2)	Average (3)
Poor (1)	Easy (3)	High (3)	Good (4)
Good (2)	Stressful (1)	Low (1)	Poor (1)
Good (2)	Stressful (1)	Medium (2)	Bad (2)
Good (2)	Stressful (1)	High (3)	Average (3)
Good (2)	Moderate (2)	Low (1)	Bad (2)
Good (2)	Moderate (2)	Medium (2)	Average (3)
Good (2)	Moderate (2)	High (3)	Good (4)
Good (2)	Easy (3)	Low (1)	Average (3)
Good (2)	Easy (3)	Medium (2)	Good (4)
Good (2)	Easy (3)	High (3)	Excellent (5)
Excellent (3)	Stressful (1)	Low (1)	Bad (2)
Excellent (3)	Stressful (1)	Medium (2)	Average (3)
Excellent (3)	Stressful (1)	High (3)	Good (4)
Excellent (3)	Moderate (2)	Low (1)	Average (3)
Excellent (3)	Moderate (2)	Medium (2)	Good (4)
Excellent (3)	Moderate (2)	High (3)	Excellent (5)
Excellent (3)	Easy (3)	Low (1)	Good (4)
Excellent (3)	Easy (3)	Medium (2)	Excellent (5)
Excellent (3)	Easy (3)	High (3)	Excellent (5)

Defuzzification: After the aggregation of the three inputs viz., safety, reach and comfort, there is a fuzzy set for each output variable, which is to be defuzzified.

The defuzzification in this research is done using center of gravity (CoG) method or centroid method, because it is physically appealing and the most commonly used method. The aggregation operator is used to combine the fuzzy sets obtained as consequent of each rule. Defuzzification of the resulting fuzzy set gives the output of the system.

6. 3 Ergonomic index of a car using Mamdani Fuzzy Inference systems (FIS)

The Ergonomic index of a car is the ergonomic score of a car for various combinations of factor scores. This value can be found out from the Mamdani FIS model using the MATLAB software (Fuzzy Logic Toolbox). The computer program in MATLAB for the mathematical model for determining the ergonomic compatibility (index) of a car is shown at *Appendix V.*

A look-up table of ergonomic index based on the above model, for input variables at an interval of 10, has also been framed. This table gives the approximate value of ergonomic index of a car, when all the factor score are ascertained. The look-up table is shown at *Appendix VI.*

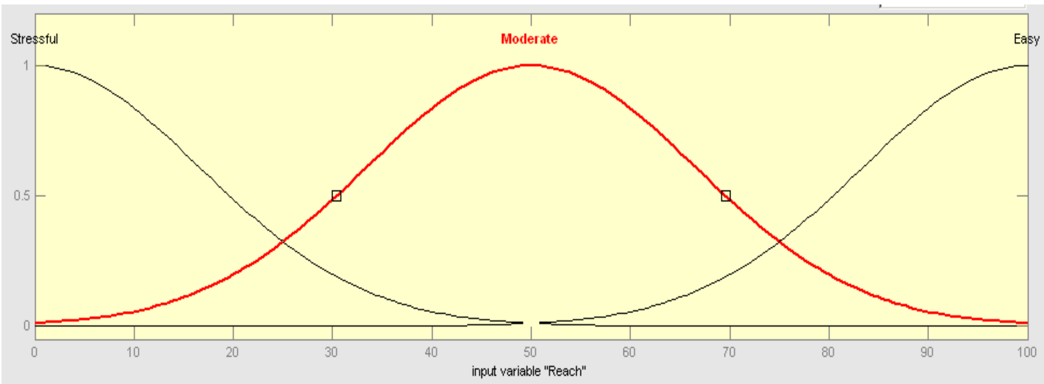
The plots of the membership functions of the three input factors (or variable) and output variable used in the Mamdani FIS model generated through MATLAB software are shown in *Fig. 6.1*.

In this Mamdani FIS model, if we substitute the values all three inputs variables (safety, reach and comfort) as 50, then the output variable (Ergonomic compatibility) also equals 50. The plot of the rule views and defuzzification, for this particular case, generated through MATLAB software, is shown in *Fig. 6.2*.

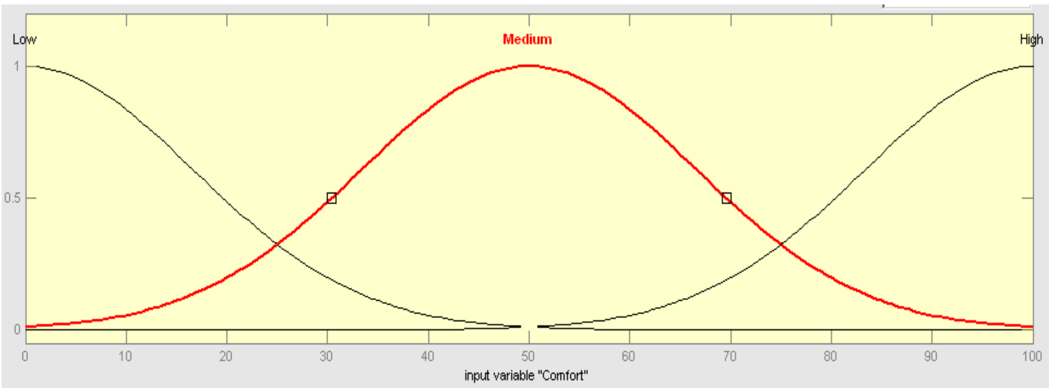
6. 4 Surface Views from Mamdani Fuzzy Inference systems (FIS)

There are three input variables and an output variable. Four dimensional spaces cannot be plotted on a plane sheet of paper. Surface showing the variation of ergonomic compatibility of car while varying any two input variables and holding the third input variable constant can be shown in the surface views. Surface views generated through MATLAB software are shown in *Fig. 6.3*.

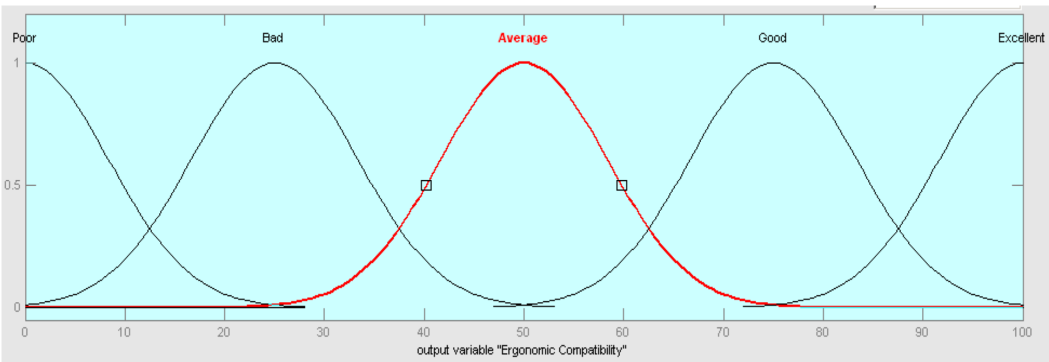
Input Variable 1: Overall Safety Factor



Input Variable 2: Musculoskeletal/ Reach Factor



Input Variable 3: Compatible Man Machine Interface/ Comfort Factor



Output Variable: Ergonomic Compatibility of a car

Fig. 6.1 Input and output Membership Functions.

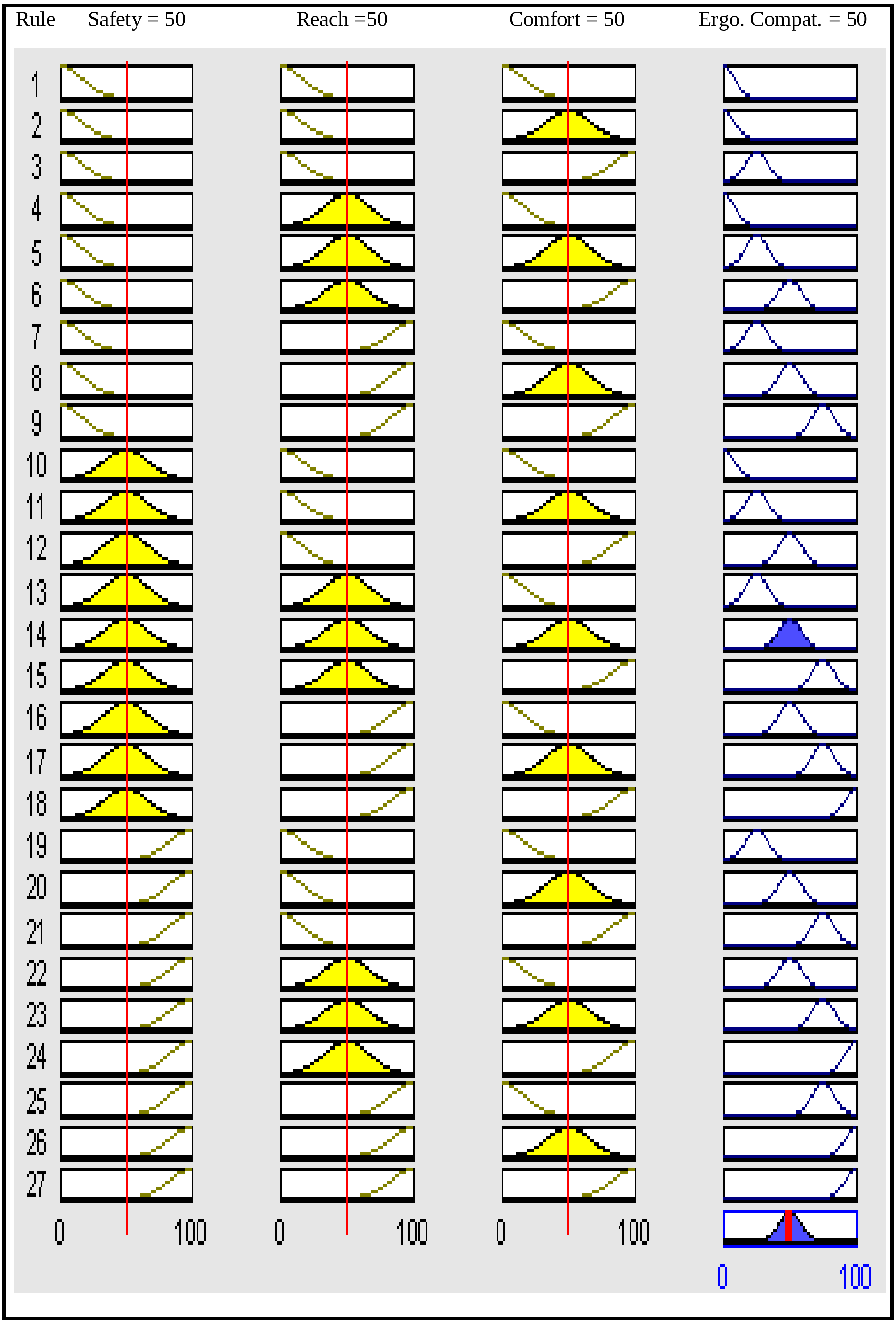
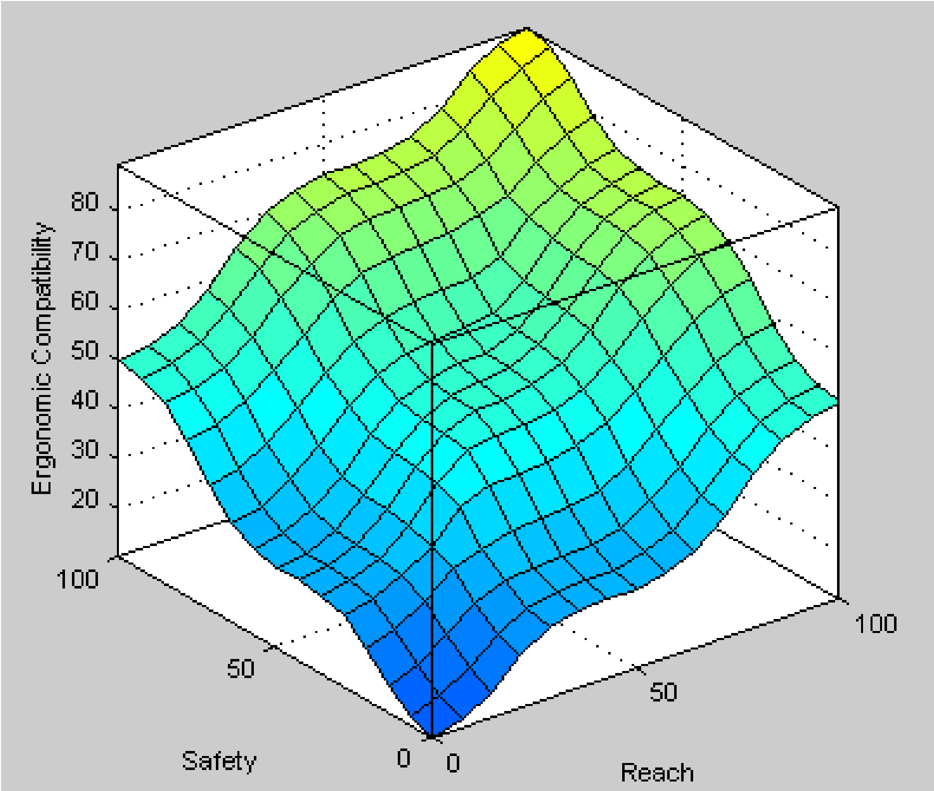
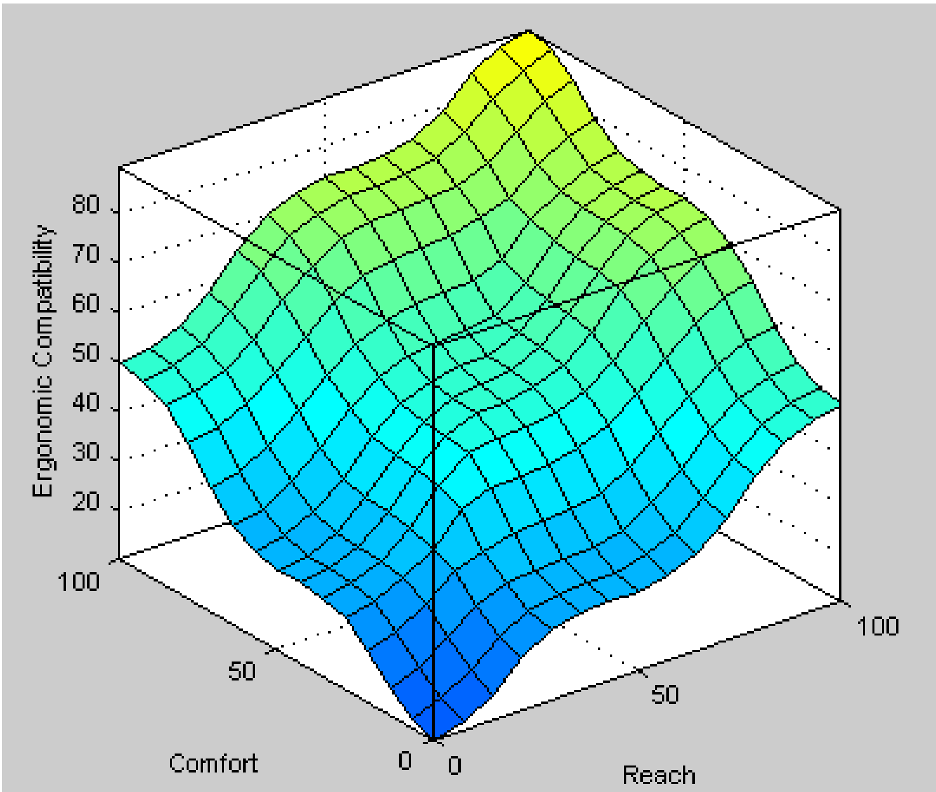


Fig. 6.2 Rule views and defuzzification from Mamdani FIS.



Comfort value fixed at 50



Safety value fixed at 50

Fig. 6.3 Surface views from Mamdani FIS.

Chapter: 7.
Results and Discussions

7. 1 Discussions on the new framework: House of Ergonomics Deployment

Innovation always leads to a competitive advantage in the long term. Technological advancements have surpassed the limits of our expectations of what can be integrated into cars. Research in the field of automobile engineering is going to revolutionize the cars.

This research was aimed to identify various stated and unstated needs of the ergonomic features of the car. From extensive market survey and literature reviews, ergonomic needs of the users were identified and were classified into 20 ergonomic attributes, which were grouped into three main ergonomic factors, i.e. Musculoskeletal/ Reach factor, Compatible Man-Machine Interface/ Comfort factor and Overall Safety factor. The consumer preferences about these attributes were captured from fuzzy Kano survey and the priorities were calculated in HED. This model (HED) brought out the unstated needs and desires of the consumers concerning various features of a car.

From HED, Automatic Transmission with no clutch and gear lever [AT] comes out to be the most preferred attribute. This is an *attractive* feature from Compatible Man-Machine Interface factors. Many drivers find it difficult to change gear frequently while driving in busy traffic and it is a significant concern for Indian drivers when there is traffic congestion.

Efficient Air Bags [AB] comes at 2nd priority as it is a significant safety priority for consumers. This is also an *attractive* feature from Overall Safety factors. With the increasing number of high-speed vehicles and overcrowded roads, the numbers of accidents with tragic outcomes are rising and hence efficient air bags are becoming a necessity.

Glare Prevention glass and mirror [GP] occupies the 3rd place. This is also an *attractive* feature from Compatible Man Machine Interface factors. Glare causes maximum discomfort during night driving and causes many accidents. These three features have a very high value for CS indicating that these attributes will strongly aid in enhancing the customer satisfaction.

These features are not available in most low-cost sedans available to buyers in India. Car manufacturers and automobile designers should specifically work on these features to make them available at competitive prices. These features also have a very high value for CS indicating that they will strongly aid in enhancing customer satisfaction, in addition to safety.

Absolute Importance (AI) indicates how the ergonomically compatible car can be developed on the basis of the result of Kano model. Cost is the most important characteristic to meet the user's expectations. Sensor Quality is the next important criteria whereas weight is the least important criteria. These absolute results prioritise the technical requirement for improving the ergonomic design process.

The priorities were compared with the priorities obtained from FAHP. These rankings obtained from the two methods were not exactly similar. Out of the 20 attributes, 2 attributes namely (i) Fatigue Detection sensor [FD] and (ii) Door locking sensors and Control of doors and child lock near driver [DC], show large variation in ranking but 18 attributes does not show large differences in ranking (±2 ranks).

The reason for the large variation in rankings was due to the familiarity of the attributes in the mind of the respondents. Since the respondents were very much familiar with [DC] they gave it a higher rank but they were not aware of the utility of [FD] and so they gave it a lower rank in AHP method which used direct user attribute importance (DAI). The ranking of these two attributes was reversed in HED which used the Fuzzy Kano method. The reason is that the Kano category of [FD] is *Attractive* whereas that of [DC] is *Must-be*.

The HED method tries to bring out the unstated needs and desires of the consumers in terms of *Attractive* category. The 9 attributes of *Attractive* category excites the consumers more and hence ranking is higher (1^{st} to 10^{th} rank except 5^{th}). The 9 attributes of *Must-be* category are the basic needs and hence ranking is lower

(11^{th} to 20^{th} rank except 14^{th}). The 2 attributes of *One-dimensional* category are the performance needs and have intermediate ranking (5^{th} and 14^{th} rank).

The small difference (±2) in the ranks of 18 other attributes as obtained from the two methods, was because of the inherent difference in the procedure adopted in these methods. In the FAHP method, we have used the direct user attribute importance (DAI) as indicated by all the users in response to the part (D) of the questionnaire. In HED, the ranks were obtained after ascertaining Kano category, finding user satisfaction, satisfaction target, checking CS, CD values, calculation of adjustment improvement ratio and finally calculating the adjusted importance value. Hence the ranking obtained from HED is considered to be more realistic in terms of actual priorities of the consumers for the ergonomic attributes. Moreover, in this research, the number of attributes was large (20) and all respondents were not well aware of all of the features, so the priorities obtained by Fuzzy Kano survey is a better method for prioritising the ergonomic attributes.

7. 2 Limitations of the House of Ergonomics Deployment framework

The results obtained above are based on a sample size of 100 respondents, all from urban cities of India and hence may be more suitable in the Indian car market. Human judgment in the form of responses of the respondent had a pivotal role in making these decisions and prioritising the attributes. Consequently, it is hard to assure that these priorities are consistent and free from bias. A bigger sample covering respondents from all sections of society and from various metro towns would portray a broader view and may reveal a more accurate ranking of attributes.

7. 3 Discussions on the results of fuzzy model based on Mamdani FIS

Based on the attributes present in any brand of a car, the attribute score and factor scores have been derived. Since the factor scores were derived from the human response so they were considered to be fuzzy. The fuzzy approach has been used because a fuzzy rule-base model is reasonably precise in drawing inferences.

The ergonomic index of a car is the ergonomic score of a car for various combinations of factor scores. This value was found from the Mamdani FIS model.

In the Mamdani FIS model, it was necessary to have input MFs to be completely and symmetrically overlapped by neighboring MFs, and distribute output MFs over the whole range of output space, in order to produce input-output relation with desirable continuity and monotonicity.

7. 4 Limitations of fuzzy model based on Mamdani FIS

The inputs to the model were human response for the ergonomic factors. These inputs could not be considered precise and were considered fuzzy. A variable is fuzzy, if there is uncertainty due to imprecision, indistinctness or similar reasons. The fuzzy sets can model uncertain or ambiguous real life data. The fuzzy logic based models are the closest approximation of human thinking. But such models have some limitations which is the inherent features of all FIS models.

With the increase in the numbers of fuzzy set in input variables, better controllability of input-output surface is achieved but this creates extra degree of freedom which needs more time to integrate output membership functions and this impairs the smoothness of input-output surface.

When all the inputs are situated around the centre of input scale, or located to different ends, the 'Intermediate' MF of input with greater area will have the decisive role. If the input values are changed slightly, the output MFs will be affected simultaneously, but there will be no substantial change in the geometric centre of aggregated area.

When all the inputs are situated near the centre of input scale, all the output membership functions contributes to the aggregated area. Since the location of the geometric centre depends more on the greater area, hence the rate of change of the output near the middle region is very less when compared to the change of input values. Thus some deformation is expected in the middle region of input-output surface.

Due to the overlap between the output membership functions, the distance between their centers of area tends to decrease. Due to this reason, the centre of area of membership functions does not reach the endpoints of output scale in the Centroid method, and hence the outermost values of input-output surface can never be 0 or 100.

7. 5 Effectiveness of both the models

Even with the limitations and some deformations, both the models, viz:

(i) House of ergonomics deployment, and

(ii) Fuzzy model based on Mamdani FIS

portray the results effectively.

Even though the sample size of the survey used for framing HED was small, the results were very clear and the eigen values of the attributes were sufficiently distinct. Moreover, this framework averts pair-wise comparison and is largely free from bias.

Similarly, the fuzzy mathematical model based on Mamdani FIS for determining the ergonomic compatibility (index) of a car, yields meaningful results and can be a very useful tool for comparing the ergonomic compatibilities of cars.

Chapter: 8.
Conclusions

Ergonomic compatibility has wide implications for selecting a car and an ergonomically well-designed car with a comfortable environment, advanced safety features, state-of-art assistive technologies, easy to reach controls, diminished glare, etc., will aid in safe driving and reduce driver and passenger fatigue. This will help in bringing down the number of accidents and the resulting fatalities.

In present competitive scenario, it is necessary for all car manufacturers and automobile designers to address all the ergonomic factors such as Musculoskeletal/ Reach factor, Compatible Man-Machine Interface/ Comfort factor and Overall Safety factor. Integrated ergonomic car design can be achieved by a design process where the engine-side and the user-side are simultaneously taken care of.

This research provides a novel method for comprehending the varied and vague voice of customers to prioritising the ergonomic attributes of a passenger car and developing an easy to use mathematical model for estimating ergonomic compatibility of passenger cars even with fuzzy human responses. This will give the automobile designers a broad view of the needs and desires of the drivers.

The results of this research can be used by the prospective buyers of a car who can be benefited by comparing the ergonomic score and ergonomic attributes of one model of car with another and satisfy their desire to get better ergonomic features at the least cost. These results can also be used by the manufacturers and automobile designers to stay ahead in the competition by assessing and improving the ergonomic attributes of a car.

The ergonomic attributes identified in this study are significant and all drivers would be benefitted by the enhanced safety feature, better seat design, automatic braking etc. Technological evolution in the design will aid in overcoming the physical limitations of body and age. These features will imbibe confidence in drivers. The Federal government can motivate research for understanding the potential limitations of passenger cars and evolving essential safety and accident mitigation measures. Pilot evaluations of some innovative modification may also be undertaken. The lessons learned may be widely disseminated among automobile designers and manufacturers so that they can apply this knowledge in future models of cars. Federal government may also frame proactive legislation that guides the automobile manufacturers to include some of the most essential modifications in cars that will boost the self-assurance of drivers and aid in ensuring safe and comfortable driving.

8. 1 Strength of the Model

This approach of user-centered model of product design by considering the needs of the users could be very effective method of product design and adapted to many products and services. The strength of this model are:

(i) It avoids bias towards any particular attribute and averts the pair-wise comparison.

(ii) Even though the response of individuals may not be clear or may change with time, but a model based on fuzzy approach can serve the needs of a large section of the society for a longer time.

The methodologies explained in this research can be applied to other products and services as well that present a similar design challenge to designers and manufacturers.

8. 2 Limitations and Future Scope of Research

The research was targeted to find out the ergonomic needs of passengers and driver of a car. The survey was conducted either personally or the questionnaire was sent by email only to the sedan car user within India, hence some of the results may not be applicable globally, due to different climatic, environmental, legal and physical characteristics. Some limitations of this study are that the number of respondents was limited (n = 100) and it could not represent all the anthropometry and limitations in functional capacities that exist in the population. The response was based on the experience of the respondents from driving their own cars, which may be a few years old model. The interventions discussed in this research relate to existing technologies. It was not possible to explore how new technological interventions might be useful in meeting the needs of the users and drivers. This would be an area of further research. The sample surveyed consists of only the fit drivers. Those who have given up driving due to any reason were not surveyed. The sample size was small. Even with these limitations and limited resources, the results portray the priorities very clearly.

The literature survey and the review of technological advancements in the automobile industry indicated some advanced features like self-driving intelligent cars, self-parking enabled car, augmented reality (Head-up) display, lane departure warning, stability and cruise control etc. These features were not considered in this research as they might not be feasible under the present traffic conditions in India. These features could form a part of separate research.

A study incorporating the new technological interventions and a bigger sample size comprising of respondents from other countries can further improve the model.

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Appendix I: Kano-Model Based Survey Questionnaire

Respected Sir/ Madam,

Please find attached herewith a survey form regarding Ergonomic compatibility of a Sedan Car. You are requested to kindly fill it and sent it back to me.

In the survey form, each question has 4 parts – (A), (B), (C) and (D).

In part (A) & (B), you are required to specify your choice, under a given conditions.

In part (A), as a condition, imagine that the desired criterion is existing or adequate and select one of the following responses:

"*1. I am satisfied*
2. It must be that way
3. I am neutral (Indifferent)
4. I can live with it that way
5. I am dissatisfied"

In part (B), as second condition, imagine that the desired criterion is missing or inadequate and again select one of the above answers.

In part (A) and (B), multiple choices in terms of percent liking are also acceptable.

In part (C) of each question, rate your car on each feature on a scale 1 to 5 (1 for minimum or not existing and 5 for maximum or excellent).

In part (D) of each question, rate each feature on a scale 1 to 5 (1 for minimum or not required feature and 5 for most essential feature).

Typical responses for any question may be:

Part No. of Question	Single response	Multiple response
Part A	**2**	**1=30%** **2=70%**
Part B	**4**	**4=40%** **5=60%**
Part C/ D	**4**	**4**

I will be using it personally for my research work. Your responses will not be used commercially and will be anonymous. In case you feel any doubts in filling the form, please feel free to ask me. You can send your responses through email.

A few minutes of your precious time for filling this form will be a great help to me towards my research work.

With warm regards,

Ashish Dutta
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Sedan car user survey for "Ergonomic compatibility"

Name of the respondent:

Age: **years** **Mobile number:**

Make and model of sedan car using:

Category: **(i) Economy class sedan,** **or** **(ii) Luxury class sedan**

For each question:
In part (A) and (B), select any option (or multiple options with percentage) out of the following:

"1. I am satisfied
2. It must be that way
3. I am neutral (Indifferent)
4. I can live with it that way
5. I am dissatisfied"

In part (C), rate your car on that feature on a scale 1 to 5 (1 for minimum or not existing and 5 for maximum or excellent).
In part (D), rate the feature on a scale 1 to 5 (1 for minimum or not required feature and 5 for most essential feature).

1(A) If a car is having efficient air bags of 3 types (front, side and curtain), what is your opinion?

1(B) If a car is not having efficient air bags of 3 types (front, side and curtain), what is your opinion?

1(C) Status of air bags in your car?

1(D) Essentiality of air bags in car

2(A) If a car is having braking assistance with automatic emergency brake (using radar sensors), what is your opinion?

2(B) If a car is not having braking assistance with automatic emergency brake (using radar sensors), what is your opinion?

2(C) Status of braking assistance with emergency brake in your car?

2(D) Essentiality of braking assistance with emergency brake in a car?

3(A) If a car is having fatigue detection sensor, what is your opinion?

3(B) If a car is not having fatigue detection sensor, what is your opinion?

3(C) Status of fatigue detection in your car?

3(D) Essentiality of fatigue detection in a car?

4(A) If a car is having Hilly Terrain driving support, what is your opinion?

4(B) If a car is not having Hilly Terrain driving support, what is your opinion?

4(C) Status of Hilly Terrain driving support in your car?

4(D) Essentiality of Hilly Terrain driving support in a car?

5(A) If a car is having faster retractable seat belts, what is your opinion?

5(B) If a car is not having faster retractable seat belts, what is your opinion?

5(C) Status of seat belts in your car?

5(D) Essentiality of seat belts in a car?

6(A) If a car is having GPS navigation and assistance, what is your opinion?

6(B) If a car is not having GPS navigation and assistance, what is your opinion?

6(C) Status of GPS navigation and assistance in your car?

6(D) Essentiality of GPS navigation and assistance in a car?

7(A) If a car is having sensor for head light intensity and auto dimmer, what is your opinion?

7(B) If a car is not having sensor for head light intensity and auto dimmer, what is your opinion?

7(C) Status of sensor for head light intensity and auto dimmer in your car?

7(D) Essentiality of sensor for head light intensity & auto dimmer in car?

8(A) If a car is having fog lights and rain sensing wipers, what is your opinion?

8(B) If a car is not having fog lights and rain sensing wipers, what is your opinion?

8(C) Status of fog lights and rain sensing wipers in your car?

8(D) Essentiality of fog lights and rain sensing wipers in a car?

9(A) If a car is having two-axis adjustable power steering, what is your opinion?

9(B) If a car is not having two-axis adjustable power steering, what is your opinion?

9(C) Status of two-axis adjustable power steering in your car?

9(D) Essentiality of having two-axis adjustable power steering in a car?

10(A) If a car is having camera for motion in reverse gear and side and back clearance indicators, what is your opinion?

10(B) If a car is not having camera for motion in reverse gear and side and back clearance indicators, what is your opinion?

10(C) Status of camera for motion in reverse gear and side and back clearance indicators in your car?

10(D) Essentiality of camera for motion in reverse gear and side and back clearance indicators in a car?

11(A) If a car is having door locking sensors, control of doors & child lock near driver, what is your opinion?

11(B) If a car is not having door locking sensors, control of doors & child lock near driver, what is your opinion?

11(C) Status of door lock sensors, control of doors & child lock near driver in your car?

11(D) Essentiality of door lock sensors, control of doors & child lock near driver in a car?

12(A) If a car is having frequently used controls on steering, what is your opinion?

12(B) If a car is not having frequently used controls on steering, what is your opinion?

12(C) Status of frequently used controls on steering in your car?

12(D) Essentiality of frequently used controls on steering in a car?

13(A) If a car is having effortless engine bonnet, fuel tank and dickey (trunk) operations, what is your opinion?

13(B) If a car is not having effortless engine bonnet, fuel tank and dickey (trunk) operations, what is your opinion?

13(C) Status of engine bonnet, fuel tank and dickey (trunk) operations in your car?

13(D) Essentiality of having effortless engine bonnet, fuel tank and dickey (trunk) operations in a car?

14(A) If a car is having comfortable driver seat with three-axis adjustments and comfortable passenger seats, what is your opinion?

14(B) If a car is not having comfortable driver seat with three-axis adjustments and comfortable passenger seats, what is your opinion?

14(C) Status of comfort of driver seat with three-axis adjustments and comfortable passenger seats in your car?

14(D) Essentiality of comfortable driver seat with three-axis adjustments and comfortable passenger seats in a car?

15(A) If a car is having good A.C. air circulation and temperature difference upto 2^0C, what is your opinion?

15(B) If a car is not having good A.C. air circulation and temperature difference upto 2^0C, what is your opinion?

15(C) Status of A.C. air circulation and temp difference in your car?

15(D) Essentiality of good A.C. air circulation and temp difference upto 2^0C in a car?

16(A) If a car is having automatic transmission (no clutch and gear lever), what is your opinion?

16(B) If a car is not having automatic transmission (no clutch and gear lever), what is your opinion?

16(C) Status of automatic transmission in your car?

16(D) Essentiality of automatic transmission in a car?

17(A) If a car is having sufficient head, knee and leg space for driver and passengers, what is your opinion?

17(B) If a car is not having sufficient head, knee and leg space for driver and passengers, what is your opinion?

17(C) Status of head, knee and leg space for driver and passengers in your car?

17(D) Essentiality of sufficient head, knee and leg space for driver and passengers in a car?

18(A) If a car is having effective shock absorbers and vibration damping, what is your opinion?

18(B) If a car is not having effective shock absorbers and vibration damping, what is your opinion?

18(C) Status of shock absorber and vibration damping in your car?

18(D) Essentiality of effective shock absorber and vibration damping in a car?

19(A) If a car is having efficient sound system and blue tooth compatibility for phone and audio streaming, what is your opinion?

19(B) If a car is not having efficient sound system and blue tooth compatibility for phone and audio streaming, what is your opinion?

19(C) Status of sound system and blue tooth compatibility in your car?

19(D) Essentiality of efficient sound system and blue tooth compatibility in a car?

20(A) If a car is having Glare prevention glass and mirror, what is your opinion?

20(B) If a car is not having Glare prevention glass and mirror, what is your opinion?

20(C) Status of Glare prevention glass and mirror in your car?

20(D) Essentiality of Glare prevention glass and mirror in a car?

Feedback:

1) *Was the questionnaire understandable to you? Yes/ No*

2) *Any suggestions regarding ergonomics of car?*

Signature

Appendix II: Responses to part (d) of the Questionnaire (Sample Size, r =100)

Resp. #	AB	BA	FD	HT	SB	GN	SH	RF	AS	CI	DC	FS	BT	SA	AC	AT	SD	VD	EC	GP
1	4	5	3	3	2	4	5	4	4	3	3	3	4	5	5	5	4	4	4	4
2	4	3	4	4	1	3	5	3	4	4	3	4	4	4	4	5	4	4	3	5
3	4	4	4	4	1	3	5	4	3	3	3	3	5	4	5	5	5	4	3	5
4	3	4	3	4	1	3	4	3	2	3	4	3	5	3	5	5	4	4	4	5
5	4	3	3	4	2	3	5	4	4	3	3	3	2	3	5	5	4	4	3	5
6	4	4	3	3	1	4	4	4	4	4	4	2	3	4	5	5	3	3	3	5
7	4	4	3	3	2	3	5	4	4	3	3	3	2	4	5	5	3	4	4	5
8	4	3	4	3	4	3	4	3	4	4	3	3	4	3	5	5	4	4	4	5
9	4	4	2	4	2	4	5	4	3	2	4	3	3	4	5	5	3	4	3	5
10	3	3	4	3	2	4	5	4	4	2	4	4	2	4	4	5	4	4	3	4
11	4	4	4	4	1	3	4	4	2	4	4	2	3	4	5	5	2	4	4	5
12	4	4	4	4	2	4	5	4	4	3	5	3	3	4	4	5	3	4	3	4
13	3	4	4	2	2	3	4	4	5	4	4	2	2	4	5	5	3	4	4	5
14	4	4	3	4	3	4	5	4	5	3	3	3	4	4	5	5	4	4	4	5
15	4	4	4	1	4	4	4	4	4	4	2	2	2	4	5	5	3	4	3	4
16	5	3	2	4	1	4	5	4	5	2	4	2	3	3	5	5	3	4	3	5
17	5	4	3	4	3	3	5	3	4	3	2	3	2	4	5	5	4	5	4	3
18	3	4	2	3	2	3	4	4	5	2	2	2	3	4	5	5	3	4	4	5
19	5	3	4	3	1	4	5	4	4	4	2	2	3	3	5	5	3	4	3	5
20	4	4	3	4	3	4	4	4	5	3	3	3	3	4	5	5	3	4	3	3
21	5	4	2	3	2	3	5	3	5	4	5	3	2	3	5	5	4	5	4	5
22	5	4	3	4	1	4	5	4	4	3	5	2	2	4	5	5	2	4	4	5
23	4	5	3	4	3	4	5	4	2	3	3	3	4	5	5	5	2	4	2	4
24	4	4	4	3	2	4	4	2	3	2	5	3	2	5	1	4	2	3	2	3
25	4	3	2	4	2	5	5	2	3	3	4	3	2	5	1	5	2	4	3	3
26	4	4	3	4	1	4	4	1	3	2	5	2	2	4	2	4	3	3	3	4
27	5	4	2	4	1	5	2	2	3	2	4	2	2	4	2	4	3	2	1	4
28	5	3	2	1	1	4	2	1	2	3	4	2	2	3	1	5	3	3	2	3
29	5	4	4	2	2	4	1	2	2	3	4	2	2	4	2	4	4	1	2	4
30	5	4	1	1	1	4	3	1	4	1	5	2	2	3	2	5	4	4	1	3
31	5	4	1	1	2	4	1	3	4	2	4	2	2	3	2	4	3	1	3	3
32	4	4	2	4	2	5	1	1	3	2	4	3	2	4	2	4	4	2	1	4
33	5	4	2	1	1	4	2	2	4	1	5	3	2	3	2	4	3	1	2	3
34	5	4	2	2	3	5	1	2	3	3	4	3	2	4	2	4	3	3	2	3
35	5	4	3	1	1	5	3	1	2	1	5	1	2	3	2	5	4	1	1	4
36	4	3	2	1	1	3	1	2	2	2	4	2	2	4	2	4	3	2	1	4
37	4	4	2	2	2	5	3	1	2	2	5	2	2	3	3	5	3	2	2	3
38	5	3	3	2	2	5	1	3	2	1	4	2	3	3	2	5	4	1	1	3

Resp. #	AB	BA	FD	HT	SB	GN	SH	RF	AS	CI	DC	FS	BT	SA	AC	AT	SD	VD	EC	GP
39	4	4	3	1	1	4	2	1	3	1	4	2	2	4	2	5	4	2	3	3
40	5	4	2	4	3	5	2	1	4	2	4	2	3	4	1	5	3	1	1	3
41	4	1	2	1	1	3	1	3	3	1	4	2	1	3	2	5	3	3	3	4
42	4	3	2	2	1	4	3	1	3	3	4	3	3	4	1	4	3	1	2	3
43	4	1	1	1	2	4	3	2	4	1	5	1	1	3	3	5	3	1	3	5
44	4	2	3	3	1	3	2	3	5	1	4	3	2	3	1	3	4	4	3	3
45	5	2	1	1	3	3	2	3	5	4	5	1	2	4	3	3	4	4	2	4
46	4	1	2	2	1	4	2	2	4	4	5	2	1	3	1	4	5	2	2	5
47	5	1	2	2	3	3	3	4	5	3	3	2	2	3	2	3	4	3	4	4
48	5	2	1	1	1	2	3	3	4	2	5	2	1	4	2	3	4	3	2	5
49	3	1	1	2	2	2	2	4	5	2	5	3	3	4	1	4	5	2	2	5
50	5	3	2	1	2	3	2	4	4	4	4	3	1	3	3	5	4	3	2	5
51	5	1	1	3	1	3	2	4	5	2	5	2	1	3	1	2	5	2	4	5
52	4	1	3	1	3	3	3	4	5	2	3	2	4	3	1	5	5	2	3	4
53	5	3	1	1	1	3	2	2	4	2	3	3	3	3	4	3	5	3	4	5
54	3	2	1	3	1	4	3	3	2	4	4	2	3	4	4	3	5	3	3	4
55	3	4	3	2	3	3	2	3	2	3	4	2	2	3	4	3	4	3	2	5
56	3	4	1	1	1	3	3	4	4	4	3	1	2	4	5	3	5	2	3	4
57	4	3	1	2	1	4	2	3	2	3	3	2	1	4	5	4	4	3	4	5
58	3	4	3	3	3	4	2	4	4	2	4	2	1	3	4	3	5	3	3	5
59	3	4	1	2	2	3	3	4	2	3	3	1	1	3	4	3	4	4	4	4
60	3	3	3	2	2	4	2	3	2	4	3	1	2	3	5	4	5	3	3	5
61	5	4	3	3	2	3	2	3	4	3	4	2	2	4	5	4	5	4	3	4
62	4	3	1	3	2	3	2	3	3	4	4	2	2	3	4	3	4	4	4	5
63	5	4	2	2	2	3	4	3	3	2	3	2	3	3	5	5	3	3	3	5
64	3	3	2	3	2	3	3	4	2	2	3	3	3	3	4	4	3	4	4	4
65	5	2	2	2	2	4	3	4	3	2	4	4	3	3	4	5	3	4	3	5
66	3	4	2	3	2	3	4	4	2	2	4	2	2	3	4	4	3	3	3	4
67	4	4	3	3	2	4	3	3	2	2	5	3	2	4	5	5	2	3	4	5
68	5	3	3	3	2	3	4	4	2	3	3	3	1	3	5	4	4	3	4	4
69	4	3	2	2	2	3	3	4	2	2	4	2	1	3	4	5	1	4	4	5
70	4	4	1	2	2	4	4	2	2	2	3	3	1	4	4	5	3	4	3	4
71	4	3	2	2	1	4	3	4	5	2	4	2	3	3	4	4	3	3	4	4
72	4	4	2	2	2	4	2	4	3	2	4	4	3	4	5	5	3	4	3	5
73	4	4	2	3	2	3	3	3	4	2	3	3	4	3	4	5	2	4	2	5
74	5	4	2	3	2	4	2	2	3	2	3	3	4	3	4	4	2	3	4	4
75	4	4	1	3	2	4	3	3	3	1	4	4	2	4	5	5	2	4	2	5
76	5	3	2	2	2	3	3	3	4	2	4	4	2	3	4	4	2	4	2	4
77	5	3	3	3	2	4	3	3	5	2	3	3	4	3	4	5	2	3	2	5
78	4	3	2	3	2	4	2	2	3	2	3	3	3	3	4	4	3	4	3	4

Resp. #	AB	BA	FD	HT	SB	GN	SH	RF	AS	CI	DC	FS	BT	SA	AC	AT	SD	VD	EC	GP
79	5	3	2	2	2	4	2	4	4	2	4	2	3	3	4	5	3	4	2	5
80	5	4	1	2	2	4	3	3	3	1	4	4	2	3	5	5	2	4	2	5
81	5	4	1	3	2	4	2	4	3	1	2	2	4	3	4	4	2	3	3	4
82	4	3	2	3	2	3	3	3	4	2	2	2	2	3	5	5	2	4	4	5
83	3	3	1	3	2	4	2	3	4	2	4	2	4	3	4	5	2	4	4	5
84	5	4	1	2	2	3	2	4	4	1	3	2	2	3	4	4	2	3	3	4
85	4	3	3	2	1	3	2	4	3	2	3	2	3	3	4	4	2	4	4	4
86	4	4	4	3	2	4	2	4	4	2	2	2	2	3	5	5	2	3	4	5
87	4	3	2	2	2	3	2	4	5	2	4	2	2	3	4	4	2	4	4	4
88	4	3	2	1	2	2	2	4	5	2	4	2	1	3	4	5	2	4	4	5
89	5	2	3	1	2	2	2	4	4	2	2	2	4	3	5	5	2	3	4	5
90	4	4	2	2	2	3	3	3	5	2	4	2	4	4	4	5	2	4	4	5
91	5	3	4	1	2	3	3	3	4	2	4	3	2	4	5	5	2	4	4	5
92	4	3	2	2	2	3	3	3	5	2	3	2	2	3	4	4	2	3	3	4
93	4	4	3	1	2	3	1	2	4	3	4	3	2	4	5	5	2	4	4	5
94	4	3	2	3	2	4	3	3	5	2	3	3	1	3	4	4	3	3	3	4
95	4	4	2	2	2	3	2	3	5	2	3	2	1	3	4	5	2	4	4	5
96	5	4	2	2	2	3	2	4	4	1	3	3	3	4	4	4	3	3	3	4
97	4	4	4	1	2	4	3	3	4	2	4	4	4	4	4	5	5	4	4	5
98	4	3	4	1	2	4	2	4	2	2	3	2	2	3	5	5	5	4	3	5
99	4	4	2	2	2	3	2	4	4	2	3	4	1	3	4	4	4	3	4	4
100	5	4	2	2	2	4	2	4	2	2	4	2	3	3	4	5	4	4	4	5
Min (l_j)	**3**	**1**	**1**	**1**	**1**	**2**	**1**	**1**	**2**	**1**	**2**	**1**	**1**	**3**	**1**	**2**	**1**	**1**	**1**	**3**
Max (u_j)	**5**	**5**	**4**	**4**	**4**	**5**	**5**	**4**	**5**	**4**	**5**	**4**	**5**	**5**	**5**	**5**	**5**	**5**	**4**	**5**
Avg (m_j)	**4.2**	**3.4**	**2.4**	**2.4**	**1.9**	**3.6**	**3.0**	**3.1**	**3.6**	**2.4**	**3.7**	**2.5**	**2.4**	**3.5**	**3.7**	**4.5**	**3.3**	**3.3**	**3.0**	**4.4**
FAHP (w_j) *	**4.15**	**3.24**	**2.41**	**2.45**	**2.08**	**3.55**	**2.97**	**2.92**	**3.53**	**2.43**	**3.62**	**2.48**	**2.61**	**3.65**	**3.48**	**4.13**	**3.17**	**3.19**	**2.85**	**4.23**

** The crisp value w_j, for the TFN (triangular fuzzy number), used in FAHP calculations are given by:*

$$w_j = \left\{ \frac{l_j + (4 \times m_j) + u_j}{6} \right\}, \text{ (eqn 15)}$$

where (l_j) is the minimum value, (m_j) is the average value and (u_j) is the maximum value.

Appendix III: House of Ergonomics Deployment (HED)

	Engineering characteristics / Ergonomic Attribute	User Importance (i)	Indian Standards	Raw mat. quality	Sensor Quality	Weight	Dimension	Cost	Fuzzy Kano Category	k value	User satisfaction (u)	User satisfaction target (t)	Adjustment factor (f)	Improvement Ratio (R_0)=(t/u)	Adj. Improvemt. Ratio (R_1)	Adjusted importance (j)	Fuzzy Kano Rankg (FKR)
			Relationship: 1=Weak, 3=Moderate, 5=Strong								Importance Scale: 1=Least, 5=Most						
1	[AB] Efficient air bags (front, side and curtain)	5.00	5	3				3	A	1.5	2.62	4.22	0.65	1.61	3.41	17.07	2
2	[BA] Brake assist with auto. emergency brake	1.96			5	3	1	5	A	1.5	1.25	3.36	0.49	2.69	4.91	9.62	7
3	[FD] Fatigue detection sensor	2.23			5			5	A	1.5	1.03	2.37	0.53	2.30	4.36	9.73	6
4	[HT] Hilly Terrain driving support	3.24			3			1	M	0.5	2.69	2.43	0.56	0.90	1.13	3.65	16
5	[SB] Faster retractable seat belts	1.00	5	3				1	M	0.5	2.28	1.87	0.52	0.82	1.01	1.01	20
6	[GN] GPS navigation and assistance	4.09			5		3	5	A	1.5	2.64	3.57	0.57	1.35	2.66	10.88	4
7	[SH] Sensor for head light intensity and auto dimmer	2.44			5			5	A	1.5	1.83	2.95	0.49	1.61	2.95	7.19	10
8	[RF] Fog lights and rain sensing wipers	3.03	1					1	M	0.5	2.51	3.13	0.62	1.25	1.59	4.80	13
9	[AS] Two-axis adjustable power steering	2.76						3	A	1.5	2.21	3.55	0.48	1.61	2.89	7.98	9
10	[CI] Camera for motion in reverse gear & clearance indicatoı	1.11					3	3	M	0.5	2.54	2.40	0.63	0.94	1.21	1.34	19
11	[DC] Door locking sensors and control of doors near driver	3.13	1					1	M	0.5	3.38	3.68	0.77	1.09	1.45	4.53	15
12	[FS] Frequently used controls on steering	2.17						1	M	0.5	2.70	2.47	0.50	0.91	1.12	2.43	18
13	[BT] Effortless engine bonnet, fuel tank and trunk operations	3.29						1	M	0.5	3.39	2.42	0.65	0.71	0.92	3.02	17
14	[SA] Comfortable and addustable driver and passenger seats	4.79		3		1		3	O	1.0	2.84	3.48	0.70	1.23	2.08	9.98	5
15	[AC] A.C. air circulation and temp. difference upto 2 deg C	3.08			5		3	3	A	1.5	2.32	3.72	0.55	1.60	3.09	9.53	8
16	[AT] Automatic transmission (no clutch and gear lever)	4.73				1		5	A	1.5	1.92	4.45	0.66	2.32	4.94	23.37	1
17	[SD] Sufficient head, knee and leg space	3.67				3	5	1	M	0.5	2.96	3.25	0.67	1.10	1.42	5.20	11
18	[VD] Effective shock absorbers and vibration damping	3.13		3		3	3	3	M	0.5	2.77	3.28	0.70	1.18	1.54	4.83	12
19	[EC] Efficient sound system and blue tooth compatibility	2.92						1	O	1.0	3.13	3.03	0.67	0.97	1.62	4.72	14
20	[GP] Glare prevention glass and mirror	3.83			3			3	A	1.5	2.50	4.35	0.61	1.74	3.54	13.56	3
	Absolute Weight, AW		36.16	41.76	90.21	35.80	54.54	170.80									
	Absolute Importance, AI		99.73	98.67	286.41	92.32	115.38	526.21									

Appendix IV: Data sheet for ergonomic score of the attribute and factor scores

Attribute Acronym	Factor Name	Attribute Eigen value (AEV)	Ergonomic Score of Attribute (ESA)	Attrib. Score (AS) = AEV × ESA	Factor EV = Σ (AEV)	ASF = Σ(AS of factor)	Factor Score (%) #	Sub Classification of each attributes. (Guidelines for finding ergonomic score of attribute, range 0 to 5)
AB	*Overall Safety Factor (8 Attributes)*	0.111			**0.415**			Driver AB, Front passenger AB, Dual stage AB, Side AB, Curtain AB
BA		0.062						Anti-Lock Braking System, Electronic Stability Program, Electronic Brake-force Distribution, Brake Assist, Radar sensors
FD		0.063						FD using time or distance driven, FD using path traversed, FD using camera of cell phone, FD using fixed camera, full marks for FD using combination of response
HT		0.024						Four Wheel drive, Traction control System, Hill decent control, Limited slip differential, Cruise control
SB		0.007						Rear three-point seatbelt, Child Seat Anchor Points, Seat Belt Warning, Pretensioners on front seats, Electronically controlled Faster retractable
GN		0.070						Route guidance, Shortest route, Real time traffic information, Fastest Route, Memorize destinations
SH		0.047						Headlight off reminder, Sensor for head light intensity, Auto dimmer, Adjustable Cluster Brightness, Projector type & Cornering head lights
RF		0.031						Rain-sensing wipers, All time Running Lights, Fog Lamps Front and Back, Rear Wiper, Defogger
AS	*Musculoskeletal/ Reach Factor (6 Attributes)*	0.052			**0.191**			Leather wrapped soft grip, Power steering, Tilt adjustment, Telescopic adjustment, Steering collapsible in emergency
CI		0.009						Parking Assistance, Camera on reverse motion, Rear Clearance Sensors, Side Clearance Sensors, Voice warnings.
DC		0.029						Remote Central Locking, Child Safety Lock, All Doors locking sensors, All Doors Ajar Warning, Engine immobilizer
FS		0.016						Music control, Cell phone control, AC controls, Light control, GPS Navigation control
BT		0.020						Press button opening of bonnet, Pneumatic lift of bonnet, Press button opening of trunk, Pneumatic lift of trunk, Press button to open fuel tank
SA		0.065						Driver seat with three-axis adjustments, Driver seat with height adjustments and Lumbar Support, Electrically Adjustable Head-rests on all seats, Rear Passenger individual Adjustable seats with Lumbar Support, Ventilated Seats
AC	*Compatible Man Machine Interface/ Comfort Factor (6 Attributes)*	0.062			**0.397**			Cooling/ Heating within 2 minutes, Automatic Climate Control, Humidity control, Rear AC vents, Differential A.C. air circulation and temp. difference up to 2º C
AT		0.151						Smooth and fuel efficient automatic transmission (0 to 5 marks)
SD		0.034						Egress from car without bending head (for a person of height 185 cm), Sufficient clearance between knees and steering when seat is at extreme back (for a person of height 185 cm), Clearance between knees and steering when seat is at extreme front (for a person of height 155 cm), Sufficient leg space for front passenger, Sufficient leg space at rear seat
VD		0.031						Efficient Vibration Damping (1 to 5 marks)
EC		0.031						Sound proofing of external noise, Integrated music system, Display screen for rear passengers, Bluetooth compatibility for phone, Bluetooth compatibility for audio streaming
GP		0.088						Night glare prevention glass, Anti-glare internal mirrors, Anti-glare rearview mirror, Electrically adjustable & retractable rearview mirrors

$$\# \; \boldsymbol{Factor\ Score\ FS\ (in\%)} = \left[\frac{(\boldsymbol{\Sigma\ Attribute\ score\ for\ a\ factor})}{(\boldsymbol{\Sigma\ Attribute\ Eigen\ Value\ for\ that\ factor})\times(\mathbf{5})}\right] \times \mathbf{100}\% = \left[\frac{\boldsymbol{ASF}}{(\boldsymbol{FEV}\times\mathbf{5})}\right] \times \mathbf{100}\%$$

Appendix V: Computer Program in MATLAB for the Mathematical Model for determining the Ergonomic Compatibility (index) of a car

```
[System]
Name='Ergo 333G sd1666 n 5G sd833 rules logical'
Type='mamdani'
Version=2.0
NumInputs=3
NumOutputs=1
NumRules=27
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

[Input1]
Name='Safety'
Range=[0 100]
NumMFs=3
MF1='Poor':'gaussmf',[16.66 0]
MF2='Good':'gaussmf',[16.66 50]
MF3='Excellent':'gaussmf',[16.66 100]

[Input2]
Name='Reach'
Range=[0 100]
NumMFs=3
MF1='Stressful':'gaussmf',[16.66 0]
MF2='Moderate':'gaussmf',[16.66 50]
MF3='Easy':'gaussmf',[16.66 100]
```

[Input3]

Name='Comfort'

Range=[0 100]

NumMFs=3

MF1='Low':'gaussmf',[16.66 0]

MF2='Medium':'gaussmf',[16.66 50]

MF3='High':'gaussmf',[16.66 100]

[Output1]

Name='Ergonomic Compatibility'

Range=[0 100]

NumMFs=5

MF1='Poor':'gaussmf',[8.33 0]

MF2='Bad':'gaussmf',[8.33 25]

MF3='Average':'gaussmf',[8.33 50]

MF4='Good':'gaussmf',[8.33 75]

MF5='Excellent':'gaussmf',[8.33 100]

[Rules]

1 1 1, 1 (1) : 1

1 1 2, 1 (1) : 1

1 1 3, 2 (1) : 1

1 2 1, 1 (1) : 1

1 2 2, 2 (1) : 1

1 2 3, 3 (1) : 1

1 3 1, 2 (1) : 1

1 3 2, 3 (1) : 1

1 3 3, 4 (1) : 1

2 1 1, 1 (1) : 1

2 1 2, 2 (1) : 1

2 1 3, 3 (1) : 1

2 2 1, 2 (1) : 1

2 2 2, 3 (1) : 1

2 2 3, 4 (1) : 1

2 3 1, 3 (1) : 1

2 3 2, 4 (1) : 1

2 3 3, 5 (1) : 1

3 1 1, 2 (1) : 1

3 1 2, 3 (1) : 1

3 1 3, 4 (1) : 1

3 2 1, 3 (1) : 1

3 2 2, 4 (1) : 1

3 2 3, 5 (1) : 1

3 3 1, 4 (1) : 1

3 3 2, 5 (1) : 1

3 3 3, 5 (1) : 1

Appendix VI: Look-up Table for Ergonomic index of a car

(Safety = Safety Factor; Rch = Reach Factor; Comft = Comfort Factor)

		Safety									
Rch	**Comft**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
10	**10**	15.5	18.7	18.7	15.6	16.9	22.1	27.2	30.6	30.7	30.9
	20	18.7	21.5	21.5	21.6	22.7	27.2	32.4	34.4	36.2	36.4
	30	18.7	21.5	26.3	26.4	27.2	30.6	34.4	42.5	44.6	45.0
	40	15.6	21.6	26.4	27.3	27.9	30.7	36.2	44.6	49.7	50.0
	50	16.9	22.7	27.2	27.9	28.1	30.9	36.4	45.0	50.0	51.8
	60	22.1	27.2	30.6	30.7	30.9	31.4	36.9	45.4	50.3	52.1
	70	27.2	32.4	34.4	36.2	36.4	36.9	43.1	50.3	55.4	57.6
	80	30.6	34.4	42.5	44.6	45.0	45.4	50.3	57.6	63.8	66.6
	90	30.7	36.2	44.6	49.7	50.0	50.3	55.4	63.8	69.3	72.1
	100	30.9	36.4	45.0	50.0	51.8	52.1	57.6	66.6	72.1	73.8
20	**10**	18.7	21.5	21.5	21.6	22.7	27.2	32.4	34.4	36.2	36.4
	20	21.5	28.2	28.2	28.3	29.1	32.4	39.9	40.7	42.4	42.7
	30	21.5	28.2	31.1	31.2	31.8	34.4	40.7	47.6	49.7	50.0
	40	21.6	28.3	31.2	32.8	33.4	36.2	42.4	49.7	54.6	55.0
	50	22.7	29.1	31.8	33.4	33.7	36.4	42.7	50.0	55.0	57.3
	60	27.2	32.4	34.4	36.2	36.4	36.9	43.1	50.3	55.4	57.6
	70	32.4	39.9	40.7	42.4	42.7	43.1	45.5	52.4	57.5	59.8
	80	34.4	40.7	47.6	49.7	50.0	50.3	52.4	59.3	65.6	68.2
	90	36.2	42.4	49.7	54.6	55.0	55.4	57.5	65.6	69.4	72.8
	100	36.4	42.7	50.0	55.0	57.3	57.6	59.8	68.2	72.8	75.1
30	**10**	18.7	21.5	26.3	26.4	27.2	30.6	34.4	42.5	44.6	45.0
	20	21.5	28.2	31.1	31.2	31.8	34.4	40.7	47.6	49.7	50.0
	30	26.3	31.1	39.6	39.7	40.2	42.5	47.6	54.5	56.9	57.3
	40	26.4	31.2	39.7	41.9	42.4	44.6	49.7	56.9	63.1	63.6
	50	27.2	31.8	40.2	42.4	42.7	45.0	50.0	57.3	63.6	66.3
	60	30.6	34.4	42.5	44.6	45.0	45.4	50.3	57.6	63.8	66.6
	70	34.4	40.7	47.6	49.7	50.0	50.3	52.4	59.3	65.6	68.2
	80	42.5	47.6	54.5	56.9	57.3	57.6	59.3	60.1	67.6	70.9
	90	44.6	49.7	56.9	63.1	63.6	63.8	65.6	67.6	72.8	77.3
	100	45.0	50.0	57.3	63.6	66.3	66.6	68.2	70.9	77.3	80.5
40	**10**	15.6	21.6	26.4	27.3	27.9	30.7	36.2	44.6	49.7	50.0
	20	21.6	28.3	31.2	32.8	33.4	36.2	42.4	49.7	54.6	55.0
	30	26.4	31.2	39.7	41.9	42.4	44.6	49.7	56.9	63.1	63.6
	40	27.3	32.8	41.9	47.4	47.9	49.7	54.6	63.1	68.6	69.1
	50	27.9	33.4	42.4	47.9	48.2	50.0	55.0	63.6	69.1	71.9
	60	30.7	36.2	44.6	49.7	50.0	50.3	55.4	63.8	69.3	72.1
	70	36.2	42.4	49.7	54.6	55.0	55.4	57.5	65.6	69.4	72.8
	80	44.6	49.7	56.9	63.1	63.6	63.8	65.6	67.6	72.8	77.3
	90	49.7	54.6	63.1	68.6	69.1	69.3	69.4	72.8	77.9	83.1
	100	50.0	55.0	63.6	69.1	71.9	72.1	72.8	77.3	83.1	87.0
50	**10**	16.9	22.7	27.2	27.9	28.1	30.9	36.4	45.0	50.0	51.8
	20	22.7	29.1	31.8	33.4	33.7	36.4	42.7	50.0	55.0	57.3
	30	27.2	31.8	40.2	42.4	42.7	45.0	50.0	57.3	63.6	66.3
	40	27.9	33.4	42.4	47.9	48.2	50.0	55.0	63.6	69.1	71.9
	50	28.1	33.7	42.7	48.2	50.0	51.8	57.3	66.3	71.9	73.7
	60	30.9	36.4	45.0	50.0	51.8	52.1	57.6	66.6	72.1	73.8
	70	36.4	42.7	50.0	55.0	57.3	57.6	59.8	68.2	72.8	75.1
	80	45.0	50.0	57.3	63.6	66.3	66.6	68.2	70.9	77.3	80.5
	90	50.0	55.0	63.6	69.1	71.9	72.1	72.8	77.3	83.1	87.0
	100	51.8	57.3	66.3	71.9	73.7	73.8	75.1	80.5	87.0	89.7

		Safety									
Rch	**Comft**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
60	**10**	22.1	27.2	30.6	30.7	30.9	31.4	36.9	45.4	50.3	52.1
	20	27.2	32.4	34.4	36.2	36.4	36.9	43.1	50.3	55.4	57.6
	30	30.6	34.4	42.5	44.6	45.0	45.4	50.3	57.6	63.8	66.6
	40	30.7	36.2	44.6	49.7	50.0	50.3	55.4	63.8	69.3	72.1
	50	30.9	36.4	45.0	50.0	51.8	52.1	57.6	66.6	72.1	73.8
	60	31.4	36.9	45.4	50.3	52.1	52.6	58.1	67.2	72.7	74.5
	70	36.9	43.1	50.3	55.4	57.6	58.1	60.3	68.8	73.6	75.9
	80	45.4	50.3	57.6	63.8	66.6	67.2	68.8	71.7	78.4	81.7
	90	50.3	55.4	63.8	69.3	72.1	72.7	73.6	78.4	84.4	88.5
	100	52.1	57.6	66.6	72.1	73.8	74.5	75.9	81.7	88.5	90.8
70	**10**	27.2	32.4	34.4	36.2	36.4	36.9	43.1	50.3	55.4	57.6
	20	32.4	39.9	40.7	42.4	42.7	43.1	45.5	52.4	57.5	59.8
	30	34.4	40.7	47.6	49.7	50.0	50.3	52.4	59.3	65.6	68.2
	40	36.2	42.4	49.7	54.6	55.0	55.4	57.5	65.6	69.4	72.8
	50	36.4	42.7	50.0	55.0	57.3	57.6	59.8	68.2	72.8	75.1
	60	36.9	43.1	50.3	55.4	57.6	58.1	60.3	68.8	73.6	75.9
	70	43.1	45.5	52.4	57.5	59.8	60.3	60.4	68.9	73.7	76.1
	80	50.3	52.4	59.3	65.6	68.2	68.8	68.9	71.8	78.5	81.9
	90	55.4	57.5	65.6	69.4	72.8	73.6	73.7	78.5	81.3	86.3
	100	57.6	59.8	68.2	72.8	75.1	75.9	76.1	81.9	86.3	89.2
80	**10**	30.6	34.4	42.5	44.6	45.0	45.4	50.3	57.6	63.8	66.6
	20	34.4	40.7	47.6	49.7	50.0	50.3	52.4	59.3	65.6	68.2
	30	42.5	47.6	54.5	56.9	57.3	57.6	59.3	60.1	67.6	70.9
	40	44.6	49.7	56.9	63.1	63.6	63.8	65.6	67.6	72.8	77.3
	50	45.0	50.0	57.3	63.6	66.3	66.6	68.2	70.9	77.3	80.5
	60	45.4	50.3	57.6	63.8	66.6	67.2	68.8	71.7	78.4	81.7
	70	50.3	52.4	59.3	65.6	68.2	68.8	68.9	71.8	78.5	81.9
	80	57.6	59.3	60.1	67.6	70.9	71.7	71.8	71.8	78.5	81.9
	90	63.8	65.6	67.6	72.8	77.3	78.4	78.5	78.5	81.3	86.3
	100	66.6	68.2	70.9	77.3	80.5	81.7	81.9	81.9	86.3	89.2
90	**10**	30.7	36.2	44.6	49.7	50.0	50.3	55.4	63.8	69.3	72.1
	20	36.2	42.4	49.7	54.6	55.0	55.4	57.5	65.6	69.4	72.8
	30	44.6	49.7	56.9	63.1	63.6	63.8	65.6	67.6	72.8	77.3
	40	49.7	54.6	63.1	68.6	69.1	69.3	69.4	72.8	77.9	83.1
	50	50.0	55.0	63.6	69.1	71.9	72.1	72.8	77.3	83.1	87.0
	60	50.3	55.4	63.8	69.3	72.1	72.7	73.6	78.4	84.4	88.5
	70	55.4	57.5	65.6	69.4	72.8	73.6	73.7	78.5	81.3	86.3
	80	63.8	65.6	67.6	72.8	77.3	78.4	78.5	78.5	81.3	86.3
	90	69.3	69.4	72.8	77.9	83.1	84.4	81.3	81.3	84.5	88.7
	100	72.1	72.8	77.3	83.1	87.0	88.5	86.3	86.3	88.7	91.0
100	**10**	30.9	36.4	45.0	50.0	51.8	52.1	57.6	66.6	72.1	73.8
	20	36.4	42.7	50.0	55.0	57.3	57.6	59.8	68.2	72.8	75.1
	30	45.0	50.0	57.3	63.6	66.3	66.6	68.2	70.9	77.3	80.5
	40	50.0	55.0	63.6	69.1	71.9	72.1	72.8	77.3	83.1	87.0
	50	51.8	57.3	66.3	71.9	73.7	73.8	75.1	80.5	87.0	89.7
	60	52.1	57.6	66.6	72.1	73.8	74.5	75.9	81.7	88.5	90.8
	70	57.6	59.8	68.2	72.8	75.1	75.9	76.1	81.9	86.3	89.2
	80	66.6	68.2	70.9	77.3	80.5	81.7	81.9	81.9	86.3	89.2
	90	72.1	72.8	77.3	83.1	87.0	88.5	86.3	86.3	88.7	91.0
	100	73.8	75.1	80.5	87.0	89.7	90.8	89.2	89.2	91.0	91.4

Appendix VII: List of Publications

Publications: International Journals (published/ accepted)

1. Dutta, A., Bhardwaj, A.K. and Rathore, A.P.S. (2019) 'Ergonomic intervention in meeting the challenges of elderly drivers: identifying, prioritising and factorising the ergonomic attributes', *International Journal of Vehicle Design*, Vol. 79, Nos. 2/3, pp.168–189. [doi:10.1504/IJVD.2019.102336] *(Inderscience Publisher)* [SCIE (Science Citation Index Expanded) and Scopus indexed].
2. Dutta, A. and Rathore, A.P.S. 'Identifying and prioritising the futuristic attributes of a car in the Industry 4.0 era', *International Journal of Business Innovation and Research (Inderscience Publisher).* [Scopus indexed].
3. Ashish Dutta and A.P.S. Rathore. 'Estimating Ergonomic Compatibility of Cars: A Fuzzy Approach', *Procedia Computer Science Journal (Elsevier).* [Scopus indexed].

Publications: International Journals (submitted: re-review)

1. Dutta, A. and Rathore, A.P.S. 'A novel method to prioritise the ergonomic attributes of a passenger car using fuzzy approach', *International Journal of Business and Systems Research (Inderscience Publisher).* [Scopus indexed].

Publications: International Conference

1. Dutta, A., Bhardwaj, A. K., Rathore. A. P. S. 'Factorizing and Prioritizing the Ergonomic Attributes of a Passenger Car for Aged People'. *Proceedings of 15th International Conference on Ergonomics for Improved Productivity* (held at AMU, Aligarh, India; from 8th to 10th December' 2017). Humanizing Work and Work Environment **HWWE 2017**. ISBN: 978-93-86724-25-0.
2. Ashish Dutta, A. K. Bhardwaj, A. P. S. Rathore. 'Expectations from a Car in Industry 4.0 Era: Identifying and Prioritizing the Futuristic Attributes of a Car'. *Proceedings of International Conference on Role of Industrial Engineering in Industry 4.0 Paradigm* **ICIEIND 2018** (held at S'O'A, Bhubaneshwar, Odhisa from 27th to 30th September' 2018).
3. Ashish Dutta, A.P.S. Rathore. 'Estimating Ergonomic Compatibility of Cars: A Fuzzy Approach'. *International Conference on Computational Intelligence and Data Science* **ICCIDS 2019** (held at The North Cap University, Gurugram from 6th to 7th September' 2019).

Appendix VIII: Biography of Ashish Dutta

Ashish Dutta was born on 12th December, 1971 in Alwar (Rajasthan), India. He completed his schooling from Kota (Rajasthan), India. He received his Bachelor of Engineering (B.E.) (Honours) degree in Mechanical Engineering from Regional Engineering College, Durgapur under University of Burdwan (presently known as National Institute of Technology, Durgapur, West Bengal) in the year 1993. He completed PGDM (equivalent to MBA) in Marketing Management from All India Management Association, New Delhi in the year 2000. He has done Master of Technology (M. Tech.) in Manufacturing Systems Engineering from the Department of Mechanical Engineering, Malaviya National Institute of Technology (MNIT), Jaipur in the year 2013. He pursued his doctoral research (Ph.D.) in Industrial Engineering from MNIT, Jaipur, under the able guidance of Prof. A.P.S. Rathore. He is working in Public Health Engineering Department (PHED) under Government of Rajasthan. His research interest includes Industrial Engineering, Ergonomics and New Product Development.

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Chapter 1:

Introduction

Chapter 2:
Literature Review, Research Gap, and Aim of this Research

Chapter 3:

Methodology

Chapter 4:

Attribute Identification and Survey

Chapter 5:

Framing HED and Comparing Priority of Attributes using FAHP

Chapter 6:

Formulation of the Mathematical Model using Fuzzy Approach

Chapter 7:

Results and Discussions

Chapter 8:

Conclusions

References

Appendices