

Identification of most suitable in-vehicle position of mobile-phone as navigation device for minimizing driver distraction: A study on drivers of Mobile Application Based Taxi Services (MABTS)

*A thesis submitted
in partial fulfilment of the requirements for the degree of*

DOCTOR OF PHILOSOPHY

by
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Submitted by
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June 1, 2021





*Dedicated to My Parents
(Shri. Yogeshwar Prasad Verma and Smt. Aruna Verma),
My Brother (Dr. Priyesh Verma)
and My Wife (Aashita Verma)*





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DECLARATION

I hereby declare that the work contained in this thesis entitled “**Identification of most suitable in-vehicle position of mobile-phone as navigation device for minimizing driver distraction: A study on drivers of Mobile Application Based Taxi Services (MABTS)**” is carried out by me, a bonafide student of Department of Design, Indian Institute of Technology Guwahati, Assam, India under the guidance of Dr. Sougata Karmakar at the Department of Design, Indian Institute of Technology Guwahati, Assam. This work is done for the award of Doctor of Philosophy. It has not been submitted elsewhere for any other degree or diploma.

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CERTIFICATE

This is to certify that the work contained in this thesis entitled “**Identification of most suitable in-vehicle position of mobile-phone as navigation device for minimizing driver distraction: A study on drivers of Mobile Application Based Taxi Services (MABTS)**” has been carried out under my guidance and supervision and is a bonafide work of Indresh Kumar Verma. This work, submitted for the degree of Doctor of Philosophy is original and contains no materials previously published or written by any other person for degree or diploma at IIT Guwahati or any other institute or university. All the requirements including mandatory coursework as per the rules and regulations as mentioned in the Ph.D. ordinance for submitting the thesis for Ph.D. degree of Indian Institute of Technology Guwahati have been fulfilled.



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Indresh Kumar Verma



ABSTRACT

The advancement in technology has led to the use of gadgets in our daily life. There has been a rapid growth in the use of these gadgets in the past few decades; one such device is mobile phones. The number of mobile phone subscribers has increased many folds in India recently. According to the Telecom Regulatory Authority of India (TRAI), there are about 1.13 billion mobile-phone subscribers in India as of May 2018 (TRAI, 2018b). Mobile phones are used not only for texting and calling but also for various other purposes, ranging from booking a movie ticket, calculators, radio, music systems, camera, a navigation system, and many more. There has been a proliferation of these mobile phones inside the four-wheeler as well. Advancements in communication and information technologies have led to the use of mobile phones as an in-vehicle information system (IVIS) (Horrey, Wickens, & Consalus, 2006). These mobile phones, used as IVIS, provide information to drivers (personal as-well-as hired car) regarding driving and non-driving tasks (navigation, vehicle status, weather, and entertainment). The use of mobile phones while driving causes diversion of attention from the primary task of driving, which is one type of driver distraction (Kircher, 2007). According to Ranney et al. (2001), driver distraction is “any activity that takes a driver’s attention away from the task of driving”. Any distraction from rolling down a window, over adjusting a mirror, tuning a radio, and using a mobile phone can contribute to a crash. Distracted drivers are four times more likely to be in a crash than non-distracted drivers (Bendak & Al-Saleh, 2010).

In the past decade, there has been a growth in the taxi companies that use mobile phones to provide their services. In the present research, these taxi service companies are referred to as Mobile Application Based Taxi Services (MABTS). Although using a mobile phone while driving causes distraction, its complete elimination is not possible, especially for the MABTS drivers, since they use mobile phones for rendering their services (booking rides, fare, navigation, etc.)

Following initial interaction with the MABTS drivers, it was observed that neither there is a guideline by the taxi service providers nor specific locations followed by the MABTS drivers for mounting their mobile phones for navigation purposes. The drivers placed their mobile phones on the dashboard and around the steering wheel according to their perception of convenience. This behavior may lead the drivers to position the mobile phones at sub-optimal locations, which may increase their distraction (poor driving), and incidences of accidents and near-missed chances.

Hence, there is a need to study the suitability of in-vehicle mobile phone position to ensure the minimum adverse effect on driving performance (lane keeping, error/ lapses, maneuvering) and minimal effort (bio-mechanical, reachability) while operating/ navigating during driving. Particular emphasis has been given to the MABTS drivers since they are subjected to the condition of using mobile phones and driving. Following the literature survey and pilot study,

the following research questions were raised.

- (1) Which are the different activities performed by the drivers of Mobile Application Based Taxi Services (MABTS), that causes distraction?
- (2) What are the presently practiced methodologies to measure driver distraction?
- (3) Which is the preferred in-vehicle positions/ locations of mobile phone, for navigation purpose, by majority of MABTS drivers?
- (4) Which position (out of the various preferred locations) of mobile device is most preferred/ optimal for navigation purpose in terms of reducing driver distraction and enhancing driving performance?

Hence, the research presented in this dissertation aimed to identify the most suitable in-vehicle position among the various preferred positions for mounting mobile phone (used as navigational device) by the MABTS drivers, to minimize driver distraction and ensure less affected driving performance. To achieve the studies' aim, the following objectives were set.

- (1) To identify the various methodologies currently practiced for measurement of driver distraction.
- (2) To identify the factors influencing driver to distract attention from primary task of driving.
- (3) To identify various in-vehicle locations/ positions which are commonly practiced by MABTS drivers for navigation purpose.
- (4) To identify the position/ location preferred by the majority of MABTS drivers for keeping mobile phones for navigation purposes, using questionnaire survey.
- (5) To identify the optimal/ most preferred in-vehicle position for placing mobile phone for navigation purpose in terms of minimizing the bio-mechanical effort.
- (6) To identify the most suitable in-vehicle position in terms of reduced driver distraction and less affected driving performance for mounting the mobile phone (as navigational device), among the various preferred positions by MABTS drivers.

To proceed further in research, the following hypothesis has been formulated.

- H₁:** Driver distraction due to use of mobile phone for navigation can significantly be reduced by identifying optimal/ most preferred position of the mobile phone considering minimal obstruction of external view field, minimal eye/ neck movement (to visualize the screen) and easy reach for navigational purpose.

H₂: Reduced driver distraction due to most suited position of mobile phone for navigation purpose significantly increases the driving performance.

The overall framework of the current research was divided into five phases: problem identification; questionnaire survey of MABTS drivers; DHM based study of mobile phone positions; development of a novel mobile phone holder to be mounted at the center of the steering wheel; and empirical evaluation of the in-vehicle mobile phone positions in a driving simulator. Phase – I was the problem identification stage, where a review of literature related to the study of this thesis was carried out, followed by identification of the research gap. During this phase, research questions were raised, aim & objectives were set, and hypotheses were formulated for conducting the research.

In the phase – II, a questionnaire-based survey was conducted to understand the drivers' involvement/ engagement in distracting activities/ tasks and their preferred location for placing in-vehicle mobile phones for navigation purposes. The study involved MABTS drivers (n = 188). The questionnaire was found to be reliable with a Cronbach's alpha (α) = 0.72. Inferences drawn from the outcome of the survey concluded to some interesting findings. The majority of drivers (48.8%) preferred to keep their mobile phones on the steering wheel's left side for navigation purposes. It was also observed that 40.4% of drivers reported that they kept mobile phones on the steering wheel's right side, near the A-pillar. A small percent (10.1%) of drivers mentioned that they change the position of their mobile phones during night/ evening, and keep it below the dashboard. Additionally, about 22.3% of drivers reported that they reduce the mobile phone's screen's brightness during the night. These behaviors could be seen as an act of counter measuring glare from the mobile device during night/ evening. A total of 'nine' in-vehicle mobile phone positions (on & around the dashboard and the steering wheel) were used in this study.

In phase – III, a digital human modeling (DHM) based study was conducted using the CATIA-DELMIA software. This study was carried out to identify the head (rotation, flexion/ extension), torso movement, and hand reachability, required for easy information access from different in-vehicle mobile phone position. Head rotation and flexion/ extension values were measured for 5th, 50th, and 95th percentile digital manikins. These measurements were made for nine different mobile phone placement locations. Reach analysis was also done to identify which in-vehicle mobile phone positions were easily operable. An overview of all the in-vehicle mobile phone positions in the car interior is given in figure 3.1. The minimum head rotation was recorded for the positions '8', '5', and '2', which were on the same vertical line and close to the line-of-sight. Negligible head rotation (1°, 1°, 1°), and head flexion (5°, 7°, 8°) was also recorded for position '5', for the three different percentile manikins. Although, the least head rotation was recorded for position 8, head flexion (17° – 19°) were outside the comfortable range suggested by Kee and Karwowski (2001). Position 8 had a better hand reach than others, and it did not obstruct the forward vision of the drivers.

Following DHM study (details in chapter 4) it was noticed that placing in-vehicle mobile

phone at a straight forward location nearer to normal line-of-sight would reduce the neck/ eye movement and subsequently reduce distraction. Hence, placing in-vehicle mobile phone at position '5', and '8' would benefit MABTS drivers in-terms of improved driving performance. However, no mobile phone holder which could be easily mounted at the steering wheel's hub (that maintains the mobile phone in vertically up-right position even when the steering wheel rotates), could be found in the automobile accessories market. Hence, in phase – IV, an innovative self-adjusting mobile-phone holder was developed, which can be mounted on the hub of steering wheel, by adopting a systematic product development process. The product's primary requirements were, (a) it could be mounted in the center of the steering wheel, (b) it should self-adjust and remains vertically upright even when the steering wheel rotates. A systematic product development process was followed, which included – customer needs identification, concept generation, concept screening, prototyping, customer feedback. The entire process is discussed in detail in chapter 5.

To empirically examine the effect of in-vehicle mobile phone position on the drivers' driving performance and visual behavior, a simulated driving study in a laboratory setup was conducted in phase – V. In this study, four highly preferred in-vehicle mobile phone positions (left, right, front, and middle of the steering wheel) were used (details in chapter 6). The experiment was conducted in a within subjects design, and the study subjects had to drive in a simulated road environment, under five driving conditions (one baseline – only driving, and four dual-task driving – driving + secondary task on mobile phone located at one of the positions mentioned earlier). The subjects performed four secondary tasks under each of the four dual-task driving conditions (details in chapter 6).

The hypotheses formulated at the commencement of the research were tested by fulfilling various objectives. The DHM study's outcome revealed that the minimum head movement (rotation: 1°, flexion: 5° – 8°) was achieved for in-vehicle mobile phone placed at the front position of the steering wheel for 5th, 50th, and 95th percentile manikins. The outcome of the driving simulator-based experiment revealed that the driver distraction (in-terms of driving performance) was minimum for front position of in-vehicle mobile phone. A repeated measures ANOVA was conducted to find the difference (if any) in the M. Dev values, among the dual-task driving conditions. The results of repeated measures ANOVA revealed that there is a significant effect of driving condition ($F(4, 116) = 36.80, p < 0.05, \eta^2 = 0.559$, large effect size) on M.Dev values. Further, a post hoc test using bonferroni correction revealed that significant difference in M.Dev values exist between front and middle mobile phone positions ($p < 0.05$). Among the dual-task driving scenario, the mean deviation (M.Dev = 0.68) value was minimum for the front mobile phone position. In terms of driving workload, the front mobile phone position was rated to be the least loading ($M = 30.35$). Since the front position of the in-vehicle mobile phone was least distracting and drivers had a high perception of safety for this position, the fixation ($M = 24.64$ s) and glance ($M = 31.06$ s) duration of the drivers was longest at front mobile phone position. Hence, we can say that the front mobile phone position with minimum

head rotation, and easy arm reach, has the least distracting effect (better driving performance and visual behavior). **Thus, establishing the hypothesis – 1 of the research.**

The simulated driving experiment revealed that the driving performance depends on the position of in-vehicle mobile phones used for ride-booking, navigation, checking fare, and calling by the MABTS drivers. A repeated measures ANOVA showed that M.Dev values differed significantly among the different driving conditions ($F(4, 116) = 36.80, p < 0.05, \eta^2 = 0.559$, large effect size). The best lane keeping performance (low value of mean deviation) was achieved when an in-vehicle mobile phone was placed at the front position ($p < 0.05$) compared to the other dual-task driving scenario. For lane change error, a Friedman test revealed that there was a significant effect of driving condition ($\chi^2(4) = 14.09, p < 0.05$) on lane change errors. The least amount of lane change error ($M = 3.50$) was also observed for the front position among the different mobile phone positions. **Hence, the hypothesis – 2 of the research work was established.**

The present dissertation work demonstrated a systematic research approach from the review of existing literature, field survey to establish the rationale of research, and formulate the problem statement. Following laboratory-based experimentation in driving-simulator, current research has identified the most preferred location of mobile phone (as navigation purpose) in terms of reduced driver distraction and less impact on driving performance. Current research has employed field survey to understand the MABTS drivers' behavior and their common practice to position the mobile phone as navigation device. A systematic product development strategy developed an innovative self-adjusting steering wheel-mounted mobile phone holder, need analysis, concept generation using the morphological chart, concept selection via the Pugh matrix, and user feedback was applied. Use of digital human modeling (DHM) techniques for evaluating comfortable head movement (flexion/extension and rotation), and reach to various in-vehicle mobile phone locations was unique and brings novelty in driver distraction research. The eye-tracking was used for recording drivers' visual behavior during performing dual-tasks in a driving simulator in a laboratory setup to understand drivers' driving performance and level of driver distraction due to the different mobile phone locations. Drivers' subjective workload was measured using the driving activity load index (DALI) questionnaire. Statistical analysis (repeated measures ANOVA) was performed to identify, significant difference (if any) in the driving performance (M. Dev and lane change error), visual behavior (fixation, glance, total-eye-off-road time), and driving workload, among the different in-vehicle mobile phone positions. The policy-makers/ road-transport authorities can utilize the current research findings to formulate guidelines for the efficient and safe use of in-vehicle navigation devices. It is anticipated that this research's outcomes would be beneficial to the wide spectrum of drivers (both personal and professional) driving a variety of vehicle classes (auto, truck, buses, etc.) by giving them a clear perspective on the placement of in-vehicle mobile phones. Further, the automobile companies can use the present research outcome for judiciously placing the in-vehicle displays for reduced driver distraction. The knowledge gained from the study about

visual and driving behavior could be used by the designers and the ergonomists for developing safer and user-friendly in-vehicle displays. Additionally, the industrial designers can also use the knowledge to design mobile holders/ space integrated within the dashboard, keeping in mind smaller visual angles for safety and usability (to guide the driver to place the mobile device in the correct position).

Key contributions of the thesis

- The current research work addresses the widespread problem of distraction faced by professional (taxi/ cab/ auto-rickshaw) drivers in particular and personal automobile drivers.
- Development of in-vehicle mobile phone holder which can be mounted at the center of the steering wheel.
- Identified the most suitable in-vehicle mobile phone position (from the existing driver preferred positions), requiring minimal head movement (rotation and flexion/extension), arm reach, and improved driving performance and visual behavior.

Keywords: *Distraction; Driver behavior; Digital human modeling; Safety; Eye-tracking; Simulated driving; Lane change test (LCT); Driving activity load index (DALI); Visual behavior; Mobile application based taxi services (MABTS)*

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List of Abbreviations

η^2	Effect size
ADAS	Advanced Driver Assistant System
ANOVA	Analysis of Variance
AOI	Area of Interest
CAD	Computer-Aided Design
CAGR	Compound Annual Growth Rate
CDMA	Code-Division Multiple Access
CMS	Camera Monitor System
DALI	Driver Activity Load Index
DHM	Digital Human Modeling
DS	Driving Simulator
ECG	Electrocardiogram
EEG	Electroencephalogram
GOI	Government of India
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HRV	Heart-Rate Variability
HUD	Head Up Display
IEA	International Ergonomics Association
IHEC	Institute Human Ethics Committee
ISO	International Organization for Standardization
IVER	In-Vehicle Event Recorder
IVIS	In-vehicle Information System

LBFTS	Looked-But-Failed-To-See
LCT	Lane Change Test
LTE	Long-Term Evolution
M.Dev	Mean lateral Deviation in Lane Change
MABTS	Mobile Application Based Taxi Services
MDT	Mobile Data Terminal
MORTH	Ministry of Road Transportation and Highways
NASA-TLX	National Aeronautics and Space Administration Task Load Index
NHTSA	National Highway Traffic Safety Administration
PDT	Peripheral detection task
POI	Point of Interest
RSME	Rating Scale Mental Effort
SAGAT	Situation Awareness Global Assessment Technique
SDLP	Standard Deviation of the Lane Position
SDT	Signal Detection Task
SMI	Senso-Motric Instrument
SRR	Steering Reversal Rate
SUS	System Usability Scale
TDT	Tactile Detection Task
TEORT	Total eye-off road time
TRAI	Telecom Regulatory Authority of India
VDT	Visual Detection Task
WHO	World Health Organization

— The more thoroughly I conduct scientific research, the more I believe that science excludes atheism.

Lord Kelvin

1

Introduction

Abstract

The wave of technological advancement has touched every industrial sector. The automobile sector has also taken advantage of this situation and introduced sophisticated mobile communication and navigation devices in the vehicles. Unfortunately, these mobile devices have become one of the causes of driver distraction, forming the base of the research presented in this dissertation. This introductory chapter includes the background of present research work, research gap formulates the research questions, and hypothesis. This chapter outlines the aim, objectives, scope, and rationale of the research work. The framework and organization of this dissertation's research work have been presented at the end of this chapter.

1.1 Background

We are using technology every day in each aspect of life. Today's technology is helping people to connect 24×7 to their near and dear ones. A communication revolution has come up in this era and has touched everyone. In modern world, automobiles especially four-wheeler (passenger cars) has become an important means of commutation. Cars were built about a century ago and thereafter they have been evolving rapidly, both in style and technology. They are used as both, public transport (taxi services) and personal means of transportation. The technological advancement in the field of digital electronics has captured every aspect of our lives; digital devices and ubiquitous computing have changed the way we communicate with each other. The automobile industry is of no exception to these events. Out of the many factors responsible for the rapid development of the automobile industry, electronics is one of them. With internet-enabled mobile phones and devices, we can do more than before, and their presence in automobiles has changed the way drivers used to drive. According to MOTOROLA, "Current production cars contain more computing power than was used to send the Apollo spacecraft to the moon" (Damiani, Deregibus, & Andreone, 2009). An important motive behind

the current evolution process is the ability to “communicate anywhere and anytime” or to be connected continuously.

Improvement in communication technology has brought about the revolutionary change of continuous connectivity within the past few decades, where everyone communicates with each other anytime. There has been an escalation in mobile phone usage in the last decade because of mobile internet connectivity. Automobile companies have taken advantage of this situation by bringing mobile and wireless technologies into the four-wheeler, which has enriched the capability of entertainment (infotainment), and navigation system installed in the vehicles.

These assistive technologies/ devices installed inside the car are expected to support the driver to efficiently maneuvering the vehicle by providing information about road, traffic, and condition of the vehicle itself (speed, temperature, fuel, etc.). Many ill-effects have also crept in with these technologies when used inside the vehicle. One of the detrimental effects of the technology of the 21st century is the distraction caused to the drivers commonly referred to as ‘driver distraction’. Under the condition of distraction, the driver focuses on activities that are considered secondary or non-essential to the primary task of driving. In most cases, distracted driving leads to cases of accidents or near-crash situations. One of the prominent causes of death and injury has been traffic crashes. While many factors lead to crashes, major reason has been attributed to driver distraction by many researchers (Kircher, 2007; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Klauer et al., 2014; Olson, Hanowski, Hickman, & Bocanegra, 2009; Ranney, 2008). With more sophisticated devices and smartphones being used inside the vehicle these days, it is expected that a new variety of activities may arise that are capable of diverting the attention of drivers from the primary task of driving. Hence, investigation of their influence on the behavior of drivers and road safety is very essential.

Sources of driver distraction can vary significantly, however, in the past decade, cell phone-related distractions have increased dramatically, and their impact on driving performance is significant. Phone activity records have been used to investigate cell phones’ impact on crash risk (McEvoy et al., 2005; Redelmeier & Tibshirani, 1997). McEvoy et al. (2005) estimated that texting and talking on a mobile phone increases the odds of being in a crash by fourfold. Similarly, Redelmeier and Tibshirani (1997), demonstrated that, the risk of a collision when using a mobile phone for making or receiving calls, was four times greater than the risk when it was not used. On the other hand, less complex tasks, such as combing/ fixing hair, retrieving tapes/ CDs, and eating, increase the odds of being in a crash or near-crash by twofold (Klauer et al., 2006).

The crash risk associated with driver distraction is already alarming, and this situation is going to worsen as more technologies are introduced into the vehicles (Regan, Hallett, & Gordon, 2011). Unfortunately, despite efforts to increase awareness of the consequences, drivers continue to engage in activities unrelated to driving (Schroeder, Meyers, & Kostyniuk, 2013). It is crucial to understand the motivating factors or facilitators of drivers’ engagement in distractions to maximize distraction mitigation strategies’ effectiveness.

Driver distraction and incidences of near crash & accidents

Vehicles in the recent times are getting fitted with numerous instruments due to rapid advancement in technology and customer needs. However, there is an increasing concern related to inattention, mental workload and reduction of driving performance. Distraction occurs when the driver shifts attention from driving (referred to as a primary task) to any other activity (secondary task), which is not critical for safe driving. Driver Distraction is one form of inattention. Driver gets distracted when interacting with instruments inside the vehicles, which are meant to help and support in driving. In recent years, drivers are using mobile phones inside the vehicle either as an assistive or communication device. Using mobile phone while driving causes the driver to take their eye-off road, hands-off steering wheel, and mind away from the road and surrounding situation. Global body like, WHO has recognized driver distraction as a major cause of road traffic injuries (WHO, 2011).

Global scenario of distraction and accidents

Globally, the concern about driver inattention and distraction is increasing. Studies have shown that involvement in the secondary task while driving impairs driving performance, leading to serious road-traffic safety concerns. There has been a gradual increase in the use of mobile phones while driving and is becoming a common driver distraction. Studies have shown a four-fold increase in the risk of accidents when mobile-phone (for talking or texting) is used while driving (Redelmeier & Tibshirani, 1997). According to the '100-car naturalistic study' completed in the US suggests that 80% crashes and 65% of near-crash incidences are accounted for driver inattention. In Spain, approximately 20% drivers were involved in some kind of secondary tasks while driving, talking to the passenger (11.1%), smoking (3.7%) and talking on the handheld phone (1.3%) (Prat, Planes, Gras, & Sullman, 2015). In New Zealand, about 52.3% of driver reported sending and 66.2% reported reading messages while driving (Hallett, Lambert, & Regan, 2012). In the UK, it was reported that about 14% of drivers send text messages whereas 25% read text messages while driving (Lansdown, 2012). In a similar epidemiological study in the US, it was observed that 16.6% of drivers texted or dialed and 31.4% talked on phone (Huisinigh, Griffin, & McGwin, 2014). Countries like the United States have a separate institute like NHTSA, which is heavily investing in studying, understanding, and developing methods to mitigate the effect of distraction. Sources of driver distraction can vary significantly. However, in the past decade, mobile-phone related distractions have increased dramatically and their impact on driving performance has been found significant. Sources of distraction to drivers can either be external or internal, depending on where they occur with respect to the vehicle.

External Source: These sources of distraction are those activities/ elements/ things that occur outside the vehicle. These include roadside advertisements, billboards, pedestrian, signs in traffic/ highways.

Internal Source: It consists of all the elements/ activities/ things that occur inside the vehicle. They include talking/ texting on mobile-phone; talking to passengers; eating, drinking, smoking; operating in-vehicle instrument; listening to radio/ music/ entertainment system.

Mobile phones subscribers – global overview and scenario in India

According to “Ericsson’s mobility report,” the mobile subscriptions around the world was around 7.9 bn in the Q3 of 2018, it also estimated 8.9 bn subscribers by 2024 (Ericsson, 2018). There has been numerous fold increase in the subscribers of mobile phone. About two decades ago, in 1997, India’s Telecom market was a modest 14.5 million phone connections, with an initial policy of “telephone on demand.” However, now in July 2018, the Indian Telecom industry is 2nd largest globally, with over 1.17 billion telecom subscribers, out of which 1.15 billion are wireless (GSM, CDMA & LTE) subscribers, and 22.27 million are wire-line subscribers (TRAI, 2018a). According to TRAI, the urban telecom subscribers (wireless) are 639.71 million, whereas rural telecom (wireless) subscribers are 517.33 million as of July 2018. The telecom sector has seen exponential growth because of 4G, inexpensive tariffs, mobile number portability, and a conducive regulatory environment.

Growth of automobile in India

India has seen a rapid increase in motorized vehicle usage due to sustained economic growth. According to report of Ministry of Road Transportation and Highways (MORTH), GOI, 2018, the number of registered vehicles in India is over 253 million, and in the period between 2007 – 2017, it has grown at a compound annual growth rate (CAGR) of 10.11%. During the years 2010 – 17, the number of registered motor vehicles in India increased at a CAGR of 10.3%, increasing the vehicle density from 28 per km in 2007 to 42.95 per km in 2017. Road users are at a high risk of accidents since the same road is being used by a variety of motorized, non-motorized, and pedestrians (MORTH, 2018). During the decade of 2005 – 15, the highest CAGR of 10.7% was registered for car, taxis, and jeeps combined, followed by 10.1% for two-wheeler, 8.8% for goods vehicle, and 8.2% for buses. For every 1000 people, the number of vehicles has increased from 8 in 1981 to 167 in 2015 (MORTH, 2016).

Road accident scenario in India

In 2015, India signed the Brasilia Declaration in the road safety conference held in Brazil. In 2016, road traffic-related accidents had taken more than 1.35 million lives globally and continue to be the chief concern of public health (MORTH, 2018). According to the World Road Statistics 2018, India is ranked 1 out of 199 countries in road accident deaths, followed by China and the U.S (MORTH, 2018). Road accidents are multi-causal and occur due to a combined influence of errors by humans, defects in vehicles, roads, external circumstances like visibility, glare, weather, etc. The rapid expansion of the road network and motor vehicles

has resulted in a rise in India's road traffic accidents. These accidents have resulted in injuries, fatalities, disabilities, and hospitalization with severe socioeconomic costs. According to the World Health Organization (WHO), among the causality of deaths, accidents are ranked eight and first among children between 5 – 14. According to the WHO's "Global Report on Road Safety 2018", 11% of the accidents related to death in the world happens in India (WHO, 2018). In the age group of 15 – 49, deaths due to accidents is ranked fourth in India. Based on the report, "Road Accidents in India 2018" published by MORTH, during 2018, the total reported accidents in India was 4,67,044, which injured 4,69, 418, and killed 1,51,417 people (MORTH, 2018). Compared to 2017, there has been an increase of 0.46% in road accidents in the year 2018. The number of persons killed and the number of injuries have increased by 2.37% and 0.33%, respectively, in 2018. In the year 2018, two-wheeler were responsible for 35.2% (maximum) of the accidents, killing a total of 31.4% and injuring 32.7% of the people, whereas, car/taxi/van caused 24.3%, and 12.3% of the accidents were because of truck/ lorry (MORTH, 2018). Wearing a helmet has been made mandatory, and penalties have been increased via the amended Motor Vehicle Act passed in 2019 (MORTH, 2018). Road accidents happen due to a variety of reasons and their interplay. In 2018, over- speeding was the prime reason in 66.5% of the cases, whereas the wrong side/lane indiscipline accounts for 5.3% of accidents. Alcohol consumption, red-light violation, and using mobile-phone while driving together account for 6.5% of accidents (MORTH, 2018). Distraction while driving can lead to serious road accidents. The activity of driving and simultaneously talking on mobile phones is of prime concern, and a cause of road accidents. It is recently being reported as a causal factor for road accidents. During the year of 2016, using a mobile phone while driving caused 4,976 road accidents, causing 2,138 fatalities and 4,746 injuries (MORTH, 2016). Whereas in the year 2017, the use of mobile phones has resulted in 8,526 number of accidents, causing 3,172 deaths and 7,830 number of injuries. It is important to note that during 2018, accidents and deaths decreased due to red-light violation, over-speeding, lane indiscipline, and drunk driving. However, accidents and deaths related to mobile phone use increased in 2018 compared to 2017 (MORTH, 2018). The subscribers of mobile-phones and its use while driving has shown rapid growth in the past couple of years. During the last decade there has been a rise in the mobile application based taxi service (MABTS) companies which utilize mobile phones for providing their services. A few examples of these MABTS companies in India include, 'OLA', 'Uber', 'Meru Cabs', 'Carzonrent', 'Savaari'. The drivers of these MABTS companies are more vulnerable to mobile phone based distraction, since they use mobile phones for rendering their services (car booking, navigation, fare, etc.). There is a need to promote, conduct research & development activities, education, and awareness programs to face the challenges presented by the upcoming in-vehicle technologies. A recent survey was conducted by the SaveLIFE foundation with the support of Vodafone India to explore the current scenario of driver distraction due to the use of the mobile phone in India. The survey took place in eight different cities. It was found that about 47% of drivers received calls on the mobile phone while driving, whereas 28% made calls while

driving (SaveLIFE, 2017).

1.2 Research gap/ area unexplored

A good amount of work pertaining to driver distraction has been done in different countries like the Philippines, Portugal, Germany, Denmark, USA, UK, and Canada (Alconera, Garcia, Christine Mercado, & Portus, 2017; Cordazzo, Scialfa, Bubric, & Ross, 2014; Ferreira, Simões, Piccinini, & Rôla, 2013; Martinussen, Hakamies-Blomqvist, Møller, Özkan, & Lajunen, 2013; Metz & Krueger, 2010; Simons-Morton, Guo, Klauer, Ehsani, & Pradhan, 2014; M. S. Young & Mahfoud, 2007). It is also evident that research work regarding the influence of age, gender, experience on distraction of drivers have also been carried out. As compared to the work carried out in different countries, the amount of work reported in Indian Scenario is very less. Following literature review, it has been observed that there are various unexplored areas where further research are needed to be carried out to maximize driver distraction for ensuring safe and efficient driving. Various research gaps demonstrated in figure 1.1, are listed below.

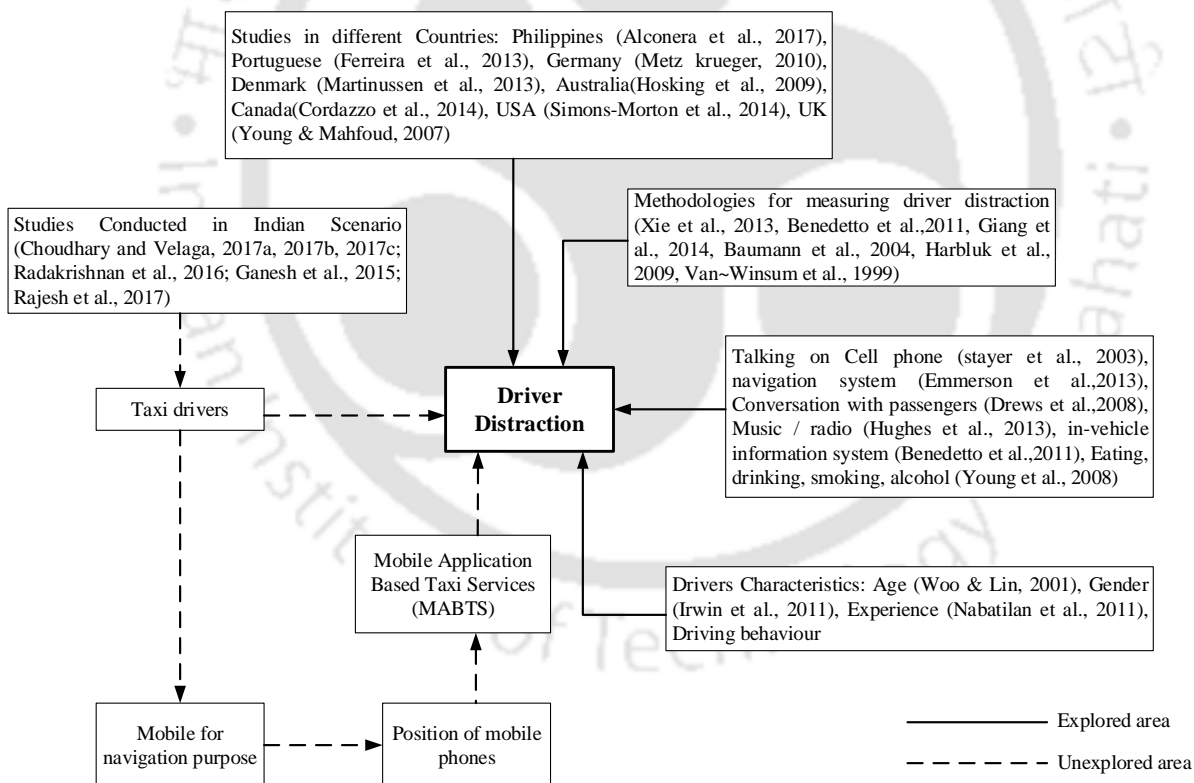


Figure 1.1: Summary of the Research gap/ Area unexplored

- Following the literature review, clear research gap has been identified regarding lack of guideline/ standard in national/ international scenario for optimal positioning of mobile phone (as portable navigation system) to minimize distraction. Neither there is a guideline

by the service providers, nor there are specific locations followed by the MABTS drivers for mounting their mobile for navigation purpose.

- Drivers are exposed to many in-vehicle communication/ navigation devices these days. Many researches have reported the impact of using mobile phones while driving. However, there is rarely reported study on distracting effect of using mobile phone for navigation purpose by MABTS drivers.
- The existing studies on driver distraction are limited only to in-vehicle display (Camera monitor system, MDTs) positions (Beck, Lee, & Park, 2017; McKinnon, Callaghan, & Dickerson, 2012) and have not considered positioning of mobile phone (as portable navigation system) to minimize distraction.
- Large number of research work are being carried out on different types (manual/ voice control) of navigation systems (Chiang, Brooks, & Weir, 2004; J. Harbluk, Burns, Lochner, & Trbovich, 2007; Maciej & Vollrath, 2009). There is rarely reported study on the effect of position of mobile phone (used for navigation) on driving performance as well as on driver distraction.
- There are research related to influence of driver characteristics on distraction (Irwin, Chekaluk, & Geaghan, 2011; Nabatilan, Aghazadeh, Nimbarte, Harvey, & Chowdhury, 2012; WOO & LIN, 2001) but rarely any study considering the drivers of MABTS.
- A good deal of research is already going on in other parts of the world (US, UK, Australia, Canada, Germany, Denmark, Philippines), but significant knowledge base in Indian scenario is absent.

1.3 Research questions

Based on the above research gaps, and initial interactions with the MABTS drivers, a set of research questions were raised as listed below.

- Q₁:** Which are the different activities performed by the drivers of MABTS, that causes distraction?
- Q₂:** What are the presently practiced methodologies to measure driver distraction?
- Q₃:** Which is the preferred in-vehicle positions/ locations of mobile phone, for navigation purpose, by majority of MABTS drivers?
- Q₄:** Which position (out of the various preferred locations) of mobile device is most preferred/ optimal for navigation purpose in terms of reducing driver distraction and enhancing driving performance?

1.4 Rationale behind the research work

The mobile-phone subscribers in India has risen rapidly in the recent years. According to the Telecom Regulatory Authority of India (TRAI), there are about 1.13 billion mobile-phone subscribers in India as of May 2018 (TRAI, 2018b). With technological advancement, most of the drivers (personal as-well-as hired car) use mobile-phones as a portable navigation device for cars.

Literature review indicates that distracted driving due to the use of the mobile phone (texting, talking, navigating, etc.) has been identified as the significant cause of road-accident (Kircher, 2007; MORTH, 2014, 2018). Researchers empirically examined the effect of the positions of car navigation display on eye movement and braking reaction time (Itoh, Yamashita, & Kawakami, 2005). The earlier studies (Beck et al., 2017; McKinnon et al., 2012) related to the position of in-vehicle displays (Camera monitor system, MDTs) and infotainment system (Radakrishnan, Dharmar, Balakrishnan, & Padattil, 2016) showed that positions of displays affect driver distraction and thereby driving performance. Ishiko et al. (2013) evaluated two different sizes of navigation systems at three locations for driving safety, based on gaze data and subjective rating. Wittmann et al. (2006) attempted to determine the relative safety of onboard display positions and concluded that drivers' performance is disturbed exponentially as a function of the distance between the on-road line of sight and the onboard display position. A comparison of 3 different locations and sizes of in-vehicle displays was performed by Doi, Murata, Moriwaka, and Osagami (2019) to evaluate driving performance as a measure of driver distraction.

According to the Anti-Distracted Driving Act (ADDA), RA 10913 of The Republic of Philippines, placing navigational devices/ mobile phones beyond the defined safe zone is prohibited, as this area is around the line of sight region. This act considers only the driver's horizontal line of sight and does not specify the ideal location of the navigation device (LTO, 2017).

De Lumen, Lim, Orosa, Paralleon, and Sedilla (2019), based on their study on 3 different positions of the navigation devices for Transportation Network Vehicle Services (TNVS), showed that the driver's distraction level is significantly affected by the position of the navigation device. In the earlier reported studies, only three or four different locations of the in-vehicle displays were examined, whereas mobile phones, due to their small size and availability of diverse types of holders, are being conveniently placed by the drivers at different positions around the steering wheel, dashboard, mid-console and windshield as the portable navigation systems. Moreover, the driver's comfort and safety in biomechanical effort and reachability are still unexplored.

Stating the aforesaid literature review, it can be concluded that driver-distraction due to the varied position of the in-vehicle navigational device (like mobile-phone) might impact driving performance and thereby the possibility of the road accident. Thus, the identified research problem and its corresponding hypothesis are based on literature review and field observation

of diverse mobile phone positions as navigational devices. Here, it is worthy of mentioning that the aim of the present research is to study the influence of mobile-phone positions on driver distraction and thereby driving performance but not directly related to accident data.

In India, MABTS companies like 'OLA' and 'Uber', are using mobile-phone applications for executing their services. Although mobile phone is a major cause of distraction, its complete elimination is impractical, as it has become an inevitable part of driving, particularly for the drivers of Mobile Application-Based Taxi Services. It was observed from the field study that mobile-phone used for navigation purpose was generally mounted at different locations on and around the dashboard and steering wheel, as per the driver's perception of convenience (Verma & Karmakar, 2017). Neither there is a guideline, nor there are specific locations followed by the MABTS drivers for mounting their mobile-phone for navigation purpose. Positioning the in-vehicle mobile phone at un-optimal location would reduce the driving performance and increase the chances of accidents for the drivers. Hence, there is a need to study the suitability of in-vehicle mobile phone position to ensure the minimum adverse effect on driving performance (lane keeping, error/ lapses, maneuvering) and minimal effort (bio-mechanical, reachability) while operating/ navigating during driving.

Delimitations of the thesis

The pinpoint the research scope following constraints have been imposed on the research design.

- The research in this thesis only considered male MABTS drivers.
- The study presented in this thesis deals with only passenger cars used for MABTS services. Generally, such taxi services do not use high-end cars where facilities like voice-activated user-interface, Head-Up Display (HUD), advanced driver assistance system, and satellite navigation system enabled automotive technologies are present.
- The study presented in this thesis only considers the identification of suitable in-vehicle mobile phone positions based on the laboratory-based experiment in a low-fidelity simulator.

1.5 Aim and Objectives

Aim

The aim of this study is to identify the most suitable in-vehicle position among the various preferred positions for mounting mobile phone (used as navigational device) by the MABTS drivers, to minimize driver distraction and ensure less affected driving performance.

Objectives

Following objectives were set to achieve the aim.

- 1: To identify the various methodologies currently practiced for measurement of driver distraction.
- 2: To identify the factors influencing driver to distract attention from primary task of driving.
- 3: To identify various in-vehicle locations/ positions which are commonly practiced by MABTS drivers for navigation purpose.
- 4: To identify the position/ location preferred by the majority of MABTS drivers for keeping mobile phones for navigation purposes, using questionnaire survey.
- 5: To identify the optimal/ most preferred in-vehicle position for placing mobile phone for navigation purpose in terms of minimizing the bio-mechanical effort.
- 6: To identify the most suitable in-vehicle position in terms of reduced driver distraction and less affected driving performance for mounting the mobile phone (as navigational device), among the various preferred positions by MABTS drivers.

1.6 Hypothesis

To proceed further in research the following hypothesis has been formulated.

H₁: Driver distraction due to use of mobile phone for navigation can significantly be reduced by identifying optimal/ most preferred position of the mobile phone considering minimal obstruction of external view field, minimal eye/ neck movement (to visualize the screen) and easy reach for navigational purpose.

H₂: Reduced driver distraction due to most suited position of mobile phone for navigation purpose significantly increases the driving performance.

1.7 Framework of research work

The study presented in the thesis attempted to find the most preferred/ suitable location for placing the mobile phone, used as a navigation device.

Figure 1.2 shows the research framework adopted to achieve the goals of this dissertation. The research framework is presented into five phases. Phase – I was the problem identification stage, where a review of literature related to the study of this thesis was carried out, followed

	Milestones	Methodological approach	Objective fulfilled
Phase I	Problem identification <ul style="list-style-type: none"> • Literature Survey • Research gap • Problem Identification • Defining Research Question • Hypothesis • Defining Aim & Objectives 		Objective 1 and 2
Phase II	Field Survey <ul style="list-style-type: none"> • Data collected from 188 taxi drivers • Identification of distracting behaviour involvement • Identifying all possible mobile phone positions and relative preference 	Semi-structured questionnaire and interview	Objective 3 and 4
Phase III	DHM based Study <p>Identification of most suitable mobile phone location in-terms of least biomechanical load of information access by head flexion/ extension and rotation and reachability analysis.</p>	Digital human modelling simulation in DHM software	Objective 5
Phase IV	Innovative product development <p>Development of an innovative self-adjusting steering wheel based mobile-phone holder.</p>	A systematic product development approach	Objective 6
Phase V	Empirical study in laboratory <p>Empirically identify the most suitable in-vehicle mobile phone position in terms of driving performance and visual behaviour</p>	Driving simulator and eye tracking glass	Objective 6

Figure 1.2: Framework adopted in this research work

by identification of the research gap. During this phase research questions were raised, aim & objectives were set, and hypothesis were formulated for conducting the research.

In phase – II, field study was conducted to identify the extent of MABTS drivers' involvement/ engagement in distracting task and their preference of location for placing the in-vehicle mobile phone used as a navigation device. In this phase, data was collected from the drivers using a semi-structured questionnaire and a few open-ended questions. The questionnaire survey was used to identify the involvement of drivers in various distracting task while driving. In this phase, drivers ranked the different mobile phone locations around the dashboard and

steering wheel.

In phase – III, a digital human modeling (DHM) based study was conducted using the CATIA-DELMIA software. This study was carried out to identify the head (rotation, flexion/extension), torso movement, and hand reachability, required for easy information access from different in-vehicle mobile phone position. Head rotation and flexion/extension values were measured for 5th, 50th, and 95th percentile digital manikins. These measurements were made for nine different mobile phone placement locations. Reach analysis was also done to identify which in-vehicle mobile phone positions were easily operable.

In phase – IV, an innovative self-adjusting mobile-phone holder was developed, which can be mounted on the hub of steering wheel, by adopting a systematic product development process. The outcome of DHM based study in the previous phase revealed, if the mobile phone is placed at the center of the steering wheel, there would be minimum head rotation, flexion/extension and torso movement. Hence, a steering wheel based mobile-phone holder was developed so that an empirical study could be carried out to identify the most suitable/preferred position of mobile phone.

During phase – V, an empirical study was carried out on a driving simulator in a laboratory setup. In this study, the drivers' driving performance was measured using the lane change task (LCT), and visual behavior was measured using the eye-movement recorder. This study was conducted by placing the mobile phones at four highly preferred locations (left, right, front, and middle of the steering wheel) to identify the most preferred position.

1.8 Organization of the dissertation

This dissertation comprises seven chapters. A brief description of these chapters is presented here. Chapter 1 provides the state-of-art literature review in concise form. It deals with the identification of research gap, raising research questions, setting the aim & objectives, formulation of hypothesis, and finally description of research framework.

Chapter 2 gives an overview of the literature covering the previous studies relevant to the study taken up in this dissertation. The topics covered in this chapter include attention and its importance in driving, theories related to attention allocation, a brief discussion about the definition of driver distraction, inattention, taxonomy, and sources of distraction. This chapter presents different methodologies (naturalistic and simulator-based), various objective and subjective measures of distraction adopted in driver behavior research. A detailed description of the field, simulated, and experimental studies of this study are in chapters 3, 4, 5, and 6.

Chapter 3 gives a detailed description of the field study conducted on MABTS drivers to understand their involvement in different distracting activities. This chapter also presents the drivers' preference position for placing in-vehicle mobile phones and their justification.

Chapter 4 gives details about digital human modeling (DHM) based study. The work presented in this chapter tries to understand the most suitable position for placing the in-vehicle

mobile-phone based on head rotation, flexion/ extension of percentile manikins (5th, 50th, and 95th). Reach analysis of different in-vehicle mobile-phone positions is also presented.

Chapter 5 discusses the process involved in the development of a novel self-adjusting steering wheel based mobile phone holder. This chapter gives a detailed description of the product development process starting from concept generation, concept selection, morphological, and pugh chart matrix used to develop the mobile phone holder for the steering wheel's hub. The developed product was evaluated using the system usability scale (SUS) and user feedback was taken.

Chapter 6 discusses an empirical study to find the most suitable position of the in-vehicle mobile phone. Different in-vehicle mobile phone display positions were evaluated based on driving performance and visual behavior on a driving simulator. Lane change test (LCT) was used to perform simulated driving, and an eye-tracker was used for measuring visual behavior. Variations in driving performance and impact of driver distraction due to different mobile phone positions are graphically presented.

Chapter 7 summarizes the entire research work presented in the thesis (starting from the questionnaire survey of MABTS drivers, through DHM based virtual ergonomic evaluation of the different in-vehicle mobile phone position, development of the novel mobile phone holder for the steering wheel's hub, and finally the empirical study on a driving simulator in a laboratory setup to identify the most suitable in-vehicle mobile phone position for minimized driver distraction and better driving performance). This chapter also presents the key findings and limitations of the thesis. Furthermore, this chapter also describes the testing of hypothesis and contributions (knowledge-base, methodology, society, and industry) of the research.



— You have to dream before your dreams can come true.

A. P. J. Abdul Kalam

2

Review of literature

Abstract

Before carrying out the research, it is essential to study and understand the existing literature on the topic under consideration. The chapter presents a comprehensive review of the literature on driver distraction. Different theories of attention allocation and driving are discussed at the start, followed by various studies and empirical work previously done in the field of driver distraction. This chapter also touches a variety of areas related to driver distraction (definition, taxonomy, sources). Different aspects that may lead to distraction and different methods for measuring distractions are also presented in this chapter.

2.1 Overview

Driving is a complex task requiring visual and manual senses to be engaged. Drivers draw about 90% of their information from visual senses and process this information, and as a feedback, they perform manual maneuvering of the vehicle. Drivers are required to focus their attention on the road to maintain self and other road commuters' safety. If the driver deviates their focus from the primary task of driving, then the chances of accidents and near-crash situation arises. This condition of the driver not focusing on driving tasks is termed as 'Driver distraction.' Many factors fuel this problem of the driver being distracted from driving. For understanding the domain of driver distraction, a systematic survey of the literature was carried out. Scholarly databases of 'Science Direct', 'Scopus,' and 'Web of Science' were searched; keywords used in this search were 'driver distraction,' 'driver behavior,' 'driver inattention,' 'distracted driving.'

Different theories of attention, information processing, and driving are presented at the start, followed by the definition of inattention and distraction suggested by various researchers. Sources of distraction (internal/ external) and their related studies, methodologies for measuring distraction, and different distraction measurement metrics mentioned in the literature are presented in vivid detail.

2.2 Attention, information processing and driving

To understand distraction the basic understanding of the context of driving task, information processing, and attention allocation is necessary. Figure 2.1, shows the information processing during driving. This model was proposed by Houtenbos (2008), and is based on the information processing model proposed by Endsley (1995); Wickens, Hollands, Banbury, and Parasuraman (2015) with addition of concept of expectancy. On a basic level, humans take information about their environment, then process the data and then responds according to the situation (Eysenck, 2000). However, all the information is not processed at the same time. Even though there is a stimulus, one may not respond to it if another stimulus is answered at the same time.

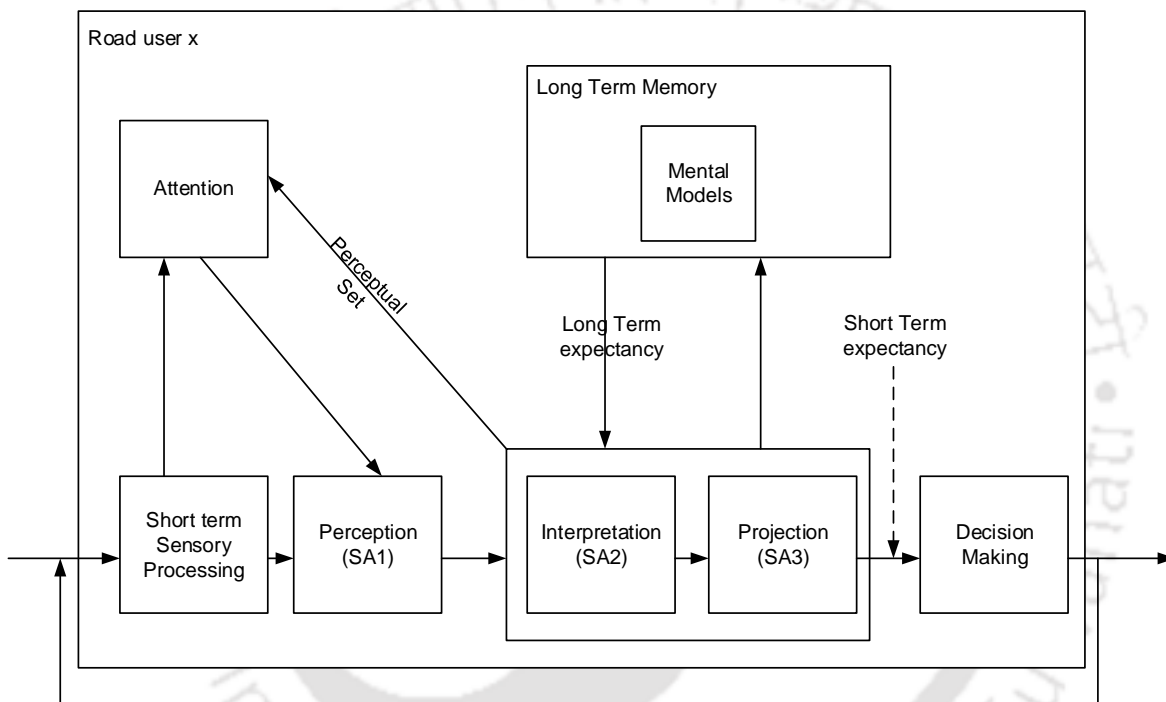


Figure 2.1: Information processing during driving, adapted from Houtenbos (2008)

The process of attention helps to allocate one's available resources on a portion of environment assisting when stimuli are difficult to perceive in the execution of a simultaneous task, and when people are overloaded with information. Attention can either be directed voluntarily or drawn by external stimuli. During driving, attention can be guided by the expectation or by sudden changes in the environment. Thus, attention can be focused (only listening to music) or divided (listening to music while driving) (Eysenck, 2000).

Driving is made-up of a number of tasks and driver has to allocate attention to all of them. Michon (1985) depicted driving as a hierarchy. There are three levels; the strategic level, manoeuvring level and control level. At the strategic level the rout, trip goal, and the modal choice are planned. At the manoeuvring level, the driver negotiates curves, junctions, and obstacles by the use of common driving manoeuvres. At the control level the driver performs

automatic actions, which include braking, gear changes and steering. The time required for each activity at different levels decrease as we move from strategic to control level.

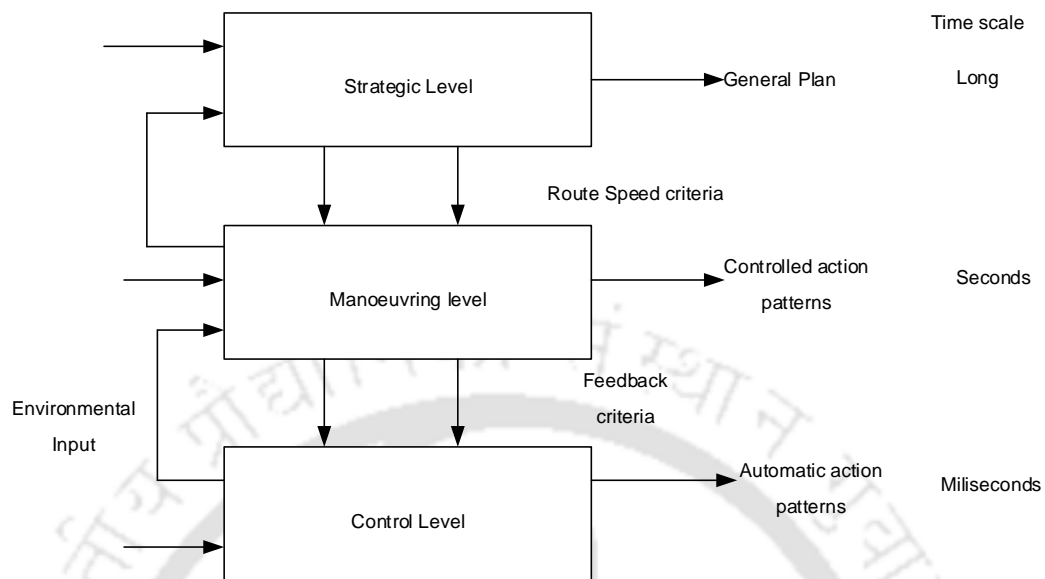


Figure 2.2: Hierarchy of driving according to Michon (1985)

The Contextual Control Model (COCOM) of driving is mainly focused on performance rather than information processing (Hollnagel, 1993). Human action cycle is mainly based upon ideas, which are driver's knowledge of and assumptions about the situation. Based on these ideas, driver will perform certain actions, which will invoke an event and there is feedback to the action. The disturbances in the event and the environment, influence the idea and the cycle continues. This model is based on role of situational awareness in generating these ideas.

According to Endsley (1995), situational awareness in driving can be described as

1. Perception of elements in the current driving situation.
2. Comprehension of the current driving situation.
3. Projecting the future characteristics of the driving situation.

Thus the driver has to take in information from the environment by 'attention', process the information to understand the situation and foresee how it might change and respond accordingly.

The driver can allocate attention to two or more things at the same time and also perform well, if there are sufficient resources to cope up with the requirement of the task. There are some theories that have tried to explain the human capacity and allocation of resources.

1. *Single Resource Theory*: This theory suggests that only a single pool of resources is available for doing the task and task performance is dependent upon whether or not sufficient capacity is being allocated from this pool for doing this task.

Allocation of resources is dependent upon persons strategy, characteristic and his motivations (Kahneman, 1973; Norman & Bobrow, 1975).

2. *Multiple Resource Theory*: It suggests that there are separate pools of resources for special and verbal information processing, different modalities, stages of information processing and motor versus verbal response. These resources may be jointly or independently utilized depending upon the task demand (Wickens, 1991).
3. *Malleable Attention Resource Theory*: According to this theory there is a separate pool available for information processing and the size is positively dependent upon mental worked-load up to a certain limit. Hence, a large reduction in mental workload can temporarily cause shrinkage in this capacity (M. S. Young & Stanton, 2002).
4. *Control Architecture*: According to this common resources can be shared effectively between two or more completing tasks true practice. Thus drivers experience of using certain systems can influence driving performance (Schneider & Detweiler, 1988).

Eysenck (2000) concluded that when task attention is divided between task then the performance is dependent upon first task similarity second task difficulty third practice. It is argued that practice can improve the dual task performance. This concept draws its similarity from the concepts of automatic and controlled processes (Shiffrin & Schneider, 1977).

1. *Automatic processes* are employed in performing highly practiced task that don't require any thought. They place minimal demand on the information processing of the humans.
2. *Controlled processes* are needed in new situations. Thus task is carried out serially. This kind of processing is slow and strenuous, but powerful.

In some driving scenarios the driver voluntarily allocates some attention to the secondary task and in some other situations, their attention is automatically drawn towards certain things or stimulus. In both the cases, driver is distracted from the primary task of driving. In this way the safety of the driver as well as other road users is jeopardized.

2.3 Driver inattention

Driver inattention and distraction are the major contributing factor in car crashes and accidents, and this problem will escalate exponentially as more and more in-vehicle devices/ technologies find their way into the vehicle. It is essential first to understand what is Inattention and distraction, to understand the problem of distraction among drivers. Often these two terms are used interchangeably.

According to Shorter Oxford English Dictionary, 2002, Inattention is defined as "failure to pay attention or take notice." However, this definition is devoid of the context of driving.

In literature, there are only a few definitions of driver inattention with varying meanings. According to J. D. Lee, Young, and Regan (2008), driver in-attention is “diminished attention to activity critical for safe driving in the absence of competing activity.”

Treat (1980), says driver inattention happens “whenever a driver is delayed in the recognition of information needed to safely accomplish the driving task, because of having chosen to direct his attention elsewhere for some non-compelling reason.”

Klauer et al. (2006), defines inattention as, “any point in time that a driver engages in a secondary task, exhibits symptoms of moderate to severe drowsiness, or looks away from the forward roadway”.

Talbot, Fagerlind, and Morris (2013), defined driver inattention as “low vigilance due to loss of focus.” Some crash studies have defined driver inattention as “when the driver’s mind has wandered from the driving task for some non-compelling reason” such as when the driver is thinking about family problems or daydreaming and not focusing on driving task (Craft & Preslopsy, 2009).

According to Victor, Engström, and Harbluk (2009), inattention is defined as the improper selection of information, which can be due to, either lack in the selection of information or by selection of inappropriate information. Hence, driver inattention is the improper selection of information, which is critical for safe driving, either by the lack in the selection of relevant information (e.g., closing of the eye due to fatigue) or selection of irrelevant information which can be both relevant as well as irrelevant for driving. The latter part of driver inattention is Driver distraction, in which the driver selects information which is not critical for safe driving. Driver distraction can be seen as a subset of driver inattention, which includes all the situations of misallocated attention except for where attention is not at all allocated.

2.4 Driver distraction

In the past decade, driver distraction has become a growing concern for governments, road safety researchers, and the general public. Empirical studies have shown the deleterious effect of driver distraction on the driving performance of drivers and a major concern of traffic safety. As per the reports of NHTSA, a total of 32,675 people were killed in vehicle accidents on U.S. roads and about 2.3 million injured these accidents in 2014. Distracted driving accounted for crashes which killed about 3,179 people, making it about 10% of all the fatalities.

Despite the heightened awareness of the issue concerning driver distraction, no consensus has been reached on its definition. Over the years, numerous definitions have emerged, many of which are vague or contradictory (Foley, Young, Angell, & Domeyer, 2013). As a result of this inconsistency, driver distraction studies are often difficult to compare and challenging to replicate (Savino, 2009). However, efforts to standardize the definition of inattention and driver distraction have been brought about by the need to reliably operationalize these concepts (Regan et al., 2011; Trick, Enns, Mills, & Vavrik, 2004).

2.4.1 Defining driver distraction

The definition for driver distraction was not properly articulated until recent past. Hence, based on their study needs and context, different researches have come up with a variety of statements to define driver distraction in the past few decades. Some definitions have been presented below:

Treat (1980) argues that driver distraction occurs “whenever a driver is delayed in the recognition of information needed to safely accomplish the driving task, because some event, activity, object, or person within (or outside) his vehicle, compelled or tended to induce the driver’s shifting of attention away from the driving task”.

According to Hoel, Jaffard, and Van Elslande (2010), driver distraction results "from interference between a driving task and an external stimulation without link with driving (e.g., guide a vehicle and tune the radio). This secondary task can be gestural or visuo-cognitive".

According to J. D. Lee et al. (2008), “Driver distraction is the diversion of attention away from activities critical for safe driving toward a competing activity.”

Ranney et al. (2001), defines driver distraction as “any activity that takes a driver’s attention away from the task of driving. Any distraction from rolling down a window, over adjusting a mirror, tuning a radio to using a cell phone can contribute to a crash.”

The common points in all the definitions is that:

- There occurs a diversion of attention away from driving.
- There is a competing activity, either inside or outside the vehicle (either related or unrelated to driving) which compels driver to divert their attention.
- There is an presumption that this competing activity adversely affect safe driving.

In the 1st International conference on distracted driving the following definition of distraction driving was adopted by the group of internationally renowned scientists (Hedlund, Simpson, & Mayhew, 2006)

“Distraction involves a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task, or event not related to driving, which reduces the driver’s awareness, decision-making, and/ or performance, leading to an increased risk of corrective actions, near-crashes, or crashes.”

According to Regan et al. (2011), driver inattention means – “insufficient or no attention to activities critical for safe driving”, and driver distraction is – “just one form of driver inattention, with the explicit characteristic of the presence of a competing activity”.

2.4.2 Taxonomy and sources of driver distraction

Driver distraction is a phenomenon that occurs due to multiple factors, which may occur either inside or outside the vehicle. Categorization of these factors is done to clearly identify the key causal activity leading to distraction. As per literature four types of distraction exist (more than one can be active at a time).

- Visual (e.g. looking away from roadway)
- Auditory (e.g. responding to ringing cell phone)
- Bio-mechanical/ physical (e.g. adjusting CD player)
- Cognitive (e.g. lost in thought).

Visual distraction: This may take one of the three types – 1) visual field of driver is blocked by an objects (sticker on windscreen etc.), which hinders the vision and driver is unable to detect hazards in road environment, 2) when the driver focuses their visual attention on other targets that are not critical for safe driving (such as in-vehicle navigation system) for long period of time, 3) when drives' visual attentiveness is lost, this is referred to as "looked, but did not see" (Hajime, ATSUMI, Hiroshi, & AKAMATSU, 2001)

Auditory distraction: This type of distraction occurs when driver is focusing their attention to sounds/ audio signals (momentarily or long duration) instead of primary task of driving; this can happen while listening to music/ radio/ talking to passengers.

Bio-mechanical (physical) distraction: This type of distraction happens when driver is physically distracted by removing their hand-off steering wheel or performing any physical task which is not critical for safe driving (Haigney, 1997).

Cognitive distraction: When driver is thinking about something to an extent that they are unable to safely maneuver the vehicle in traffic, then cognitive distraction is said to occur. Reaction to hazardous events occurring on the road environment is reduced. Talking on mobile-phone while driving has been reported as one of the cause leading to cognitive distraction.

There are several factors that can distract the driver from primary task of driving. The NHTSA has found the different sources of driver distraction (Stutts, Reinfurt, Staplin, & Rodgman, 2001). Causes of distraction can be subdivided into internal and external sources (Regan, Lee, & Young, 2008). Table 2.1, shows the different sources of distraction, categorized as internal (those occurring inside the vehicle) sources and external (occurring outside the vehicle) sources.

There exist an ample evidence of empirical studies that shows the detrimental effect of these sources on driving performance (speed, lateral position and headway) and road safety (reaction time and chances of accidents) (Brodsky & Slor, 2013; Strayer, Drews, & Johnston, 2003)

Internal sources	External Sources
Vehicle systems	Seeking location/ destination
Communication	Other vehicle
Cell phone talking/ texting	Traffic control
Daydreaming	Pedestrian/ cyclist
Passengers	Advertising signs
Coughing/ sneezing	Sun/ other vehicle lights
Animal/ insect in the vehicle	Landscape/ architecture
Eating/ drinking	Animal
Entertainment systems	Accident/ incident
Smoking	Signs and markings
Stress	Police/ Ambulance/ Fire brigade

Table 2.1: Sources of driver distraction (internal/ external)

It is noteworthy to mention here that Horberry, Anderson, Regan, Triggs, and Brown (2006) in their study observed that even though the driver's visual attention (eye glance behavior) is affected by external sources, these sources don't significantly affect driver behavior and safety.

2.5 Studies on internal sources of distraction

Distraction that occur due to activities taking place inside the vehicle are termed as internal sources of distraction. These include those caused due to use of cell phones (smart-phones), conversation with passengers, listening to radio and music, In-vehicle Information System (IVIS), eating, drinking, smoking etc. Various studies relating to these sources are discussed below.

Cell phone

A variety of studies have shown the detrimental effects of mobile phone use on driving performance and behavior; their use has also resulted in increased cases of accidents. Mobile-phone can either be used by the drivers for conversing or texting; in both situations, there is a detrimental effect on the driver's driving performance.

A driving simulator-based study conducted by Choudhary and Velaga (2017b) examined the effect of texting and talking over mobile-phone on driving performance. The variables under investigation were, ability to avoid accident and mean speed. The effect of age on driving performance was also evaluated by dividing the participants into three age groups (youngster, middle-aged, old). It was observed that the increase in workload was compensated by reducing the speed; also, it was seen that chances of accident increased when drivers were using cell-phone for texting or talking during driving.

Using mobile phones while driving results in a damaging effect on the reaction time of the driver. It is a suitable parameter to measure event detection performance under the influence of distraction. In a simulator study Choudhary and Velaga (2017c), analyzed and modeled the effect of mobile phone distraction on the reaction time of event detection; about $n = 100$, drivers were chosen for the study, with three different age groups. Two scenarios were used (1) pedestrian crossing events, (2) road crossing event by parked vehicle. Results revealed that in both cases, there was a considerable increase in reaction time.

The use of mobile-phone is more prevalent among youngsters. Due to their attitude of taking risk and inexperience in driving, the risk of accidents for this group of population increases if the mobile-phone is used while driving. Choudhary and Velaga (2019) comparatively studied the longitudinal and lateral vehicle control for younger ($n=25$) and experienced ($n=24$) age groups. Results revealed a degradation in driving performance for an in-experienced younger population during the usage of mobile-phones. However, experienced drivers also showed driving performance degradation under increased workload conditions.

In another simulator study, Haigney, Taylor, and Westerman (2000) examined the effects of mobile-phone type (hands-free and hand-held) on driving performances. Results revealed an increased mean heart rate of drivers during the phone call duration, which could be associated to increased cognitive load. This doesn't lead directly to reduced driving performance but has significance in safety and risk of accidents. However, no significant change in heart rate were observed for mobile-phone types. It was reported that drivers engaged in compensatory behavior of reducing the speed during phone-calls as a measure of dealing with the increase workload; also poor driving performance were observed for hand-held phones (as compared to hands-free).

Strayer et al. (2003) in a simulator experiment observed that, conversing on a hands-free phone while driving reduced the reaction time of driver to the braking of vehicle in its front. This result was found to be more under high traffic condition.

Papadakaki, Tzamalouka, Gnardellis, Lajunen, and Chliaoutakis (2016) examined the driving performance of experienced drivers under the influence of mobile phone use. This study was performed using a driving simulator on Greek professional drivers under varying condition. Results revealed that "variation of the steering position per second" was significantly affected by texting and text message reading, also significant changes were observed for "following distance per second" and "variation of lateral lane position per second" when compared with control time.

In a study by Dozza, Flannagan, and Sayer (2015), data was collected from the naturalistic driving study and the effect of mobile-phone usage was analyzed on lateral and longitudinal vehicle control; drivers were divided into three age groups (younger, middle-aged and older). Results showed that younger drivers were more likely to use mobile-phone while driving than middle-aged and older drivers. It was also observed that the drivers tend to increase their safety margin with age and when using phone, this can be to reduce the risk of accidents. It was also

observed that drivers tend to terminate the phone calls when driving was more demanding, this behavior showed the driver's awareness about the negative effect of mobile phone usage on driving and their safety.

Talking to passengers

Talking or conversing with the passenger tend to deviate the driver's attention from the road. This deviation of attention could increase the chances of accidents. Researches have tried to comparatively examine the detrimental effect of conversation with passenger and cell phone use. In a driving simulator experiments conducted by Laberge, Scialfa, White, and Caird (2004), 80 participants were examined under three conditions (driving alone, driving with a passenger, and driving with a cell-phone). It was observed that lane and speed maintenance variables were influenced by the demands of driving, also the response time to the incoming pedestrian increased when driver were talking and driving as compared to when drivers drove without conversation.

In another study Drews, Pasupathi, and Strayer (2008) comparatively examined talking with passengers and cell-phone conversation while driving. It was observed that cell phone conversation differ from talking to passenger in the way that traffic becomes a part of conversation allowing the sharing of situation awareness between driver and passenger; the complexity of conversation change according to driving condition. Thus, the negative effect of conversation on driving is mitigated. On the contrary, driving errors were found to be highest under cell-phone conversation condition.

White and Caird (2010) conducted a driving simulator based experiment to examine the effect of conversation with passengers on measures of driving performance (social factors, hazard detection, and looked-but-failed-to-see (LBFTS) errors). Results of the study revealed that while conversing with the passengers a higher rate of hazard detection and LBFTS errors occurred compared to when driving alone.

Listening to radio & music system

Relatively few studies are present which have evaluated the effect of music, radio and entertainment systems on driving performance. In a simulated driving study conducted by K. L. Young, Mitsopoulos-Rubens, Rudin-Brown, and Lenné (2012), the effect of using a portable music player was seen on driving performance. The results showed that when drivers performed music search tasks while driving, their eye-off-road time increased; time head-way from the lead vehicle and lane maintaining ability decreased.

Some other researchers have also examined the effect of listening to music while driving on performance of drivers. Ünal, de Waard, Epstude, and Steg (2013) empirically studied the influence of music on driving performance, arousal, and mental effort in a driving simulator-based experiment. Heart rate was also measured to observe the physiological markers

of arousal and mental effort. It was observed that listening to music didn't affect the car-following accuracy. Positive effect on response to speed change of lead vehicle and lateral control were observed. Additionally, the mental effort (measured by heart rate variability) didn't had any significant difference during music and no-music conditions, also, it was seen that arousal was more during music condition (loud and moderate music had no effect). The results suggest that listening to music don't have detrimental effect on car-following task and there are improvements in some aspects due to increased arousal.

In recent years drivers have also started to listen to audio-books while driving. Researchers have argued that there may be situation when distractions from secondary task can alleviate the boredom and fatigue due to monotonous driving. In a simulator study which supported the above argument, Nowosielski, Trick, and Toxopeus (2018) evaluated driving performance measure (speed, SD of speed, brake response time, SDLP) under simplex and complex driving conditions. It was seen that brake response time was higher in complex task than in simple. It was also seen that the overall driving performance was injurious under complex driving condition. Faster response to hazards were observed when drivers were listening to audio-books under simple driving scenario.

In-vehicle information systems (IVIS)

With the technological advancement many new technologies are being used by drivers inside the vehicle. These so called in-vehicle technologies are supposed to assist the driver by providing information about traffic, road condition, nearby vehicles and pedestrians. However, it has been argued by Carsten and Brookhuis (2005) about the safety evaluation of IVIS products and their effect on driving performance.

In the past few years, product innovation and advancement in GPS technology have made mobile-phones as navigation device. They provide maps with turn-by-turn directions. Drivers have started preferring portable (mobile-phone based) navigation device over the conventional on-board systems. An experiment conducted in real driving scenario by W. C. Lee and Cheng (2010), compared portable and on-board navigation system in terms of efficiency and car control. Results reveal that, trip duration were shorter for portable navigation system and car handling was better in portable system as compared to on-board navigation systems.

In an empirical study conducted by S. Benedetto et al. (2011) in a simulated driving environment, the effect of using IVIS on blink duration of drivers was examined. LCT was used in the simulated driving. Results showed that blink duration was more reliable and sensitive marker of visual workload of driver as compared to blink rate.

Also it is seen in recent years that, use of portable Advanced Driver Assistant System (ADAS) is raising. An empirical study conducted by Dumitru, Girbacia, Boboc, Postelnicu, and Mogan (2018), showed that using a smartphone based portable ADAS would improve the driving performance and reduced the distracting effects of using social media networks during

driving. Dumitru et al. developed a smartphone based ADAS system that would give an audio warning when the drivers are distracted and focusing their attention on non-driving related task. The ADAS notifications provided during distracted driving ensures that the drivers' attention is focused on road and there is minimum driving infractions.

Some researchers have tried to investigate effect of using Surrogate In-Vehicle instrument system on the driving performance. In a high fidelity simulator experiment carried out by Jamson and Merat (2005), two modes (visual and cognitive) of secondary task represented the surrogate IVIS were used to evaluate the primary task (driving) performance in a car following task. Results showed that no difference of performance were seen between visual and cognitive tasks. However, the driving performance was decreased as a result of increasing surrogate IVIS demand, this was shown as reduced time-to-collision and diminished prediction of braking requirements.

In the recent past, Head-up Displays (HUD) are being employed for providing in-vehicle information to the drivers in high-end passenger cars. In general these HUDs are displayed on the windshield. Although, there are certain advantages of using a HUD, that include, reduced eye-off-road time, elimination of refocusing and eye-axes convergence movements, and more time available to see on-road scene, there are several disadvantages to using HUDs (Bhise, 2012). The demerits of using HUDs include, a) attention switching, visual clutter and distraction, b) the on-road scene may get masked by images from HUD, c) the projected HUD image may not be visible in bright light and glare, d) requirement of providing additional controls for adjusting the image brightness, location and switching on/ off, e) possibility to capture driver's attention under low demanding visual environment (Bhise, 2012)

Eating, drinking, smoking, and alcohol consumption

Eating while driving can cause safety issues to the drivers and pedestrians on the road since it causes the driver to reach for the food physically. In a simulated driving study, M. S. Young, Mahfoud, Walker, Jenkins, and Stanton (2008) evaluated the impact of eating and drinking alongside driving. In the simulation program, the pedestrian crossing event happened when the instruction to eat and drink was given. Empirical results suggest that the risk of accidents was increased as an outcome of physical demand caused due to drinking and eating while driving.

The effect of talking, smoking, and eating on driving performance was analyzed by Yannis, Papadimitriou, Bairamis, and Sklias (2011) on a simulated driving on a rural road condition. The participants were instructed to consume snacks and smoke cigarettes at given points. Results revealed a decrease in speed was associated with talking (simple and complex), smoking, and eating. However, Complex conversation was associated with increased reaction time and lane departure. No relationship could be established between increased reaction time and the risk of accidents due to smoking and eating.

Alcohol intoxication negatively affects the driver's ability to maneuver the vehicle in traffic

successfully. A simulated driving study conducted by Harrison and Fillmore (2011) examined the effect of alcohol on driving performance under divided attention task. Results showed that divided attention aggravated alcohol's impairing effect on driving performance; however, no detrimental effect of divided attention task was examined for sober drivers.

2.6 Distraction due to external sources

Sources of distraction which occur outside/ external to the vehicle are termed as external sources of distraction. In many countries, due to development of highways, billboards, roadside advertisements, increased traffic density, complex roadways signboard together increase the amount of visual information being presented from outside to the drivers.

Road side advertising signs are the most prominent external sources of distraction which the drivers come across while driving. In a study conducted by Bendak and Al-Saleh (2010) in a simulated environment evaluated driving performance on a part of road with advertisement and other without it. The results of the simulated study showed that the lane excursions and crossing of intersections were significantly worse in path having advertisements, whereas, indicators such as over speeding, number of tailgating, and lane changing without signaling were also worse in advertising paths but not statistically significant. Questionnaire based response to showed that about 22% drivers were in near-crash situations due to these advertising signs.

In another simulator study M. S. Young et al. (2009) evaluated mental workload, driver attention and lateral driving performance under the influence of roadside advertisements (billboard) on varying road conditions (urban, motorway and rural). The results indicated a deleterious effect of roadside advertisement on driver attention and lateral control by increasing the mental workload of drivers.

Another empirical study that evaluated the effects of billboards on drivers Edquist, Horberry, Hosking, and Johnston (2011) examined younger (inexperienced) and older drivers. The results indicated that drivers response time to road signs and number of errors increased in driving task due to billboards. A change in drivers' visual attention was also noted.

With the road side scenery changing every mile, drivers face new kind of distractions on every mile of highways. Two new kind of external distractions (wind-turbine and video billboards) were examined by Milloy and Caird (2011) in a simulated driving condition. Speed maintenance, perception response time, lane keeping were the compared, while driving alongside the distraction and baseline. The perception response time was not found to be significantly different from the baseline in the wind-turbine task, however, slow speed were noted when passing by wind farms. In case of the video billboard task, significant large collisions to lead-vehicle braking occurred in comparison to conventional billboards and baseline.

2.7 Studies on drivers' characteristics (age, gender and experience) on distraction

Many researchers have shown the effect of age and experience on the drivers' ability to get distracted by the secondary task and their perception of hazard while performing in-vehicle tasks (McKnight & McKnight, 1993; Reed & Green, 1999).

In order to formulate any policy and corrective action plan, it's important to know the driver's understanding and attitude towards the risks associated with usage of mobile phone while driving. In a study based on the survey of Portuguese drivers carried out by Ferreira et al. (2013), tried to understand the perception of mobile-phone usage based on gender and age as an independent variable. The main findings revealed that, as compared to young and middle age drivers, old drivers, favored less usage of mobile phones while driving on highways. Also, it was observed that younger drivers send and read text messages more frequently than drivers of other age groups; the perceived risk was also higher in case of older drivers as compared to other age groups. The results in terms of gender showed that usage of mobile phone on highways was mostly favored by males whereas females (although less frequent) engaged more in sending and reading messages.

Studies similar to those mentioned earlier, McDonald and Sommers (2015) conducted a focus group study and tried to understand the perception of teenage drivers on inattention due to cell-phone usage while driving. Novice teenage drivers recognized the innate danger of using cell-phone while driving, but they still engaged; teens also gave the context or situations where they would answer a call, text or use social media app.; formulated safe driving behavior which might reduce accident risks.

The visual and cognitive ability of the old aged driver is decreased, hence their ability to share attention on coinciding tasks is greatly reduced. Therefore, these drivers are more liable to get distracted due engagement with secondary task as compared to younger drivers. Similar to this, a novice (less experienced) driver may be more vulnerable to the distracting effects of performing secondary task while driving as compared to an experienced one. Training programs and regimes as proposed by Regan, Triggs, and Godley (2000), would be helpful in training of novice drivers.

In another study to establish the relationship of internal/ external distraction with age groups, Lam (2002) concluded that drivers from a particular age group (25-29) were more susceptible to accidents when using handheld phones as compared to other age groups. This is because of their increased exposure as compared to other age groups. On the contrary Lam concluded that the danger of being involved in fatal accidents due to distraction caused by other in-vehicle tasks increases with age. Similar findings showing high susceptibility of older drivers to distraction were shown by the studies of McKnight and McKnight (1993); Reed and Green (1999).

Similarly, empirical work by Schreiner, Blanco, and Hankey (2004) on drivers of three different age groups (young, middle-aged and old) found that the forward and peripheral

event detection ability of older drivers was degraded while simultaneously performing driving and phone number dialing using voice commands as compared to normal performance. This degradation was not significant in younger and middle-aged drivers when performing the same task as mentioned above.

McPhee, Scialfa, Dennis, Ho, and Caird (2004) in an empirical study revealed that old aged drivers were slow and inaccurate in identifying the target signs in traffic as compared to young and middle-aged drivers, when simultaneously engaging in simulated conversation task.

Although many studies on driver distraction have confirmed a degradation in driving performance due to age, a good deal of other research also indicates that old aged drivers try to compensate for greater performance degradation by engaging in compensatory (self-regulatory) behavior. Horberry et al. (2006), in their studies, showed that when interacting with the entertainment system or mobile phone, the old aged drivers reduced speed to compensate for the increased workload of simultaneously performing a demanding task.

2.8 Studies carried out in India

As compared to the work which are reported from countries like US, UK, Germany, Canada, Italy, Australia; very few work have come forward very recently.

A study on Indian drivers analyses and modeled the effect of conversation and texting (each with two difficulty levels) on driving performance in terms of mean speed and accident avoiding abilities. A total of 100 drivers participated in the simulator study. The participants were divided into three different age groups (young, mid-age and old-age) The drivers significantly compensated the workload by reducing speed and accident probabilities increased when drivers were conversing or texting on phone during driving (Choudhary & Velaga, 2017b).

The effect of conversation and texting (simple and complex) on Vehicle based performance parameters such as standard deviation of lane positioning, number of lane excursions, mean and standard deviation of lateral acceleration, mean and standard deviation of steering wheel angle and steering reversal rates (1° , 5° and 10°) was studied (Choudhary & Velaga, 2017a).

Reaction time is a suitable parameter to measure the effect of distraction on event detection performance. A simulator study analyses and modeled the effect of mobile phone distraction on event detection. N=100, drivers were chosen for the study, with three different age groups. Two scenarios were used (1) pedestrian crossing events, (2) road crossing event by parked vehicle. In both the cases there was considerable increase in reaction time (Choudhary & Velaga, 2017c).

Radakrishnan et al. (2016), studied the positioning of infotainment screen inside vehicle for better visual experience using RAMSIS and SPEOS OPTIS for occupant visibility and reflection evaluation. Parameters like vision angle, avoiding any obscuration due to vehicle components, avoiding in-vehicle reflections and avoiding ambient reflections were emphasised.

Visual hindrance such as obscuration, reflection and glare on the instrument cluster which prevents the vital information flow from vehicle to the driver were studied. Ganesh, Mohammed,

Krishnan, and Rambabu (2015) described the cluster packaging process flow for in-vehicle visual hindrance free instrument cluster position.

Rajesh, Srinath, Sasikumar, and Subin (2017) presented safety risk perception model, to understand how vehicle and driver characteristics influences mobile phone usage while driving and associated risk perception of road safety. Survey was conducted on 1203 drivers in Kerala.

2.9 Studies on location/position of in-vehicle displays

In recent years, our vehicles are loaded with increasing number of displays and digital systems. Using in-vehicle displays lead to deviation in normal visual scanning behaviour and attention of drivers and increase the task completion time (Ali & Bazilah, 2014; Lamble, Laakso, & Summala, 1999). The position of in-vehicle display plays an essential role in safe commutation. Researchers empirically examined the effect of the positions of car navigation display on eye movement and braking reaction time (Itoh et al., 2005). Position is an important factor in frequently used and high attentional demand in-vehicle displays. Large, Crundall, Burnett, Harvey, and Konstantopoulos (2016), compared the configuration of CMS to the traditional side mirrors in a lane change test. They measured eye movement, driving performance, subjective rating for evaluation. The results showed reduction in decision time and eye off road when using CMS. the subjective rating showed that, configuration which was close to the traditional side mirror location were preferred by the drivers. However, they did not discuss about the size and location of the display.

Recently reported studies tried to evaluate the different positions of in-vehicle displays empirically in terms of driving performance measures. Radakrishnan et al. (2016) presented a framework for positioning of infotainment screen inside the vehicle for an improved visual experience (Radakrishnan et al., 2016).

Another study conducted by Beck et al. (2017), evaluated the in-vehicle side-view display layouts in critical lane-changing situations. They showed that the spatial arrangement of mirror/ display significantly affected the dependent measures (response time, eye-off-road time, perceived safety rating, perceived workload, and preference ratings) (Beck et al., 2017).

Ishiko et al. (2013) evaluated two different sizes of navigation systems at three locations for driving safety based on gaze data and subjective rating. They found that the 7 – inch display size was preferable than 4.3 – inch, while among the three locations, the position of the left side of the steering wheel was more desirable irrespective of display size (Ishiko et al., 2013).

A comparison of different locations and size of in-vehicle display was performed by Doi et al. (2019), for Camera Monitor System (CMS) used as a replacement of side-view mirror. They evaluated three different sizes of displays at three different locations inside the vehicle (Doi et al., 2019).

Gathering behavioral data, eye-tracking, and subjective ratings of the participants in a driving simulator study; Wittmann et al. (2006), attempted to determine the relative safety

of on-board display positions, concluded that drivers' performance is disturbed exponentially as a function of distance between the on-road line-of-sight and the on-board display position. Thus, nearer the on-board display to the straight forward line-of-sight, the less detrimental effect is on the actual driving performance during on-board visuo-motor control of a secondary task (Wittmann et al., 2006).

2.10 Methodologies for measuring distraction

Distraction is measured in terms of drivers' driving performance, and there are numerous methodologies for evaluating the driving performance. The most realistic is the naturalistic driving method, and lab test give a good amount of experimental control.

Driving performance have largely being measured by the use of instrumented vehicles on the test tracks or on road (Carney, Harland, & McGehee, 2016), and driving simulators (Horberry et al., 2006). One of the important naturalistic driving study was conducted on 100 drivers and the movement of their vehicle was recorded for 20,00,000 miles (Klauer et al., 2006). There are wide variety of driving performance, driver behavior, task performance and demand measures. Figure 2.3 shows the different methods of measurement for driving performance. It is clear from the figure that as the realism of the experiment increases, the experimental control decreases and vice-versa. The methodologies for assessing distraction has been categorized as naturalistic studies (those conducted under natural driving condition) and driving simulator studies (conducted on a simulator in a laboratory).

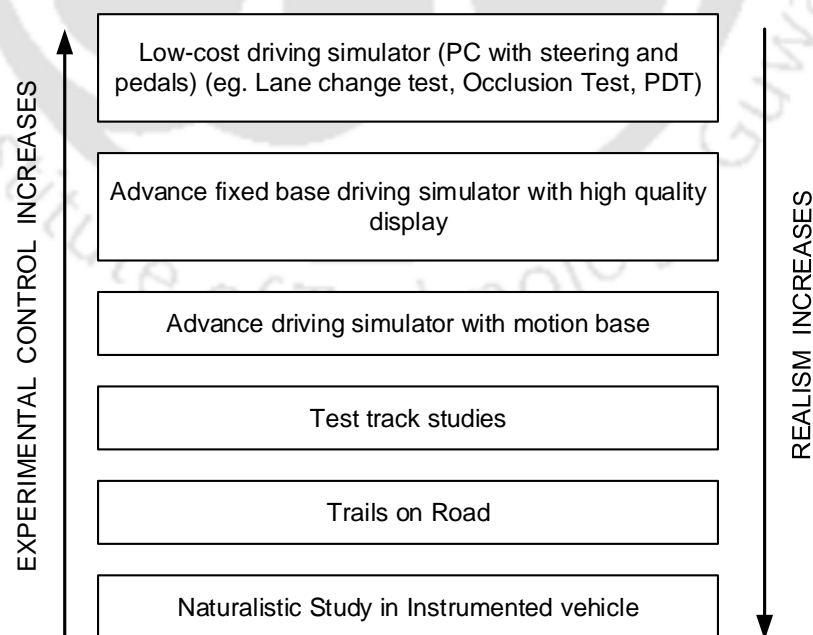


Figure 2.3: *Methods for assessing distraction*

2.10.1 Studies on naturalistic driving

For evaluating/ measuring the drivers' involvement in distracting activities in a real road scenario, naturalistic driving studies are conducted. During driving, the actions of drivers are monitored by instruments, cameras, and data loggers fitted into the car/ vehicle (Xie, Zhu, Guo, & Zhang, 2013). In this method, data is collected in a very discrete manner, and drivers are permitted to drive naturally without any instructions. Headway from lead vehicle, lateral and longitudinal controls are measured using sensors in the vehicles. These studies generate a large amount of data and are time taking (long period). For analysis and quantification of the drivers' exposure to a distracting task (personal grooming, adjusting in-vehicle instruments, drinking, and eating, reading, etc.), trained coders are needed. Carney et al. (2016) conducted a naturalistic study, and data were collected using an event-triggered IVERs (in-vehicle event recorder) technology. The accelerometer, audio, and video data were triggered by specific events and were not continuously recorded. Other sophisticated instruments can also be used in place of data loggers, such as eye-tracker for measuring visual behavior of the drivers (Xie et al., 2013; K. L. Young, Salmon, & Cornelissen, 2013).

2.10.2 Studies on driving simulator

Driving simulator (DS) studies utilize a controlled laboratory environment to conduct empirical studies to evaluate drivers' driving performance under a variety of test conditions. DS based research is safe, relatively realistic, and data from various driving performance measures can be gathered. Fidelity (realism) and validity affect the outcome of these studies. DS based study has several merits over the on-road/ test track studies. Hazardous/ unethical driving conditions/ environment can be easily and safely evaluated in the DS. Traffic and multi-vehicle scenarios can be easily simulated. A considerable amount of experimental control can be achieved in DS than the test on track/ road. A variety of hazardous driving test conditions (road, weather conditions, day/ night-time) can be easily investigated. In addition to the merits mentioned above, there are some demerits of DS based studies. Another limitation of DS based research is the effect of being monitored by the experimenter and the learning effect of using a DS. Expertise in operating the additional equipment (e.g., eye-tracker) is required in DS based research in addition to high cost (for high-fidelity) of DS. (Xie et al., 2013). Reports of DS discomfort are common for females and old-aged drivers, resulting in higher dropout compared to male drivers. Additionally, in DS, the drivers feel safer than real road scenarios; they may differently allocate their cognitive resources to secondary and primary tasks than in actual driving scenarios.

Driving simulators and its classification

DS is an advanced application of “computer-aided kinematics” and dynamic simulation. Researchers and engineers typically use them in highway design, vehicle design, and human factors (driver behavior) studies under hazardous conditions (under the influence of alcohol, drugs, severe weather condition, distracting activities), which would be illegal in a real road scenario. Studies in a DS provide safe, cost-effective, repeated measurement and controlled scenarios for testing driver behavior, vehicle, and highway designs. The DS can be used in fields ranging from advanced training, research, and entertainment. A fidelity (or utility) of a DS describes the degree with which the DS can replicate the actual driving scenario/ task. Thus, DS can be classified according to the degree of realism and subdivided as low-level, mid-level (Cuenen et al., 2015), and high-level fidelity DS (A. Benedetto, Calvi, & D’Amico, 2011); shown in figure 2.4.



Figure 2.4: A typical classification of driving simulators (a) low-level fidelity, (b) mid-level fidelity, and (c) high-level fidelity

A low-level DS typically consists of a fixed-base (FB), and fixed-screen (FS), with audio and visual cues for the drivers. The horizontal field-of-view of the low-level DS’s display screen will be narrow and displayed to the driver on a single monitor. There will be a limited provision of force-feedback through the steering wheel to the driver. These types of simulators are cost-effective and useful for students in research and dissertation work. A low-level DS is limited in its fidelity but is cost-effective.

A mid-level DS has an advanced display with wider field-of-view (horizontally), the drivers sit in a full-body vehicle, which creates a fully immersive virtual environment. In this DS, a simple motion base simulates tactile cues of road roughness and vibration.

A high-level DS has 360° field of view, 6-DoF (degrees of freedom), sophisticated graphics, full vehicle with motion base, realistic components, layout, and driving environment. The drivers will sit in a complete vehicle cab that provides full dashboard functionality. These are costly, but produce results similar to the actual road driving situation.

Apart from academic research, many automobile companies have also developed their DS. Daimler-Benz pioneered in this field by building its DS in 1985, which has upgraded over time.

Researchers have utilized different test tools combined with the driving simulator to evaluate the severity of driver distraction caused due to secondary task engagement. Combining these

test tools with the driving simulator is easy. These test tools include the peripheral detection task (PDT), visual occlusion method, lane-change test (LCT), and eye-tracker.

Lane change test (LCT)

Lane change test (LCT) is a reliable, inexpensive, and standardized test tool for measurement of in-vehicle infotainment system (IVIS) demands (Mattes & Hallén, 2009). The entire procedure of LCT requires minimum equipment and is quickly completed. It requires a simple desktop computer on which the LCT software is installed, and a simple force feedback steering wheel with accelerator and brake pedals. The LCT driving simulation consists of a 3 km test track having three lanes with 18 lane change signs along the track. Each of the sign contain one upward arrow and two "X"s, indicating the next lane into which to change. These lane change signs (same) appears on both sides of the simulated roadways. The participants have to perform lane change manoeuvres alongside maintaining the vehicle at a constant speed of 60 km/hr (which can not be increased). The mean distance between signs is approximately 150 m, having a mean duration of 9 s in between subsequent lane changes. It takes approximately 180 s time duration for each test track to complete. During the LCT, the primary driving performance measure is called the mean lateral deviation (M.Dev). There are no surrounding traffic in the driving scenario. The participants have to perform the lane change manoeuvres in a deliberate, quick, and effective manner when they were able to identify the signs. In the simulation the lane change signs are always visible, but they remain blank and appear at a distance of 40 m before the lane change sign. ISO (2010) gives a more detailed description about the LCT.

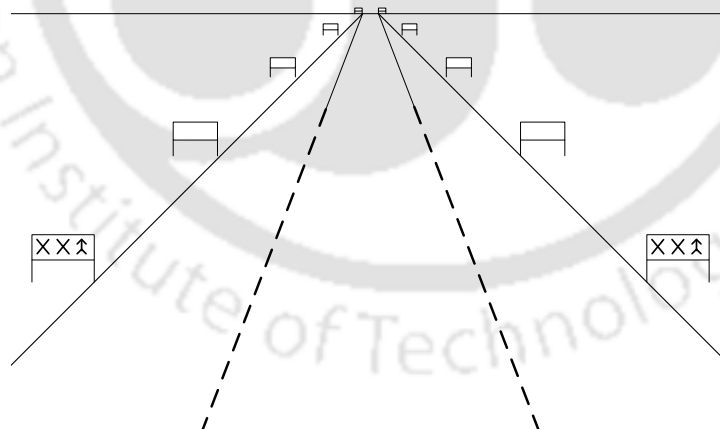


Figure 2.5: A simulated LCT roadways with lane change sign

The distracting effects of the using additional in-vehicle, navigation task along with driving has been successfully demonstrated by using LCT (J. Harbluk et al., 2007; J. Harbluk, Mitroi, & Burns, 2009; Mitsopoulos-rubens, Young, & Lenné, 2010).

Additionally, Burns, Trbovich, McCurdie, and Harbluk (2005) in an empirical study differentiated the secondary tasks based on the levels of workload by using the LCT. Higher values of mean deviation were observed while performing secondary task than when driving

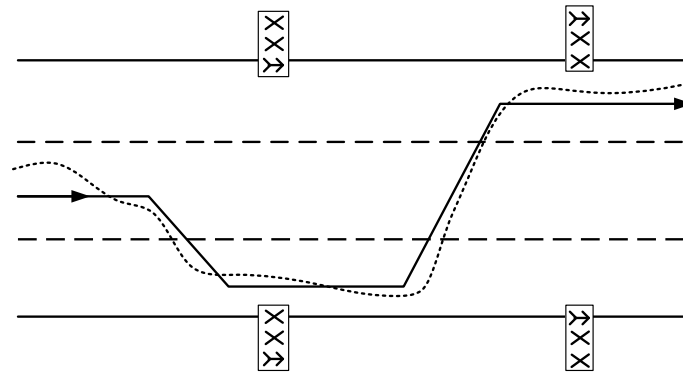


Figure 2.6: LCT test track with drivers trajectory compared with normative model

without performing it. For change in task type and complexity, the mean deviation values also showed differences.

Engström and Markkula (2007), performed a re-analysis of lane change test (LCT) data originally collected by Daimler Chrysler. They used a subset of the collected data. It was found that visual and cognitive distractions impair driving in different ways. Visual only distraction leads to reduction in path control, in contrast to cognitive distraction which affect detection and response selection.

Grane and Bengtsson (2013), used Lane change test (LCT) for empirically examining how visual and haptic interfaces affect driver performance. Four different interfaces were compared: visual only, visual-haptic with partly haptic support, visual-haptic with full haptic support, and haptic-only. The result showed that erroneous crossing of lanes were caused due to visual -only and visual -haptic with partly haptic support, whereas missed road signs were caused by haptic -only interface. Least negative effect on driver performance were observed with visual-haptic with full haptic support.

Although, ISO draft for LCT does not demand or even recommend that subject sample be balanced for gender. Petzoldt, Bär, and Krems (2009), empirically investigated if there is any change in lane change performance while engaging in secondary task across the gender. It was found that gender differences exists in LCT and secondary task performance. They concluded that the subject samples should be balanced for gender to assure comparability in LCT results.

J. Harbluk et al. (2009), examined three different navigation system with three tasks having varying complexity. They used LCT to assess the distraction demand. LCT differentiated the easy task from the difficult task. However, LCT was not able to differentiate two difficult task (having different task completion time). Hence, it was proposed to include measure of task duration in LCT since it indicates the amount of time driver deviates attention from driving (primary task).

Rodrick, Bhise, and Jothi (2013), studied the secondary task and driver characteristics (age and gender) on lane change test (LCT) performance. Four secondary tasks (data entry, memory, visual search, tracking), with each having two levels of difficulty were used in

the study. Results showed that the driving performance were least affected by the task that required memory scanning, and utilized auditory modalities, whereas, most affected by task requiring psychomotor coordination, and visual attention. Apart from this age and gender related differences were also found in LCT performance.

Peripheral detection task (PDT)

An artificial signal detection method which is lately being used in driver distraction studies is the PDT. Van Winsum, Martens, and Herland (1999) developed the first PDT, then after there has been several variations to it, namely SDT (signal detection task), TDT (tactile detection task) (Hsieh, Seaman, & Young, 2015), VDT (visual detection task). This method is based on the hypothesis that as the driving task demand increases, the stimuli' response time also increases. Simulator and on-road studies can easily implement PDT and its variants. The stimuli are presented with the spatial and temporal differences in the visual field of drivers. If an auditory stimulus is presented in the driving simulator, its referred to as the auditory detection task (ADT) Merat and Jamson (1999). The only difference between the variants of PDT is the modality of stimuli presentation; however, in all the cases, the drivers' response is collected in the same manner (micro switch attached to index finger) (Victor et al., 2009). Generally, PDT is implemented in a with-in subject experimental design, where the subjects perform driving tasks, with and without secondary task along with detecting the stimuli. Hit rate and reaction time (RT) gives the performance of a study based on PDT.

Visual occlusion method

When the driver's attention is focused on the primary task of driving, he is expected to look at the roadways; however, when he is paying attention to an in-vehicle device, his attention is not on the road. The drivers' chances to distract from driving have increased since in-vehicle devices (communication, information, and entertainment) are becoming feature-rich. Although eye-glance behavior is superior, it is time-consuming to analyze and difficult to collect. Visual demand of the in-vehicle information system (IVIS) can be measured using the visual occlusion method in the preliminary product design stage. Many researchers have used visual occlusion methods in a variety of ways to measure driver distraction.

The basis of this technique is that driving is a visual-manual task (Foley, 2009). This technique measures the visual demand of a task performed concomitantly with driving and was initially proposed by Senders, Kristofferson, Levison, Dietrich, and Ward (1967). It can be used on both simulators and on-road/ naturalistic driving studies. Visual occlusion is "physical obstruction of vision for a fixed period of time" (Gelau & Krems, 2004). In this method, the driver's vision is systematically obscured, and then the obscuration is removed. Figure 2.8, shows the obscuring and un-obscuring of driver vision. The apparatus used in the visual occlusion method is the PLATO (portable liquid-crystal apparatus for tachistoscopic



Figure 2.7: A PLATO occlusion google, Source: (Yuan et al., 2018)

occlusion) goggles, shown in figure 2.7. ISO standard 16673 (ISO, 2007) describes the various

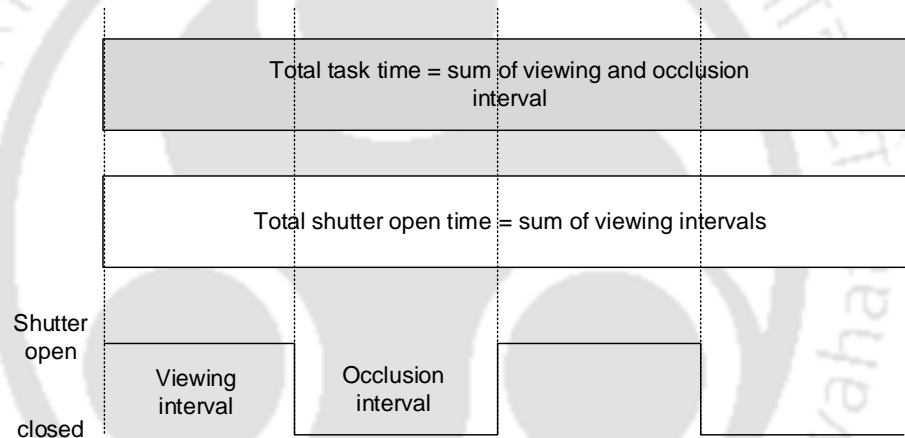


Figure 2.8: A time line showing occlusion and viewing interval, adapted from (Foley, 2009)

parameters of visual occlusion method. These parameters are; Resumability ratio (R) (*ratio of mean TSOT to the mean TTTUnoccl*), TTTUnoccl (*total task time for a task completed without occlusion*), and Total shutter open time (TSOT) (*total time during which vision is un-occluded*). The driving performance of the participants are measured under no occlusion condition and when periodically occlusion occurs. Task duration in this method is measured from the point when instruction ends to when the participants says 'done'. The acceptable shutter open time (SOT) acceptable by a standardized occlusion procedure is about 1.5 s. Several researchers have proposed this method to assess in-vehicle information system (Baumann, Keinath, Krems, & Bengler, 2004; Burnett, Lawson, Donkor, & Kuriyagawa, 2013; Gelau & Krems, 2004). Gelau and Schindhelm (2010) conducted research work to improve the sensitivity of the visual occlusion method. H. Kim and Song (2014), used visual occlusion method to evaluate the usability and safety of in-vehicle information system (IVIS). Visual occlusion method has also been used to assess the effect of work profile and age on distraction. Visual workload while

driving has also been evaluated using occlusion method (Van Der Horst, 2004).

Visual behavior study using eye-tracking

Eye-tracking studies are increasingly becoming popular for evaluating visual performance while driving. It is also observed from the literature that eye-tracking studies are conducted along with other driving performance matrices.

In an experiment to assess the changes in visual behavior due to cognitive distraction, J. L. Harbluk, Noy, and Eizenman (2002) measured mean visual gaze, mean number of saccades, percentage of time spent looking at central and peripheral area of forward view.

In a simulator based experiment, K. L. Young, Rudin-Brown, Patten, Ceci, and Lenné (2014) examined the effect of phone type (touch screen vs. numeric keypad) on visual scanning behavior of drivers. The percent of driver's total gaze time to the centre of road, frequency and glance duration to phone were used as a measure of visual behavior.

Zahabi and Kaber (2018) empirically examined visual behavior performance, workload and situation awareness in a driving simulator based experiment for current and enhanced mobile computer terminal interface design for police or emergency vehicle point the results suggest that the use of MCT (mobile computer terminal) while driving reduced perceived level of driving environment awareness an increased cognitive load of police officers. They utilized an eye-tracking variables (fixation time, off-road glance frequency, maximum off-road glance duration) along with other variables (like driver performance, level of awareness, and perceived workload, secondary task time) as the dependent variables.

Metrics used in eye-tracking studies

The components that form the basics of eye-tracking metrics are described below:

- *Point-of-regard*: The raw output data of the eye-tracker which indicates where the person is looking is said to be the point-of-regard (PORs)
- *Fixation*: A spatially stable PORs forms the fixation, which are defined by duration and location. Visual processing occurs during fixation.
- *Saccades*: The rapid eye movement which occurs between successive fixation is called saccades. There is no occurrence of visual processing during this duration.
- *Scanpath*: The sequence in which the fixation and saccades occur, through which visualization of eye-movement is possible is called scan path.
- *Area of Interest (AOI)*: Its an area/ region on the visual display, defined by the experimenter, at which the data of eye-tracking is analyzed.
- *Gaze/ dwell/ glance*: It is the sum total of the fixation duration starting with the first fixation in the particular AOI to the first fixation outside that particular.

2.11 Variables for measuring driving performance

Driving performance variables indicate the level/ degree of distraction when a driver performs a secondary task(s) while driving. Distraction affects the drivers at multiple levels; hence, a single driving performance measure can't capture the entire picture. Driving performance metrics can be categorized as longitudinal (speed, longitudinal control, headway) and lateral control (SDLP, SRR, lateral acceleration, and lane excursion) variables. While choosing the driving performance variable, its agreement with the distraction measurement method is of prime importance. Given below are the brief descriptions of the commonly used indicators of driving performance.

Longitudinal control

Most commonly used longitudinal control measures are speed and headway.

- (a) Speed is an essential and commonly used variable in driver distraction and road safety research. These variables include maximum, mean, 85th percentile, and variability of Speed. Both on-road and driving simulator research has shown drivers displaying greater speed variability while performing a secondary task during driving (A. Benedetto et al., 2011; Reimer, Mehler, & Donmez, 2014).
- (b) Headway is the distance between the front and the following vehicle. It is an indicator of safety margin and also called as a vehicle following. Standard deviation (SD), minimum, and mean headway are the most commonly used variables in driver distraction studies (A. Benedetto et al., 2011; Peng, Boyle, & Lee, 2014).

Lateral control

The steering wheel and lane-keeping metrics are the commonly used lateral control variables used in driver distraction research.

- (a) Lateral position (lane keeping) is the vehicle's relative position with respect to the center of the lane in which the vehicle is moving. The lateral position of the vehicle is affected by the secondary task demands. Commonly used lane-keeping metrics in the driver distraction research are the number of lane exceedances, SDLP (standard deviation of the lane position), and mean lane position (Cuenen et al., 2015).
- (b) Steering wheel (SW) metrics comprises of steering reversal rate (SRR), SD (standard deviation) of SW angle, and SW angle (Savino, 2009) Higher SW movements will be observed when drivers perform visual-manual secondary task compared to when not.

Reaction time & event detection

The variables which are representative of the reaction time and event detection parameters consists of response time and distance (the distance of event when detected), number of incorrect responses, number of missed/ detected events. Both driving simulator and on-road studies have shown a decline in drivers' ability to react and identify objects/ events, under the influence of secondary task (A. Benedetto et al., 2011; Haque & Washington, 2015; Yannis, Papadimitriou, Karekla, & Kontodima, 2010).

Gap acceptance

The elements of gap acceptance measure are, size of gap accepted, and the number of collisions initiated. Studies have shown that drivers initiate a higher number of collisions, and take smaller gaps when interacting with in-vehicle instruments (Ashalatha & Chandra, 2011; Cooper & Zheng, 2002).

Eye-movement metrics

Researchers have used a number of Eye-movement metrics in their studies as an indicator of driving performance. These metrics include fixations count, saccades (Wang, Wang, Wang, & Zhao, 2016) and smooth pursuits which are increasingly becoming popular in driving simulator studies (J. L. Harbluk, Noy, Trbovich, & Eizenman, 2007; Kujala & Saariluoma, 2011; Zahabi & Kaber, 2018). Eye-tracking metrics can be obtained in combination to other driving performance variables in either naturalistic or simulated studies. S. Benedetto et al. (2011) used eye-movement metrics (blink rate, blink duration, Average pupil diameter) as a measure of drivers' workload. Details about various studies using eye-movement metrics for evaluating driving performance has been discussed in section 2.10.2.

Measure of workload

According to Verwey (2000), "mental workload is related to the amount of attention required for making decisions". Mental workload is measured by either subjective or physiological measurement techniques, the following section will briefly discuss these techniques.

1. *Subjective workload measurement*: These metrics record the participants' workload after they have performed a task. In driver distraction research, the primarily used workload scales include NASA Task Load Index (NASA-TLX) (Horberrry et al., 2006), Situation Awareness Global Assessment Technique (SAGAT) (Gugerty, 2011; Salmon, Stanton, & Young, 2012), Rating Scale Mental Effort (RSME) (Zijlstra, 1993). Some studies have also reported using DALI (Driving Activity Load Index) scale (Pauzié, 2008; Pauzié, Manzan, & Dapzol, 2007; Petzoldt et al., 2009). It is a modified version of NASA-TLX

- developed to assess the driver's workload while operating in-vehicle devices. Assessment using this method is inexpensive, non-invasive, and fast.
2. *Physiological workload measurement*: These techniques are based on the fact that the physical response from the body would increase with an increased mental demand (Moray, 1979). Commonly used physiological measures of workload include cardiac, speech measure, respiratory, and brain activity. Cardiac activity (ECG, heart rate (Haigney et al., 2000), heart-rate variability (HRV), and blood pressure (BP) (Enokida et al., 2013)); Respiratory activity is measured by the number of breaths in a given time and the amount of air intake of a person. Speech measures note the rate, pitch, loudness, shimmer, and jitter in speech when measuring workload. Brain activity is measured by electroencephalogram (EEG) (Enokida et al., 2013). Eye-movement matrices such as blink rate, pupil diameter, and blink duration have also been used to measure drivers' workload (S. Benedetto et al., 2011; Dlugosch, Conti, & Bengler, 2013).

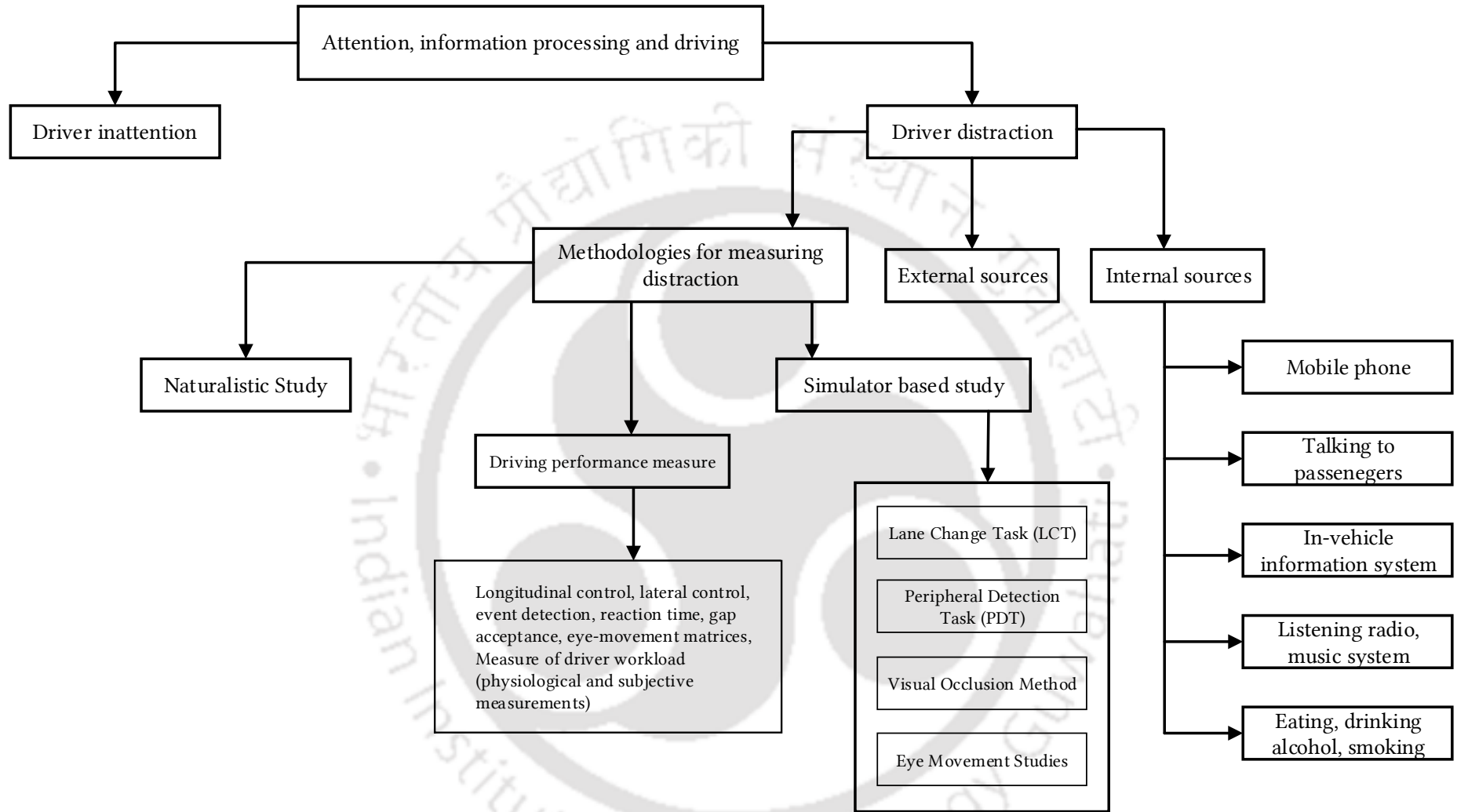


Figure 2.9: A summary of literature review

2.12 Digital human modeling (DHM) in product design and development

Every day, a wide variety of products come in the market. It is believed that the finished product will fit the consumer regardless of their physical, cognitive capabilities/ limitations; however, it is not always true—a mismatch between consumers and the end product is commonly observed phenomena. Designers of innovative products are aware that using ergonomics considerations can lead to the product's overall success.

International Ergonomics Association (IEA) defines Ergonomics (Human Factors) as “the scientific discipline concerned with the understanding of the interaction among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design to optimize human well-being and overall system performance” IEA (2019). Human-machine compatibility can be investigated with the traditional ergonomic methods, which involves physical mock-ups and consequent trails with real human beings. This process is expensive and time-consuming. With the advancement in computer technology and 3D visualization techniques, the use of DHM software for virtual ergonomic evaluation has gained momentum. Specialized Computer-aided Design (CAD) methods utilizing DHM software have given the possibility to proactively incorporate human factors in designing and developing a product. In DHM software, digital human (manikin) model of varying body types and dimensions (mostly 5th, 50th, 95th percentile) can be created which interacts with a CAD generated product in a virtual environment. With the help of these tools identification of key design issues and difficulties encountered by the humans in performing task with the product at an early phase of design is possible. This allows for early changes in configurations and design (even before making a physical prototype). Using DHM for ergonomics evaluations/ simulations is economical compared to traditional ergonomic evaluation methods in a product design/ development process (Chaffin, 2005). The need for using physical mock-ups for ergonomics evaluations is reduced due to the use of DHMs, as simulations/ evaluations are done in the virtual environment (Hanson, Blomé, Dukic, & Högberg, 2006).

The first digital manikin (called "First Man" later known as Boeman), was developed for Boeing in 1959 to assess pilot accommodation in the cockpit of Boeing 747. Some popularly available DHM software packages in the market are Safework, RAMSIS, JACK, SANTOS, CATIA-DELMIA; These software packages allow creating a complex environment, simulate tasks, analyze posture and are used by a wide variety of companies. The application ranges from comfort analysis to ergonomic design of car interior, manufacturing process, and car ingress/ egress simulation in the automotive domain. Some examples of DHM packages used by automobile companies include Ramsis by Honda, Audi, Ford, Volkswagen; Jack by BAe Systems, and John Deere.

Benefits of using DHM in product design and development include reduced design time, increased productivity, enhanced safety, evaluation with manikins (digital humans) of varying

body types and dimensions, evaluation in a hazardous condition, lower development cost, loopholes and errors can be identified even before making physical mock-up, repeated trials and modification based on DHM evaluation (Patel, Sanjog, & Karmakar, 2016; Sanjog, Chowdhury, & Karmakar, 2012; Sanjog, Patnaik, Patel, & Karmakar, 2016).

DHM has found its application in a wide variety of industries, which include the automobile sector (Lämkuill, Hanson, & Örtengren, 2009), aviation and aerospace, defense research (Karmakar, Pal, Majumdar, & Majumdar, 2012), health care application, agriculture sector (Patel et al., 2017), clothing, manufacturing (Sanjog et al., 2016), service and animation industry for the ergonomic evaluation of their products and workspace.

2.13 Innovative product design and development

The global market is becoming increasingly competitive. The economic success of any firm depends on their ability to identify needs of customer and quickly make a product which meets these needs at low cost. To bring a new product in the market, companies have to innovate and do product development. Customers satisfaction highly depends on the utility being offered by the product. A customer is willing to pay higher price for the product if it fulfills the desired utility of the customer. Products are of various types; broadly they can be classified as tangible (goods like pen, bicycle, soap, phone, car etc.) and intangible (hotels, airlines, doctor, barber etc.). Another classification could be of a consumer and industrial products; Consumer products are those which is purchased by individuals for personal or household use; Industrial products are the ones which are purchased by organizations for their business purposes.

Innovation has many meanings to it, which depend upon the context where its used. The word 'Innovation' is an outcome of creative design thinking and problem solving process. It is related to products as well as designers who conceive new products to serve the needs of the customers. Published literature show a wide variety of innovation, which can be ranging from — Product; Service; production; management; organization; process; commercial and marketing innovation. According to Schumpeter (2017), 'Innovation' can be defined as “Introducing a new product or modifications brought to an existing product; A new process of innovation in an industry; The discovery of a new market; Developing new sources of supply with raw materials; Other changes in the organization”.

2.13.1 Benefits of product development process

The sequence of steps employed for conceptualizing, designing, and commercializing a product is called a systematic product development process. Key benefits of a systematic product development process include:

Quality Assurance: Quality of the product is assured, if the stages and checkpoints of the project are chosen wisely according the product development process.

Coordination: A well documented development process defines the role of various members in the team and tells them when their contribution is needed and with whom they need to exchange information/ material.

Planning: The development process contains milestones related to the finishing of different phases. The development process is kept on track by timings of this milestone.

Management: The development process acts as a benchmark for the ongoing efforts. Actual problem areas can be found out by comparing the ongoing events with the formulated development process.

Improvement: A well articulated development process helps in finding the improvement opportunities of the organization.

Morale and satisfaction: It shows the progress of the ongoing project. This, maintains enthusiasm among the team members.

2.13.2 Generic process of product development

A product is something which is sold by an enterprise to its customers. The sequence of steps which transforms an input to output is called a process. The Generic product development process consists of six phases (shown in Figure 2.10); Planning; Concept development; System level design; detail design; Testing and refinement; Production ramp-up.

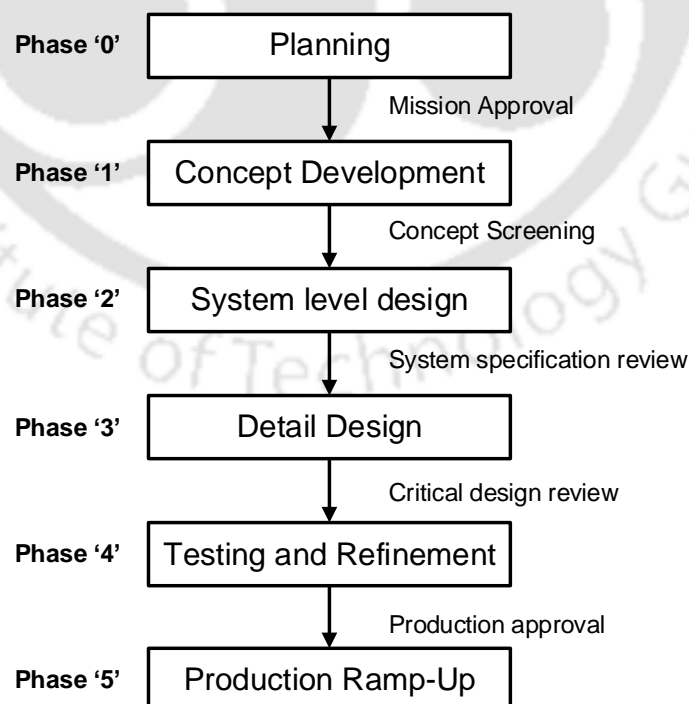


Figure 2.10: A generic product development process

Planning: Planning is referred to as the "phase zero" of the product development process. The output of the planning phase is the project mission statement. It specifies the target market, business goal, key assumptions and constraints.

Concept development: In this phase, the need of the market are identified, alternate products ideas are generated and evaluated, consequently one or more ideas are selected for testing and development.

System level design This phase defines the product architecture and further break-down into subsystems and components. The final assembly scheme is defined in this phase. The output of this phase is the geometric layout of the product, functional specification of product's subsystem and the process diagram for final assembly.

Detail design In this phase the complete specifications of geometry, material and tolerance of all the parts used in the product are given. Control documentation is the output of this phase, which describes the geometry, tooling requirements, specifications, process plan for fabrication of each part used in the product. Production cost and robust performance are addressed in this phase of detail design.

Testing and refinement In this phase multiple pre – production units of the products are made. The initial version is called the alpha unit, which is built using the parts intended for production (with same parts and geometry). Alpha Prototypes are tested to determine if they work as they are designed and if they satisfy the customer requirements. Later on the beta prototypes are developed and tested. These prototypes are tested extensively by the customers in their own environment, with the goal to identify any engineering and reliability issues. If any issues are found, necessary changes are done in the final product.

Production ramp-up In this phase the products are made using the intended parts to be used in the production system. The purpose of this phase is to prepare the workforce and to work out any remaining problems in the production process. There is a slow shift from the ramp-up to ongoing production process.

2.14 Conclusion to literature review

In the earlier sections, various aspects of driver distraction (types, causal factors, external/internal sources of distraction, drivers' characteristics, etc.), driving distraction related studies in the Indian context. This chapter also classifies the existing methodological perspective of measuring driver distraction, visual behavior of drivers & its assessment using eye-tracker, measuring of driving performance, simulation of driver-mobile interaction, etc. have been highlighted. Each of the existing methodology has its advantages/ merits. With respect to solving the research problem taken up, the lane changing task (LCT) is a reliable, inexpensive,

and standardized test tool for measurement of in-vehicle infotainment system (IVIS) demands. The entire procedure of LCT requires minimum equipment and is quickly completed. It requires a simple desktop computer on which the LCT software is installed, and a simple force feedback steering wheel with accelerator and brake pedals.

Since driving is a visual-manual task it requires focused attention and eye-tracking studies (using eye-movement recorder) are increasingly becoming popular for evaluating visual performance while driving. It is also observed from the literature that eye-tracking studies are conducted along with other driving performance matrices.

The driving simulator (DS) studies utilize a controlled laboratory environment to conduct empirical studies to evaluate drivers' driving performance under a variety of test conditions. DS based research is safe, relatively realistic, and data from various driving performance measures can be gathered. DS based study has several merits over the on-road/ test track studies. Hazardous/ unethical driving conditions/ environment can be easily and safely evaluated in the DS.

Hence, concluding from the literature review, it was decided to utilize driving simulator along with eye-movement recording to empirically study the driving performance of drivers in a controlled laboratory environment.



— Everyone thinks of changing the world, but no one thinks of changing himself.

Leo Tolstoy

3

Subjective evaluation of distracting behavior of the MABTS drivers

Abstract

Driving is a complex task where lack of attention can lead to accidents and near-crash incidences. Smartphone usage (e.g., calling, texting, navigation, etc.) while driving is among the top contributor to distraction. The number of Mobile Application Based Taxi Services (MABTS) is increasing rapidly in India. The MABTS drivers are very much dependent on their mobile phones for navigation and other purposes. Proper guidelines for the usage of mobile phones for navigation purposes are missing and needs to be formulated. Due importance has not been paid in this field of research in developing countries like India. Hence, to understand the problem of distraction among the MABTS drivers in India, a questionnaire-based survey was conducted. This chapter gives a detailed description of the survey methodology, inferences drawn, and implications for further research work.

3.1 Introduction

At present the drivers of the 'Mobile Application Based Taxi Services' (MABTS) have to rely on mobile application for confirming a booking, taking call, navigating to the desired destination and getting payment for the ride. The drivers of the MABTS have to look at their mobile phone from time to time for managing the trip and navigation. There is no conclusive evidence in the literature regarding the optimal positioning of mobile devices to ensure easy and comfortable viewing with minimal distraction. The drivers of the MABTS are positioning the mobile devices as per their own preference. Hence, the aim of the current research was to identify the most preferred location of positioning mobile phone by drivers of MABTS and to know if this location is comfortable or convenient for them. A questionnaire based survey is carried out to fulfil the above mentioned objective.

3.2 Material and methods

3.2.1 Respondents of the survey

A total of 188 MABTS drivers participated in the survey. They had a mean age of 31.77 yrs (SD = 5.59), with driving experience of a minimum of 2 yrs (M = 8.19 yrs, SD = 5.13). Only male participants responded to the questionnaire since only males drove MABTS taxis in the study area. It was an anonymous survey and the participation in the survey was completely voluntary in nature without any incentives. The participants had the choice to leave the survey at any point in time, or when they get a call for ride-booking. The inclusion criteria for participating in the survey include having a valid Indian driving license for light moving vehicle (LMV) and driving a MABTS service company vehicle. For selecting the participants, we used a purposive (non-probability) sampling technique.

3.2.2 Details of the questionnaire used

An initial pilot study was carried out on (n = 30) MABTS drivers, to prepare the final version of questionnaire used in the field study. Outcome of the pilot study revealed the common practices of the MABTS drivers for keeping their mobile phones with/ without using holder for navigation purpose. It was observed that, drivers in the study generally kept their mobile phone in one of the eight positions (1 to 9, except position '8'), as shown in figure 3.1. Upon asking, "why don't you keep the mobile phone on the hub of steering wheel?", they replied that due to the unavailability of appropriate mobile phone holder for fixing the mobile phone on the hub (which could maintain the mobile phone in vertically upright position even when the steering wheel rotates) they never tried. Researcher included position '8' (hub of steering wheel), along with all other positions practiced by drivers in the final draft of the questionnaire. Justification for including position '8' was minimal eye & neck movement for accessing visual information from the mobile phone screen while looking forward for driving. Previously, Alconera et al. (2017), used similar locations as shown in 3.1. Hence, in the questionnaire study, total nine mobile phone positions were considered. The questionnaire used for the survey comprised of five sections To evaluate the reliability of the questionnaire Cronbach's alpha (α) value was calculated. It is the most commonly used measure for evaluating the internal consistency of a survey/ questionnaire, which uses multiple likert questions (Lund Research Ltd, 2018). The calculated value of Cronbach's alpha (α) of the questionnaire (for Likert questions) was 0.72. The minimum requirement of calculated Cronbach's alpha (α) = 0.7, was satisfied (Field, 2018).

The first part of the questionnaire consisted of demographic information (name, age, education, driving experience, type of vehicle drive, driving speed range) of the drivers. The second part comprises questions about physical fitness, pain/ surgery/ injury on neck/ shoulder, and eye-sight condition. Part 3 inquired about the drivers' involvement in different distracting

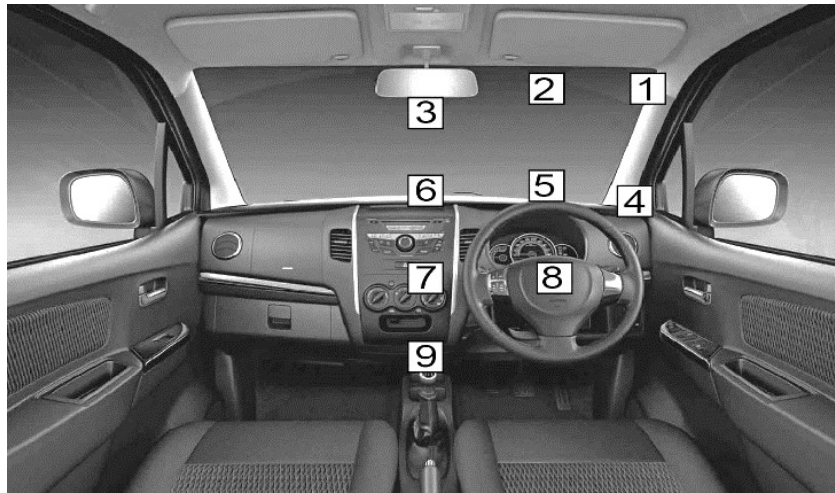


Figure 3.1: Vehicle interior with different mobile phone positions shown to the drivers for ranking

activities and their relative ease/ difficulty with which they can perform these activities. The fourth part inquired about the drivers' preference of the positioning the mobile phone display, the relative ranking of the positions with respect to each other, for the image illustrated in figure 3.1, and the relative ease of viewing the display.

Nine mobile phone display locations were shown on the car interior used in this study (shown in figure 3.1). Out of these nine mobile phone positions, three positions (3,2,1) were above the horizontal plane of the driver's normal line of sight. Three positions (6, 5, and 4) were at of top surface level of the dashboard, two positions (7, 8) horizontal level of steering wheel mid-line, and one (position 9) was located near the gearbox.

Part 5 inquired about the drivers' preference for mobile device position for navigation purpose and its relative position to the driving wheel and dashboard. In the end, a few open-ended questions were asked to the drivers. These include; "justification of their preferred position of mobile navigation system", "If there are any MABTS company guidelines for the position of mobile navigation system," and "justification of shifting the mobile device position during the night-time." A detailed questionnaire used in this study is presented in the Appendix A.1.

3.2.3 Procedure adopted for the survey

We approached the MABTS drivers at university, airport, railway station, and hospitals, where these drivers waited for ride-booking. After an initial interaction with the drivers, a questionnaire survey was conducted. It took on an average of 15–20 minutes to complete the survey. The questionnaire was administered to the drivers in their vehicle's comfort to understand the actual situation. After the initial interaction, the surveyor explained the purpose/ objective of the survey. All the respondents gave their consent to participate in the survey. They were informed about their details' confidentiality and that no part which could recognize them would be published. The surveyor explained every question to drivers in a language they were comfortable (Hindi/



Figure 3.2: Overview of survey administered to the MABTS drivers

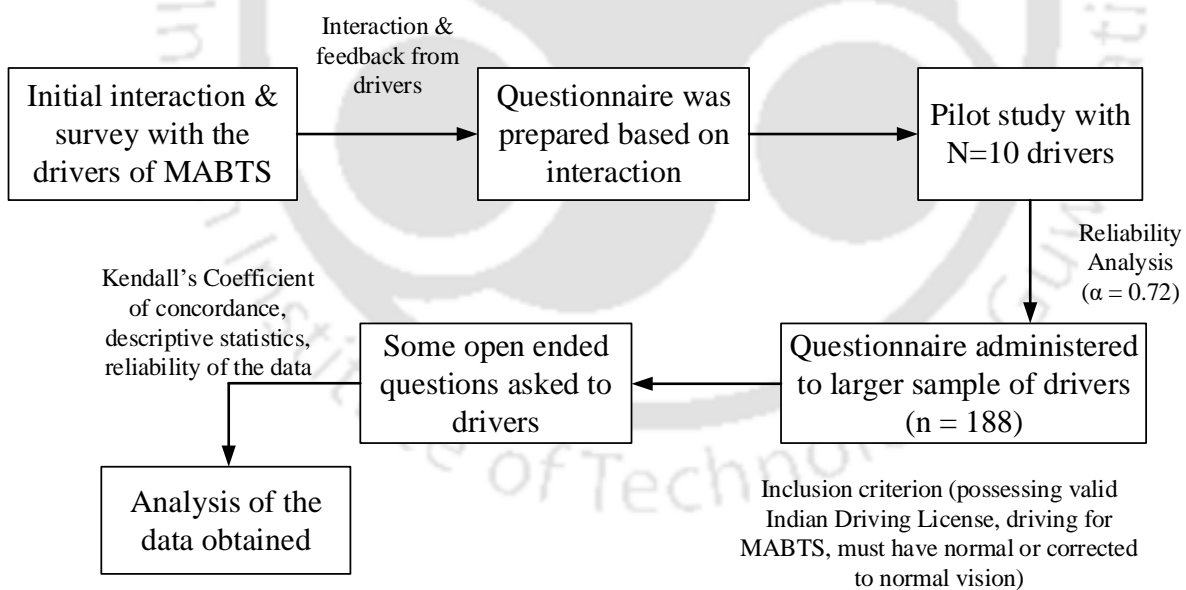


Figure 3.3: Schematic diagram of methodology adopted for the questionnaire study

Assamese). The surveyors marked the responses to the questions themselves to avoid leaving unanswered questions and errors. A few open-ended questions were asked at the end. Figure 3.3 shows the complete process of developing the questionnaire and its administration to the drivers.

3.3 Results

3.3.1 Socio – demographic information

Overall 188 MABTS drivers participated in the questionnaire based survey. All the respondents were males, since in the study area only males drove MABTS. The respondents age ranged between 21 to 50 years ($M = 31.77$ yrs, $SD = 5.59$), whereas the driving experience ranged between 2 to 32 years ($M = 8.19$ yrs, $SD = 5.13$). In terms of vehicle type 71.27 % drivers reported of driving hatchback, in comparison to 28.72 % driving sedans. Further, when asked about the driving speed range, 38.8 % drivers reported of driving between 40 to 60 km/h, whereas, about 60.1 % reported driving between 60 to 80 km/h. The demographic profile of the survey participants are given in Table 3.1.



Figure 3.4: Different positions of mobile phone with respect to steering wheel; (a) left, (b) others (at the central console), (c) right

3.3.2 Frequency of engagement in distracting tasks

The respondents were asked to identify the various distracting tasks they are involved in while driving. It was recorded that about 97.3 % indicated that they used the navigation system while driving, whereas 96.8% agreed that they had conversation with the passengers while driving. About, 91 % of the drivers agreed of using mobile phone (either for talking, texting, navigation, or weather) in some way while driving. Table 3.2 shows the frequency of engagement in various distracting activities.

3.3.3 Preference for placing mobile phones

The MABTS drivers were asked to rank the various in-vehicle mobile phone locations shown in figure 3.1 based on their preference. For determining the most preferred position, Kendall's coefficient of concordance (Kendall's W) was calculated using Statistics package, IBM SPSS V25. Kendall's W is used to determine the degree of agreement between rank givers when working with ranked data (ordinal level of measurement). The average rank of different positions is shown in Table 3.3. The Kendall's W test for concordance revealed that ($\chi^2(8) = 1177.36, p < 0.001, W = 0.783$), there is a moderate-high level of agreement between the

Table 3.1: Demographic profile of the participants

Factor	Observation	Weighted %
Gender		
Male	188	100
Female	0	0
Age (in years)		
21–30	94	50.00
31–40	87	46.27
41–50	07	03.72
Driving experience		
1–12	150	79.78
13–22	34	18.08
23–32	04	02.12
Vehicle Type		
hatchback	134	71.27
sedan	54	28.72
Education		
secondary	84	44.68
higher-secondary	94	50.00
graduation	10	05.31
Driving Speed (km/hr)		
below 40	1	0.50
40–60	73	38.80
60–80	113	60.10
above 80	1	0.50
Mobile-phone navigation system w.r.t. steering		
Left	91	48.4
Right	76	40.4
Center	1	0.5
No mobile holder	20	10.6

*participants n = 188; w.r.t. – with respect to.

ratings of the drivers. It is clear from Table 3.3, that most of the drivers gave 1st rank to position 6 (left side of steering wheel), and 2nd rank to position 4 (right side of steering wheel), and

Table 3.2: Frequency of involvement in distracting activities

Activities	Frequency, N (%)
Navigation system	183 (97.30)
Radio/ music system	110 (58.5)
Environment control (AC/ Heater)	177 (94.1)
Mobile phone	171 (91)
Look to in-vehicle meters	169 (89.9)
Interact with passengers	182 (96.8)
Adjust seat	10 (5.3)

3rd to position 7 (central console). Also, the least preferred (ranked) were the positions 8 and 9, which were at the center of steering wheel and below the dashboard near to gear box, respectively.

Table 3.3: Rankings of different mobile phone positions

Position	Mean Rank	Overall Rank
1	4.50	5
2	7.12	7
3	3.77	4
4	1.90	2
5	6.89	6
6	1.77	1
7	3.64	3
8	8.22	9
9	7.20	8

Driver's perception of the ease with which they can perform different secondary activities while driving is shown in Table 3.4. It was observed that more than 90% of the drivers rated that it was not easy for them to operate mobile phones while driving. Whereas more than 63% drivers agreed that operating radio/ music system or Ac/ heater while driving was relatively easy, and they could comfortably do these activities while driving. Further, 60% of drivers neither agreed nor disagreed and remained neutral to the notion of a navigation system's efficient operation while driving. Also, 52% of the drivers were neutral to adjusting seats while driving.

The MABTS drivers were asked some open-ended questions at the end. These questions include; "Is there any company guidelines about the location of keeping mobile phone device for navigation purpose.", "What is the reason for keeping the mobile phone at the particular location where it is now? Why don't you keep it at some other place ?", "Do you change the

Table 3.4: Perception of doing secondary activities while driving

Sr. No.	Secondary activities	Ratings, %, total n =188				
		Strongly Agree (1)	Agree (2)	Neutral (3)	Disagree (4)	Strongly Disagree (5)
1.	It is easy to operate mobile phone while driving	0.8	2.40	6.11	40.95	49.73
2.	It is easy to operate radio/ music system while driving	10.63	63.82	23.93	1.6	0.0
3.	It is easy to operate AC/ heater while driving	13.82	63.82	20.74	1.33	0.26
4.	It is easy to look at in-vehicle meters while driving	3.98	56.38	28.98	10.37	0.26
5.	It is easy to do conversation with passengers while driving	20.47	60.10	18.08	0.79	0.53
6.	It is easy to operate navigation system while driving	2.66	19.95	60.37	17.02	0.0
7.	It is easy to adjust seat while driving	13.29	28.72	52.12	5.32	0.53

mobile phone position at night, or is it in the same position?”. In response to these questions as mentioned above, all the drivers reported that they kept the mobile phone for navigation purposes according to their convenience, and there was no instruction/ guidelines from the company regarding the location of the mobile phone for navigation purposes while driving. Further, a small percentage (10.1%) of drivers also reported that they changed the location of mobile phone at night and placed it below the dashboard. Whereas, about 89% of driver didn't change the location of mobile phone at night and reported that they either reduced the screen brightness (22.3%) or left the phone as it is during the night/ evening.

Regarding the question about using navigation system on known and unknown routes, 48% of the drivers said that they rarely used the navigation system on known routes, whereas, 16% of drivers reported having used the navigation system always or almost all the time. Further, regarding the usage of navigation system on unknown routes, about 92% of drivers agreed that they used navigation systems all the time. A small portion of drivers (4%) reported that they never used the navigation systems, even on unknown routes. Additionally, 6.91% of the drivers reported that they don't use the navigation system at all, since they do not like it.

Table 3.5: Perception of comfort and visibility of controls

Sr. No.	Secondary activities	Ratings, %, total n =188				
		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1.	Controls are located at comfortable location and no head-torso movement is required	0	0.26	15.42	77.66	6.65
2.	Discomfort in viewing the device leading to distraction	6.38	76.06	17.55	0.0	0.0
3.	Discomfort in viewing more than one display	7.44	57.00	35.6	0.0	0.0
4.	Viewing auxiliary display leads to distraction	2.39	67.28	26.60	3.72	0.0

3.4 Discussion

In this study, we conducted a questionnaire survey to understand the drivers' engagement in distracting activities and their preferred location for placing mobile phones for navigation purposes. The study was administered to MABTS drivers ($n = 188$). The questionnaire was found to be reliable with a Cronbach's alpha (α) = 0.72. Inferences drawn from the outcome of the survey conclude to some interesting findings.

In general terms, although very small, 6.91% of the drivers reported that they did not use the navigation system during driving. However, this questionnaire was administered only to the drivers of MABTS, whose primary ride-booking came from mobile applications. The reason for this was their disliking of using mobile devices during driving. Additionally, another reason could be their poor technical literacy in using the taxi service mobile application. This kind of behavior (although observed on a limited number of drivers) could be seen as a countermeasure to reduce the effects of distraction caused by using mobile phones while driving. Additionally, about 22.3% drivers reported that they reduce the brightness of mobile phones' screen during night. These behaviors could be seen as an act of counter measuring glare from the mobile device during night/ evening.

More specifically in-terms of positioning of the in-vehicle mobile phones, the majority of drivers (48.8%) preferred to keep their mobile phones on the steering wheel's left side for navigation purposes. The justifications given by drivers include; 1) this is the common behavior of the other drivers, and they have adopted from them, 2) the co-passenger can easily see the mobile device at this location and would be able to look for taxi fare and there would be transparency about the route being followed. Also, some drivers reported that they used to keep the mobile phones on the right side of the steering wheel (near the A-pillar), but their

mobile phones were stolen because of the positions' nearness to the window; hence they started keeping it on the left side.

It was also observed that 40.4% of drivers reported that they kept mobile phones on the steering wheel's right side near the A-pillar. The justifications which the drivers gave include; 1) Easy to access the mobile device for operating, 2) Ease of visibility as they don't have to move their head much, 3) The mobile device doesn't obstruct their visibility of the traffic as it is against the right A-pillar. About 10.6% of the drivers reported that they did not keep the mobile phone on the left or right of the steering wheel for navigation as they either don't have a mobile holder device or it got broken. These drivers are reluctant to buy a new mobile-holder since it would break again.

A few percent (10.1%) of drivers mentioned that they change the position of their mobile phones during night/ evening, and keep it below dashboard.

The result of the ranking of the preferred position of mobile phone (shown in figure 3.1) is given in Table 3.3 revealed that position 6 (left of steering) had a mean rank of 1.77, and was the most preferred position, whereas, position 4 (right of steering) was the second most preferred position (mean rank = 1.90). Similar results were shown in the previous studies conducted by Alconera et al. (2017); however, the participants of the experiment were Filipino drivers who were driving 'left-handed vehicles'. The mean rank of the positions 3 and 7 were 3.77, and 3.64, respectively. Out of the various mobile phone positions shown in figure 3.1, positions 8 and 9 were the least preferred, with mean rank of 8.22 and 7.20, respectively. The disliking for these positions was because of their relative location around the dashboard; position 8, was located in the center of the steering wheel which required the drivers to look down by diverting their attention from the forward on-road scene, and position 9 was below the dashboard near the gearbox, which again required a head-torso movement by the drivers for focusing their attention to the mobile phone screen. It is noteworthy, that although position 5 was straight in front of the drivers' forward line of sight, this position had a mean rank of 6.89, because, most of the MABTS drivers refrained from placing mobile phone at this location, and only 1 driver (0.5%) was found who placed his mobile phone at position 5.

3.5 Conclusion

In the view of the present field study, it was concluded that drivers are engaging in distracting activities and used to keep the mobile phone for navigation purposes as per their convenience. The survey was useful in finding the various distracting behavior the drivers indulged while driving. Apart from that the survey also identified, various positions for placing the in-vehicle mobile phones and the most preferred among those given positions. The drivers' preferred positions were not found to be optimal since, for focusing attention to mobile phones at these different locations, the drivers would require movement of head, eye or both, and thus have to deviate from the forward on-road scene, leading to distraction. This could have a

detrimental effect on the safety of both drivers and other road users. Hence, further studies in the virtual simulation environment (digital human modeling), and simulated driving studies utilizing the eye-tracking system is required to empirically suggest the best possible position for placing mobile phone in-terms of minimum eye/ head movement, best driving performance, and improved visual behavior. The outcomes of the present study have many implications for policy and practices for MABTS drivers. An initiative could be to develop an educational campaign for MABTS drivers, to teach them regarding the ill effects of over usage of mobile phones while driving.





— Yesterday I was clever, so I wanted to change the world. Today I am wise, so I am changing myself.

Rumi

4

DHM based study to identify comfortable viewing position for mobile-phone

Abstract

The use of mobile phones as a portable navigation system has gained momentum in recent years due to the advancements in GPS technology. Although mobile phone is a major cause of distraction, its complete elimination from the Mobile Application Based Taxi Services (MABTS) ecosystem is impractical since it has become an inevitable part of driving, particularly for the MABTS drivers. Initial interaction and field survey revealed that drivers placed the in-vehicle mobile phones at different positions on the dashboard and the steering wheel. This chapter gives a detailed description of a digital human modeling (DHM) based virtual ergonomics evaluation study which assesses the head (flexion/ extension and rotation) movement and hand-reach required by the mobile phone at different positions. This chapter describes the methodology adopted, analysis, and the results of the DHM study.

4.1 Introduction

The number of mobile-phone subscribers in India has increased many folds recently. According to the Telecom Regulatory Authority of India (TRAI), there are about 1.13 billion mobile-phone subscribers in India as of May 2018 (TRAI, 2018b). Now-a-days, most of the drivers (personal as-well-as hired car) use mobile-phones as a navigation device. The use of mobile-phone while driving causes diversion of attention from the primary task of driving, and this is one type of driver distraction (Kircher, 2007). Mobile-phone usage while driving has become the prominent source of driver distraction causing four types of mutually non-exclusive distractions which include visual, cognitive, auditory, and manual/ physical (Schick, Ascone, Kang, & Vegega, 2014). Distracted drivers are four times more likely to be in a crash than non-distracted drivers (Bendak & Al-Saleh, 2010; Klauer et al., 2006). The Ministry of Road Transport and Highways (MORTH), Government of India, report of 2016 has shown that using mobile-phone while driving has become a vital cause of road accidents and has resulted in 4976 number

of road accidents, 2138 number of deaths and injuries to 4746 number of persons (MORTH, 2016). In India, Mobile Application Based Taxi Services (MABTS) companies like ‘OLA’ and ‘UBER’ are using mobile-phone applications for executing their services. Drivers of these MABTS use the mobile-phone for taking rides, getting information about the fare, and for navigation. However, it was observed that mobile-phone used for navigation purpose was generally mounted at different locations on and around the dashboard and steering wheel, as per the driver’s convenience (Verma & Karmakar, 2017). Neither there is a guideline, nor there are specific locations followed by the MABTS drivers for mounting their mobile-phone for navigation purpose. Hence, in this study, we have tried to identify a suitable location for mounting the mobile-phone, which ensures minimal biomechanical effort in viewing and operating mobile-phone when driving.

4.1.1 Human view-field and head movement

Unobscured on-road and in-vehicle field of vision is a crucial aspect of the driving task. During driving, vision plays an important role, as about 90% of the information received by human-being from ambient environment comes through visual channel (Jung, Shin, & Kee, 2000). Humans have a binocular field of view extending up to 120° in the horizontal field, but the vision is sharp in a small area ahead corresponding to the foveal area on the retina. An eye turn is required to focus on an object outside the foveal region. According to Grandjean (1986), the visual field is the surrounding that is taken in by the eyes when both eye and head are still. The visual field has three regions (shown in figure 4.1): a) area of distinct vision: viewing angle of 1° , b) middle field: viewing angle of 40° , c) external field: viewing angle greater than 40° .

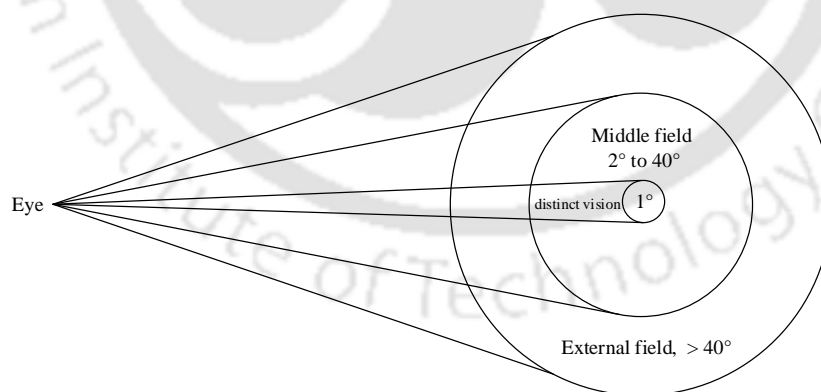


Figure 4.1: Field of view showing different regions

Strasburger, Rentschler, and Juttner (2011) have defined a foveal vision to be below 2° eccentricity and peripheral vision for anything outside 2° eccentricity. The area beyond distinct vision (foveal vision) is the peripheral vision. It is sensitive to light and motion but is not capable of seeing the details sharply (De Lumen et al., 2019). During the field survey, Verma and Karmakar (2017) observed that even though the mobile-phone is placed within the comfortable

range of eye movement (i.e. 30° horizontally), the drivers shortly turn their head to read and comprehend the data from mobile-phone for navigation purpose (Verma & Karmakar, 2017). Thus, it is worthy to note that a head/ neck movement takes place instead of eye-movement during the distinct foveal vision, even within eye field of 30° around line of sight. Hence, the movement head/ neck should be kept to a minimum ($\pm 15^\circ$) from the straight-ahead line of sight. This means that the visual displays (mirror and instrument panel, mobile-phone, etc.) should be placed as close to drivers' forward line-of-sight. In the sitting posture, Kee and Karwowski (2001), have shown the values for very-good comfort level for neck flexion (4°), extension (7°), rotation (17°), and lateral bending (13°).

4.1.2 Literature on in-vehicle display position

Although the guidelines for in-vehicle display arrangements for the convenient and safe use of on-board navigation systems are available in some countries (JAMA, 2004), there is rarely any clear guideline available for positioning of smart-phones as portable navigation systems which are different in size and with variable positions (Zheng et al., 2016).

The Department of Transportation, The Republic of Philippines has implemented the Anti-Distracted Driving Act (ADDA), RA 10913 which prohibits the drivers from using communication devices, computing gadgets, and electronic entertainment while the vehicle is moving or temporarily stopped on traffic signals. The ADDA has a provision for a safe zone (within 4 inches above the vehicle dashboard) where the placement of mobile-phones (with navigation applications like Waze and Google maps) is allowed. According to the act, placing navigational devices/ mobile-phones beyond the safe zone is prohibited, as this area is the line of sight region. This act considers only the driver's horizontal line of sight and does not specify the ideal location of the navigation device (LTO, 2017).

Similarly, the National Highway Traffic Safety Administration (NHTSA), US Department of Transport gives the criteria that the acceptable eye glances away from the road should not be more than 2 seconds while performing secondary in-vehicle task related activities (NHTSA, 2012).

Although the researchers have attempted to rank the various positions of the displays based on the different variables under study, they have not considered the suitable display position in terms of lower biomechanical effort to view and operate the in-vehicle display. During a driving simulator experiment involving 20 participants, Zheng et al. (2016) analyzed the eye-tracking data of drivers interacting with displays of different sizes and positions of portable navigation systems. They noticed that significantly shorter glance time but a significantly higher glance frequency were required for the convenient display position with a small visual angle (Zheng et al., 2016). De Lumen et al. (2019) reported that the navigation devices for Transportation Network Vehicle Services (TNVS) are mounted at different locations, and there is no fixed position which can be considered as safe or efficient (De Lumen et al., 2019). During their

study involving ‘Uber’ drivers to identify the optimal location among three different locations for the navigation device: left side, right side, and middle (speedometer area) of the steering wheel, researchers adopted the ‘Peripheral Detection Test’ to measure the driver’s distraction level. The result of the study showed that the driver’s distraction level is significantly affected by the position of the navigation device, and the position ‘right side of the steering wheel’ with least distracting was identified as ideal location among the three (De Lumen et al., 2019). Although this study is the first of its kind attempt to identify the ideal location of mobile-phone as a navigational device, it is infested with various limitations which include (a) considerations of only 3 horizontal locations above the dashboards out of many others vertical/ horizontal locations used by TNVS drivers in reality, (b) not measuring the eye glance time away from the road (straight ahead line of sight) and time to glance at the particular location of navigational device. In comparison to the onboard displays/ navigation system, the size of mobile-phones are relatively small and with varying dimensions. Although there are reported literature and guidelines for conventional onboard display ensuring driving safety, research pertaining to portable navigation systems like mobile-phones is still less explored (Zheng et al., 2016). In the previous studies, only three or four different locations of in-vehicle display were examined, whereas mobile-phones due to their small size and availability of diverse types of holders, were conveniently placed by the drivers at different positions around the steering wheel, dashboard, mid-console and windshield as the portable navigation systems. Moreover, the driver’s comfort and driving safety in terms of biomechanical effort and reachability is still unexplored.

To identify the optimal position for placing mobile-phone, researcher has studied the requirement of head and/ or torso movement (rotation, flexion/ extension) and fingertip reachability, at different positions using Digital Human Model (DHM) in a CAD generated virtual environment. It was presumed that the position of mobile-phone for navigation purpose could be considered as the most suitable one from the biomechanical point of view if it satisfies the following criteria:

- Minimal biomechanical load at neck and torso to glance at the mobile.
- Easy reachability (index fingertip) of the mobile-phone to operate/ navigate.

4.2 Material and methods

4.2.1 Software used

As there are numerous advantages of CAD based virtual ergonomics evaluation over the traditional method of testing and evaluation, digital human modeling (DHM) tools like CATIA was used for the current research. It has helped in making decisions by ergonomic design visualizations (De Magistris et al., 2013; Paul & Lee, 2011). Earlier researchers also claimed that the use of virtual ergonomics evaluations involving DHM could eliminate the development

of a physical mock-up before the generation of a prototype (Sanjog et al., 2016). DHM enables lowering development cost, shortening design time, improving quality, increasing productivity, enhancing safety, and achieving optimal human-machine interface (Chaffin, 2001). DHM finds its extensive technological application in almost all of the industrial sectors, including automobile industries (Chang & Wang, 2007; Fritzsche, 2010; Lämkuil et al., 2009). In the current research, digital human modeling software facilitated to measure biomechanical data (angular deviation) of neck/ torso joints corresponding to the visualization of mobile-phones positioned at different pre-selected locations by the manikins of different percentile anthropometric values (5th, 50th, and 95th percentile). In the real world situation, this would require a significant amount of time and incur huge costs. Moreover, finding any human subject with all the body dimensions of a particular percentile value is nearly impossible.

4.2.2 Creation of the digital manikin

CATIA (V5R19) software was used to build the digital human model (manikin) for virtual ergonomic evaluation. CATIA digital human modeling software has been extensively used to implement ergonomic improvements in the automobile sector (Chang & Wang, 2007), proactive ergonomics for product design innovation (Uday Kumar, Bora, Sanjog, & Karmakar, 2013), reproducing working posture for task simulation (Brouillette, Thivierge, Marchand, & Charland, 2012), and assessment of risk in car assembly (Fritzsche, 2010). The unavailability of the Indian anthropometric database of cab/ taxi drivers led the present researchers to use the anthropometric database of the civilian adult Indian male population (Chakrabarti, 1997) for generating the manikins for assessment.

As percentile manikins are widely being used in virtual ergonomics assessment of product and workstation design (Lanzotti et al., 2019; Potvin & Potvin, 2019; Sanjog, Patel, & Karmakar, 2019), hence, in the present research we have used 5th, 50th, and 95th percentile digital human model (manikin) respectively representing the smallest, average, and the largest anthropometric dimensions of the user population. MABTS drivers are predominantly male, and there are rarely any female MABTS drivers in the current Indian scenario. Hence, DHM analysis has been performed only by generating percentile male driver manikins (Verma & Karmakar, 2017). A flow chart of the methodology adopted in the current study is shown in figure 4.2.

4.2.3 Creation of the digital mock-up of the car/ taxi interior

The mechanical design feature of CATIA (V5R19) was used to build the car dashboard. CAD models of the car dashboard (with interior), steering wheel, car seat, and mobile-phone were prepared (shown in figure 4.3). Passenger seats and exterior of the car were not created, as they were not required for the intended assessment purpose. In the previous study by Verma and Karmakar (2017), it was observed that the majority of the drivers were driving the “Maruti-Suzuki Alto 800” model of the car. Hence, it was decided to create its CAD model using

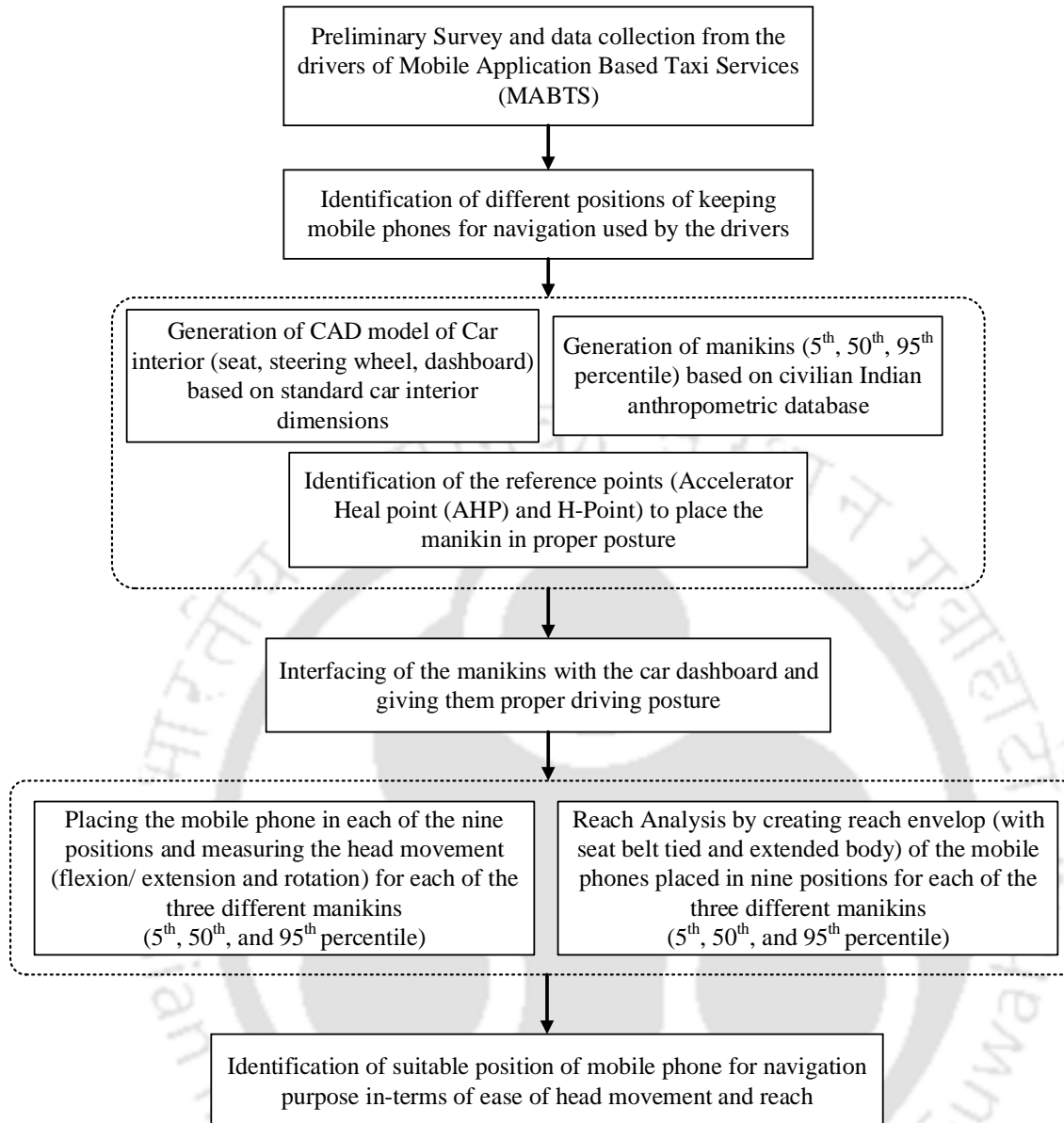


Figure 4.2: Flowchart of the methodology adopted for the experiment

interior dashboard dimensions for the purpose of the current study. The CAD model of a 4.5 – inch mobile-phone was created and placed at one of the pre-selected nine positions as found in the actual situation during the earlier reported questionnaire survey (Verma & Karmakar, 2017).

4.2.4 Selection of mobile-phones positions and their placement

In a survey involving MABTS drivers (n=188) (details in chapter 3), nine (09) different positions (around the steering wheel and on the dashboard) for mounting the in-vehicle mobile-phone were identified. These positions were generally adopted by the MABTS drivers according to their own perception of convenience. Relative positions of the mobile-phones in 3D space have been described based on the midpoint (intersecting point of the two diagonals) of the devices,

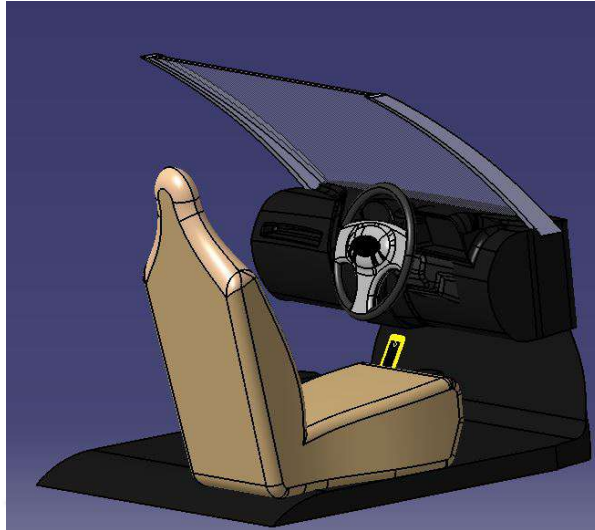


Figure 4.3: Digital mock-up showing the position of a mobile-phone in relation to other in-vehicle components (seat, steering wheel, and dashboard)

considering midpoint of position ‘8’ as the reference (shown in figure 4.4); position ‘8’ was selected by the researcher for the purpose of reference as this position is nearest to the line of sight horizontally. A description of different positions with respect to the reference position is shown in Table 4.1.



Figure 4.4: Isometric view of nine different mobile positions around the steering wheel and dashboard

4.2.5 Selection of reference points for positing driver manikins

Giving a proper position along with appropriate posture to the manikin, is a difficult task and is the main source of error. Hence, in the present work for interfacing, the manikin with the CAD generated mock-up of the car interior and giving it a correct driving posture, H-Point (SAE, 2009), and Accelerator Heal Point (AHP) (SAE, 2009) were chosen as the reference points. H-point was the referential point for all the manikins, whereas, proper adjustment of manikin on the driving seat was based on the Accelerator Heal Point (AHP). According to SAE (2009), the definition of H-Point and Accelerator Heal Point (AHP) are as follows:

- **H – Point:** It is the pivot center of the torso and the thigh on the two or three-dimensional devices used in defining and measuring vehicle seating accommodation.
- **Accelerator Heal Point (AHP):** is the lowest point of interaction, of the manikin heel and the depressed floor covering with the shoe on the un-depressed accelerator pedal.



Table 4.1: Description of the different positions and orientations of the mobile-phone

Position	Description of the position	WRT steering	Drivers preference (n, % age)	(x, y, z) coordinates (mm)	(α, β, γ) angles ($^{\circ}$)	Vector distance from reference (mm)
1	Right side, top of A-pillar	R	(3, 2.8)	(167.29, -102.29, 383.87)	(30, 25, -25)	431.05
2	Top of windshield, above the steering wheel	C	(3, 2.8)	(9.91, -161.10, 394.09)	(30, 3, -5)	425.86
3	Top of windshield, above the central console	L	(7, 6.54)	(-272.16, -93.4, 373.45)	(30, -25, 10)	471.44
4	Right side, bottom of A-pillar	R	(36, 33.64)	(170.15, 225.96, 161.04)	(110, 31, -15)	325.50
5	At the dashboard, behind steering wheel	C	(1, 0.93)	(0.515, 225.97, 153.67)	(95, 0, 0)	272.94
6	On the dashboard, above the central console	L	(45, 42.05)	(-287.05, 243.04, 85.71)	(85, 0, 20)	385.77
7	At the central console, over the AC vent	L	(10, 9.34)	(-323.93, 191.96, -44.28)	(100, -3, 5)	379.13
8	At the center of the steering wheel	C	(N.A., N.A.)	(0, 0, 0)	(100, 0, 0)	0
9	Below the dashboard, below central console	L	(2, 1.87)	(-332.2, 307.77, -348.42)	(110, 0, 5)	571.38

*center of the steering wheel (position '8') is taken as the reference point; R – right, L – left, C – center, N.A. – not available, and WRT – with respect to; x, y, and z – coordinates of intersection point of two diagonals of mobile screen; α, β, γ – angular orientation of mobile-phone w.r.t. x, y, and z axes.

4.2.6 Interfacing manikin with the CAD model of the car dashboard

Ergonomic design and analysis feature of CATIA was used to interface manikin with the CAD model of the car dashboard with seat and steering wheel. A proper driving posture was given to the manikin, which was same as that of the cab/ taxi driver. A full-scale (1:1) CAD model of the car-dashboard was interfaced with the full-scale (1:1) manikins to ensure accuracy in the investigation. Figure 4.5, shows the manikin interfaced with the car dashboard, with reference points (AHP and H-point). The 3-D coordinates of H-point for 5th, 50th, and 95th percentile driver manikins are shown in Table 4.2. The distance between the AHP and H-point of all the three manikins are shown in the last column of Table 4.2. The AHP for all the manikins in all the arrangements was kept same: $x = 465.83$, $y = 88.94$, $z = 567.10$ (mm).



Figure 4.5: Digital human model (manikin) interfaced with a virtual car dashboard with reference points

Table 4.2: Coordinates of H-Point for 5th, 50th, and 95th percentile driver manikins

Percentile	H Point (referential) (mm)			AHP – H Point distance (mm)
	x	y	z	
5th	306.38	- 598.77	716.56	721.60
50th	327.19	- 677.89	738.28	797.85
95th	299.56	- 770.69	731.01	890.77

4.2.7 Creation of the reach-envelope

Human reach assessment is an important aspect of ergonomic workplace design (Jung, Kee, & Chung, 1995). To evaluate the reachability of the mobile-phone at different positions on the dashboard, reach-envelope was created under two conditions; (a) with constrained arm-reach and (b) with extended arm-reach.

4.3 Experiment procedure

4.3.1 Head flexion/ extension and rotation

For this study 5th, 50th, and 95th percentile manikins of adult Indian male population were considered. These manikins were interfaced with the CAD model of the car dashboard with an appropriate driving posture. CAD model of mobile-phone used for navigation purposes was placed in one of the locations found in the actual situation during questionnaire survey from the MABTS drivers. For analysis, binocular vision with 2° view cone was considered, since this is the region of visual acuity or distinct vision (Miller-Keane, 2003; Strasburger et al., 2011). Head rotation, flexion/ extension required for focusing on mobile-phone was measured. For analysis, only rotation, flexion/ extension of head is performed, and all other body joint angles were kept fixed. During a survey conducted by Verma and Karmakar (2017), it was observed that the drivers of MABTS placed their mobile-phone for navigation purposes on one of the nine different positions, as is shown in figure 3.1.

A CAD model of the car dashboard with all the nine positions for mounting mobile-phone is shown in figure 4.4 (isometric view). These 'nine' positions are used in DHM evaluation in terms of head (flexion/ extension, left/ right rotation) movements of the manikins. Out of these nine positions, three positions (1, 2, and 3) were at the same horizontal plane above the normal line of sight of the driver. The other three positions (4, 5, and 6) were at the level of the top surface of the dashboard. Two positions (7 and 8) were at the horizontal level of midline of the steering wheel, and one (position 9) was located near the gearbox (Verma & Karmakar, 2017) below central console, as shown in figure 3.1. These positions are similar to the locations as adopted by Alconera et al. (2017). Firstly, the analysis was done on 5th percentile manikin, and rotation, flexion/ extension of the head was measured from an initial neutral position for one of the mobile-phone position. This process was repeated for all the positions as shown in figure 3.1 and for 50th and 95th percentile manikin. View-cone of 2° was maintained for all the manikins. Figure 4.5, shows the initial posture of the manikin. The line-of-sight was kept at 0° before starting to rotate and flex the head for focusing on the mobile-phone. AHP for all the manikins were kept constant. Movement of the thoracic region (rotation, flexion, lateral bending) was required only for viewing the mobile-phone at position 9. For rest of the other positions, the thoracic region of the manikin was constant.

4.3.2 Reach analysis

Reach analysis was performed to find out the positions of mobile-phone among the nine different positions (shown in figure 3.1) which were easy to operate during normal seating posture. Reach analysis was performed in two configurations; 1) with constrained arm-reach, 2) with extended arm-reach. The envelope for constrained arm-reach was created for manikin of different percentiles considering seat belt is attached to restrict torso movement, and joint

kinematics for reach-envelope was driven from the shoulder joint. The envelope for extended arm-reach was created for manikin of different percentiles considering seat belt was open/ not tightened to allow torso movement and joint kinematics for reach-envelop was driven, allowing axial rotation of waist joint. Reach-envelopes (both constrained and extended) were created for 95th, 50th, and 5th percentile manikins while they were seated at the rearmost, middle, and forward most positions of the seat-track travel, respectively as specified by their corresponding H-point locations given in Table 4.2. In both cases, reach-envelopes were created for the tip of the index finger. The reach-envelopes of the drivers with extended arm-reach are shown with blue color, and the reach-envelopes of the drivers with the constrained arm-reach (without flexion of upper body) are shown in red color.

4.4 Result

A graph between head flexion/ extension ($^{\circ}$) (y-axis) vs. positions of mobile-phone (x-axis) and head rotation angle ($^{\circ}$) (y-axis) vs. positions of mobile-phone (x-axis) for each of the manikins (5th, 50th, and 95th), is shown in figure 4.6 and figure 4.7 respectively. The joint angles of head/ neck and torso joints of 5th, 50th, and 95th percentile manikins when viewing the mobile-phone at nine different positions are shown in Table 4.3.

4.4.1 Head flexion/ extension

The graph in figure 4.6 shows the variation of head flexion/ extension against the position of mobile-phone. Positive value shows head flexion (towards the body), whereas extension (away from the body) is represented by negative values. Out of the nine positions, head extension is required in positions '1', '2', and '3', since; these three positions are above the horizontal line of sight of the drivers. The range of head flexion/ extension varies from 8° (extension) in position '2' for 5th percentile to 20° (flexion) in position '9' for 95th percentile manikin. The maximum amount of head flexion is required for position '9' (17° , 19° , 20° for 5th, 50th, and 95th manikin). Overall, the maximum amount of flexion is observed for 95th percentile manikin due to its inherent stature, which is opposite in case of extension.

4.4.2 Head rotation

The relation between head rotation and positions of the mobile-phone is shown in figure 4.7. The total range of head rotation varies from 30° (right side) to 41° (left side), both these extreme values are reported for 5th percentile manikin. This shows that 5th percentile manikin has to rotate his head the maximum in order to focus on the mobile-phone. It is also evident from figure 4.7 that the least head rotation is being observed in positions '2', '5', '8'. All these positions are on the same line and vertical plane, central to the normal seating posture of drivers.

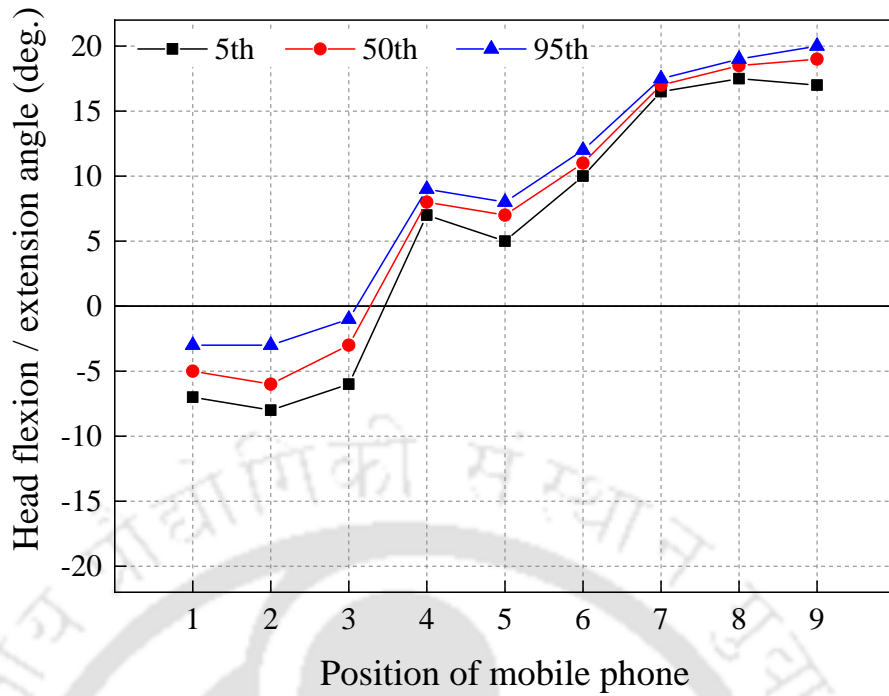


Figure 4.6: Comparative visualization of head flexion/ extension for different percentile manikins at different positions of the mobile-phone

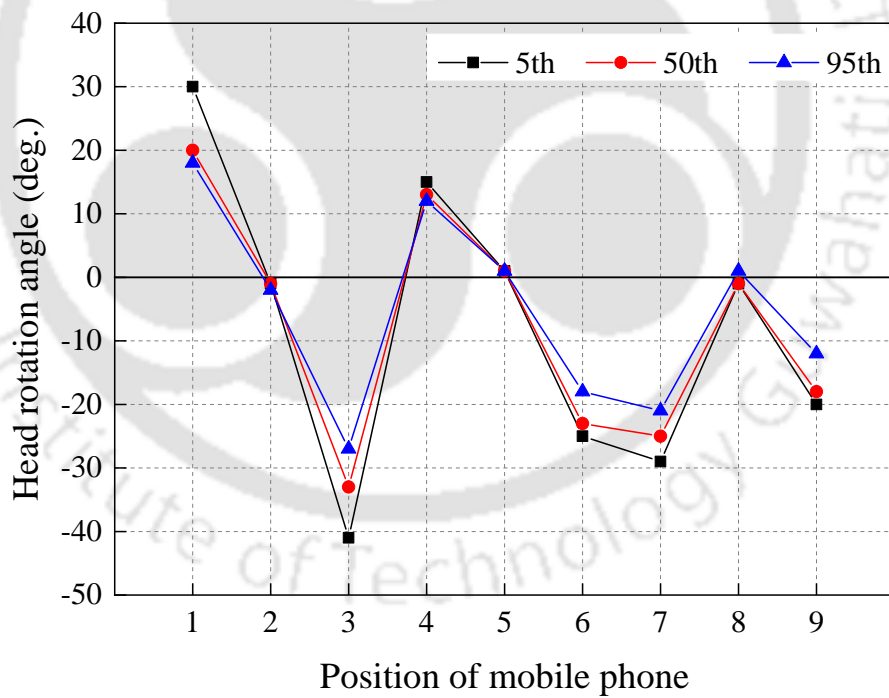


Figure 4.7: Comparative visualization of head rotation for different percentile manikins at different positions of the mobile-phone

Overall, it is observed that the maximum amount of head rotation (41°, 33°, 27° for 5th, 50th, and 95th manikin) is required for position ‘3’.

Table 4.3: Joint angles of head/ neck and torso of 5th, 50th, and 95th percentile manikins when viewing the mobile-phone at nine different positions

Pos	5th percentile		50th percentile		95th percentile	
1		Head(Ex): 7° Head (Ro): 30° (R)		Head (Ex): 5° Head (Ro): 20° (R)		Head (Ex): 3° Head (Ro): 18° (R)
2		Head (Ex): 8° Head (Ro): 1° (L)		Head (Ex): 6° Head (Ro): 1° (L)		Head (Ex): 3° Head (Ro): 2° (L)
3		Head (Ex): 6° Head (Ro): 41° (L)		Head (Ex): 3° Head (Ro): 33° (L)		Head (Ex): 1° Head (Ro): 27° (L)
4		Head (Fl): 7° Head (Ro): 15° (R)		Head (Fl): 8° Head (Ro): 13° (R)		Head (Fl): 9° Head (Ro): 12° (R)
5		Head (Fl): 5° Head (Ro): 1° (R)		Head (Fl): 7° Head (Ro): 1° (R)		Head (Fl): 8° Head (Ro): 1° (R)
6		Head (Fl): 10° Head (Ro): 25° (L)		Head (Fl): 11° Head (Ro): 23° (L)		Head (Fl): 12° Head (Ro): 18° (L)
7		Head (Fl): 16.5° Head (Ro): 29° (L)		Head (Fl): 17° Head (Ro): 25° (L)		Head (Fl): 17.5° Head (Ro): 21° (L)
8		Head (Fl): 17.5° Head (Ro): 1° (L)		Head(Fl): 18.5° Head (Ro): 1° (L)		Head (Fl): 19° Head (Ro): 1° (L)
9		Head (Fl): 17° Head (Ro): 20° (L) Head (Lat L): 6° Thorocic (Fl): 7° Thorocic (Lat L): 11° Thorocic (Ro): 18° (L)		Head (Fl): 19° Head (Ro): 18° (L) Head (Lat L): 8° Thorocic (Fl): 13° Thorocic (Lat L): 6° Thorocic (Ro): 9° (L)		Head (Fl): 20° Head (Ro): 12° (L) Head (Lat L): 10° Thorocic (Fl): 13° Thorocic (Lat L): 0° Thorocic (Ro): 6° (L)

*Ro – Rotation, Fl – Flexion, Ex – Extension, Lat – Lateral, R – Right, L – Left, Pos – Position

4.4.3 Physical validation involving real drivers

Three MABTS drivers were identified whose stature approximately matched with 5th, 50th, and 95th percentile stature data of the Indian anthropometric database (Chakrabarti, 1997). Head and torso movements were measured for all the mobile-phone mounting position using goniometer after the participants adopted a comfortable driving posture in a Maruti-Suzuki Alto 800 car. Table 4.4 shows the head rotation and flexion/ extension for 5th, 50th, and 95th

percentile participants when looking at the different positions of mobile-phone.

Table 4.4: Joint angles of head/ neck and torso of 3 real drivers (representative of 5th, 50th, and 95th percentile statures) when viewing mobile-phone at nine different positions

Position	5th percentile	50th percentile	95th percentile
1	Head(Ex): 10° Head (Ro): 26° (R)	Head (Ex): 7° Head (Ro): 18° (R)	Head (Ex): 5°, Head (Ro): 17° (R)
2	Head (Ex): 10° Head (Ro): 0°	Head (Ex): 8° Head (Ro): 0°	Head (Ex): 4°, Head (Ro): 0°
3	Head (Ex): 8° Head (Ro): 45° (L)	Head (Ex): 5° Head (Ro): 35° (L)	Head (Ex): 3°, Head (Ro): 30° (L)
4	Head (Fl): 7° Head (Ro): 20° (R)	Head (Fl): 8° Head (Ro): 17° (R)	Head (Fl): 10°, Head (Ro): 15° (R)
5	Head (Fl): 5° Head (Ro): 0°	Head (Fl): 9° Head (Ro): 0°	Head (Fl): 10°, Head (Ro): 0°
6	Head (Fl): 12° Head (Ro): 27° (L)	Head (Fl): 13° Head (Ro): 25° (L)	Head (Fl): 15°, Head (Ro): 16° (L)
7	Head (Fl): 18° Head (Ro): 35° (L)	Head (Fl): 20° Head (Ro): 30° (L)	Head (Fl): 21°, Head (Ro): 27° (L)
8	Head (Fl): 15° Head (Ro): 0°	Head(Fl): 20° Head (Ro): 0°	Head (Fl): 25°, Head (Ro): 0°
9	Head (Fl): 20° Head (Ro): 25° (L) Head (lateral L): 8° Thorocic (Fl): 9° Thorocic (lateral L): 15° Thorocic (Ro): 20°	Head (Fl): 23°, Head (Ro): 22° (L) Head (lateral L): 10° Thorocic (Fl): 15° Thorocic (lateral L): 8° Thorocic (Ro): 12°	Head (Fl): 25°, Head (Ro): 18° (L), Head (lateral L): 12°, Thorocic (Fl): 16°, Thorocic (lateral L): 2°, Thorocic (Ro): 5°

*Ro - Rotation, Fl - Flexion, Ex - Extension, R - Right, L - Left.

The output (angle of head flexion/ extension and head rotation) of the virtual study and the real physical measurements were compared for each of the manikins/ representative real drivers of similar stature (for 5th/ 50th/ 95th percentile) to find out the difference (if any) using Mann-Whitney U test, conducted in SPSS v.25.0 (IBM, USA) software. Mann-Whitney U test revealed that there was no significant difference between the virtual and physical measurement for head flexion/ extension for 5th percentile (U = 32, p = 0.451), 50th percentile (U = 29, p = 0.308), and 95th percentile (U = 30, p = 0.352) manikins/ representative real drivers of similar stature. Similar observations were also noticed for head rotation of 5th percentile (U = 39, p = 0.894), 50th percentile (U = 39, p = 0.894), and 95th percentile (U = 38, p = 0.859) manikins/ representative real drivers.

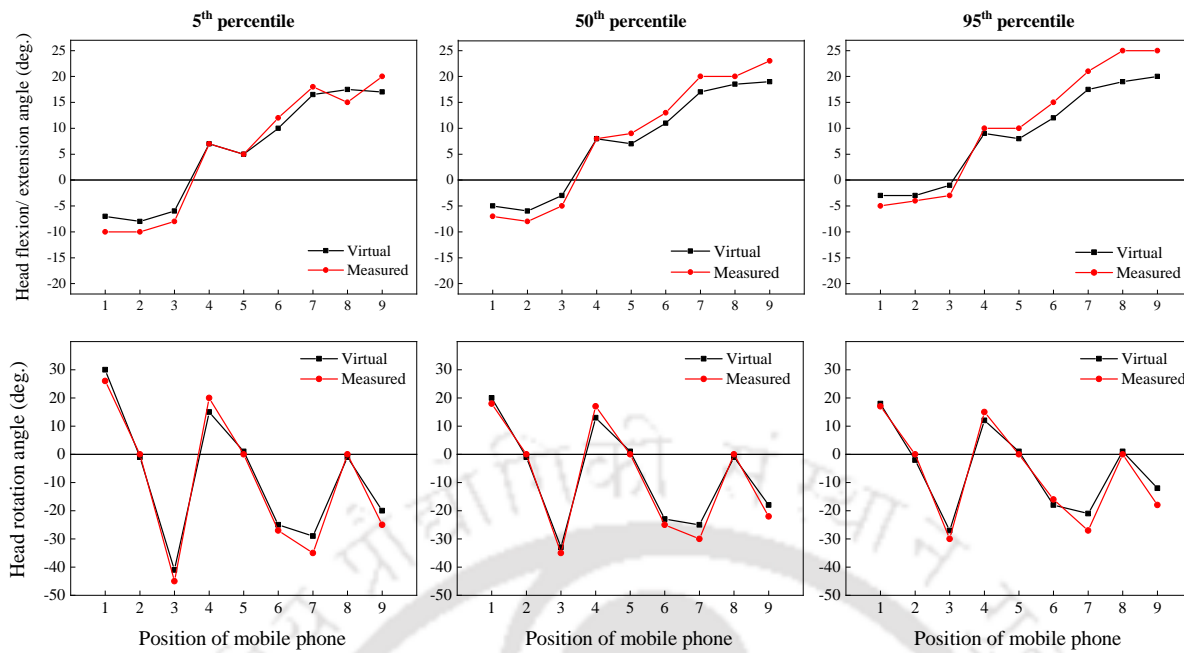


Figure 4.8: Comparative visualization of head flexion/extension and rotation for different percentile (5th, 50th, and 95th) manikins (virtual) and representative drivers (real) of similar statures

Moreover, the comparison of two sets (virtual vs. real physical) measurements for different body joints (head flexion/extension and rotation) for each of the manikin/representative real driver of similar stature (for 5th/50th/95th percentile) have been graphically shown (figure 4.8) for easy understating of the readers. From figure 4.8, it is clear that the differences between virtually and physically measured values are minimal and almost similar to each other. For a clear image of figure 4.8, please refer to appendix A.6.

4.4.4 Reach analysis

Reach-envelope was evaluated under two conditions: a) allowing forward flexion of the trunk/upper body (simulating the scenario of without seat-belt) as shown in figure 4.9. b) constraining the forward flexion of the trunk/upper body (simulating the scenario of with seat-belt) as shown in figure 4.10.

For each of these two scenarios, reach-envelopes were developed for 5th, 50th, and 95th percentile manikins. In the case of the driver wearing the seat belt, mobile-phone at positions 1, 2, 3, and 8 were within the comfortable reach for 5th, 50th, and 95th percentile manikins (shown in figure 4.10). On the other hand, in case of without seat belt condition mobile-phone at positions 1, 2, 3, 4, 5, 6, 7 and 8 were within the comfortable reach for 5th percentile manikin (figure 4.9 (a)), whereas, for 50th and 95th percentile manikin, mobile-phone at positions 1, 2, 3, and 8 were in comfortable reach (figure 4.9 (b) and 4.9 (c)).

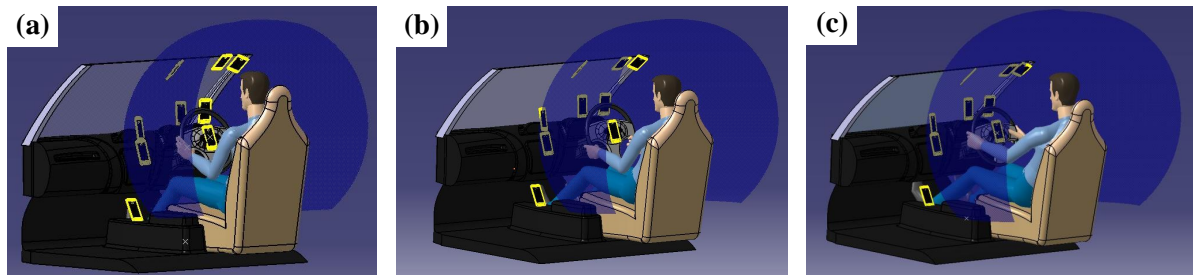


Figure 4.9: *Extended reach-envelope from the lumbar joint for (a) 5th percentile manikin (b) 50th percentile manikin, and (c) 95th percentile manikin*

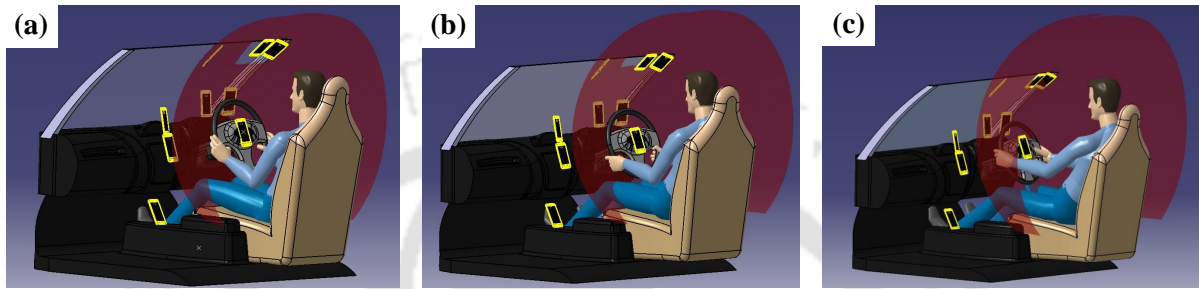


Figure 4.10: *Reach-envelope, with seat belt tied for (a) 5th percentile manikin (b) 50th percentile manikin, and (c) 95th percentile manikin*

4.5 Discussion

The DHM based analysis indicated that the position of the mobile-phone had a noticeable impact on the neck movement (flexion/ extension and rotation). According to Kee and Karwowski (2001), the very-good comfort level for the neck is defined within the flexion of 4° , extension of 7° , rotation of 17° , and lateral bending of 13° in a sitting posture. The results of the present study showed that the head rotation was minimum for positions '2', '5', and '8' as these positions were nearer to the straight forward line-of-sight of the driver and on the same vertical line. It was also seen from the results that the position '5' required minimum head flexion (5° , 7° , 8°) and rotation (1° , 1° , 1°) for all the three (5th, 50th, and 95th percentile) manikins for focusing on mobile-phone. These values were very close and inside the limit as mentioned by Kee and Karwowski (2001), for comfortable head movement. Wittmann et al. (2006) found that the positions which had the least deviation from the forward line-of-sight had the least detrimental effect on driving. The only limitation of this position was that it created a visual obstruction to the forward view-field. On the contrary, position '9' required the driver to turn/ rotate their head as-well-as their trunk/ torso in order to align their line of sight (gaze line) in the center of the mobile-phone display. This led to a longer off-road time; consequently increasing the chances of accidents and near-crash incidences. Hence, this position was deemed unfit/ unsuitable for mounting the mobile-phone. These results were found to be in agreement with the outcome of the studies conducted by Wittmann et al. (2006). All the positions above the normal line of sight (position '1', '2', and '3') which required an extension of the head/ neck for focusing attention, were also considered unsafe for keeping the mobile-phone for navigation. The studies conducted

by Wittmann et al. (2006), also showed low visibility scores in the focused condition task for these positions away from the normal line-of-sight. The position '3' was the same position as that of the rear-view mirror, and it posed severe safety and visibility issues as the rear-view mirror is frequently used while driving. The above results are supported by the findings of Doi et al. (2019) who showed increased reaction time for displays at a vertical position and reported that the vertical eye movement was difficult than the horizontal eye movement, hence any position above the normal line-of-sight would reduce the driving performance. Although the position '8' had less amount of head rotation (about 1°) for 5th, 50th, and 95th percentile manikins, the amount of head flexion was about 17° to 19° for 5th, 50th, and 95th percentile manikins. This was higher than the very good comfort level of neck flexion mentioned by Kee and Karwowski (2001), although, placing mobile-phone at this position would be convenient as there was a comfortable hand reach. Moreover, the position '8' did not obstruct the forward on-road view and instrument cluster is visible through the steering wheel. The positions '6' and '7', which were on the left side of the steering wheel is shown in figure 3.1. The head rotation angle for position '6' was 25° , 23° , 18° for 5th, 50th, and 95th percentile manikin. Similarly, the head rotation angles for position '7' ranged between 21° to 29° for different percentile (5th, 50th, and 95th) manikins. For both of these positions, the head rotation angles were way above the comfort level mentioned by Kee and Karwowski (2001). Studies conducted by Doi et al. (2019) also showed that for display positions where the horizontal neck movement was larger, there was an increase in off-road glance duration with a subsequent increase in driver in-attention as compared to where the horizontal neck movement was less. Position '4' was at the right-hand side of the steering wheel, near the A-pillar. The angle of flexion (7° , 8° , 9°) and rotation (15° , 13° , 12°) for 5th, 50th, and 95th percentile manikin was relatively close and within the limit for head rotation as mentioned for the comfort level of head movement by Kee and Karwowski (2001). Placing mobile-phone at this position would cause a small amount of neck rotation in addition to the extension of arm-reach for mobile-phone operation. Hence, position '4' is the second-best position for placing the mobile-phone. The experimental study conducted by Beck et al. (2017) also confirmed that a display located nearer to the steering wheel on the dashboard was found to be best for response time, eye-off road time, perceived workload, perceived safety, and preference. Similar results were also shown in the empirical studies conducted by Ishiko et al. (2013) for in-vehicle navigation systems.

4.6 Conclusion

The present study evaluated the different positions of the mobile-phone in terms of the comfort of head/ neck and trunk/ torso movement (rotation, flexion/ extension) and ease of arm-reach using CAD based virtual ergonomics evaluation. The results of the current study suggest that the mobile-phones are needed to be placed as nearer to or on straight in front of drivers' normal line-of-sight, in order to reduce the inherent distraction caused by inappropriate positioning of

the mobile-phone for navigation purpose. Mobile-phone position '5' (front of steering wheel) was found to be suitable in terms of comfort of head movement but it obstructed the forward view field. Thus fulfilling the objective of identifying the most preferred in-vehicle position of mobile phone, in-terms of minimum bio-mechanical effort. The position '4' (right of steering wheel on dashboard) was found to be marginally suitable for placing mobile-phones, as this would cause neck rotation and extended arm-reach for mobile operation. However, it was found that placing mobile-phone at position '8' (on the hub of steering wheel) would not only require minimum head rotation but also provide obstruction free visibility of forward view field as well as instrument cluster through the steering wheel. Moreover, this location is within a comfortable arm-reach. From the literature review Beck et al. (2017); Wittmann et al. (2006); Zheng et al. (2016), it is evident that placing the mobile-phone at defined positions (position no. 4 and 8) would reduce the response time, eye-off road, workload, and increase safety due to lesser head deviation from the normal line of sight. The work presented in this chapter is an initial study towards developing the guidelines for mounting the mobile-phone (as navigation device) inside the vehicle, with the aim to minimize the biomechanical effort of information access and off-road deviation. Thus it can be concluded that objective 5 as mentioned in section 1.5 was fulfilled by identifying the most preferred in-vehicle mobile phone position in-terms of reduced bio-mechanical effort.

Further, studies involving human subjects and driving simulator are required, so that factors like complexity of the task, task completion time, the effect of tilt of mobile-phone, glare, illumination, drivers' cognitive load could be taken into consideration to develop guidelines for well-justified placing of the in-vehicle mobile-phone for navigation purpose.



5

Mounting device development for positioning the mobile phone at steering wheel's hub

Abstract

The DHM based study revealed that in-vehicle mobile phone positions placed nearer to the normal line-of-sight are better in terms of least head movement and easy hand-reach. This chapter describes a systematic product development process used to develop a novel mobile phone holder for a car that can be easily mounted on the steering wheel. Different steps involved in the product development and design process include planning (customer need identification), concept development, concept screening/selection, prototype development, and testing. These processes are explained in general and specifically for the developed mobile phone holder.

5.1 Introduction

A product is something that an enterprise sells to its customers based on their needs. A product may be tangible (like bicycle, television, car, etc.) or intangible (services provided by the bank, doctors, airlines, etc.); it can be either a consumer (those used by common person) or an industrial (those used by industries for producing goods) product (Ulrich & Eppinger, 2016).

Product development process is the entire set of activities that an enterprise follows, from identifying the market opportunity (need identification) to designing and finally commercializing the product. A generic product development process consists of many phases, which include; need Identification, concept development, system-level design (define product architecture, subsystem and components), detailed design (detailed specification about the geometry, material and tolerance of each part), testing and refinement, and production ramp-up (Ulrich & Eppinger, 2016). Flowchart showing this generic process of product development is shown in figure 5.1.

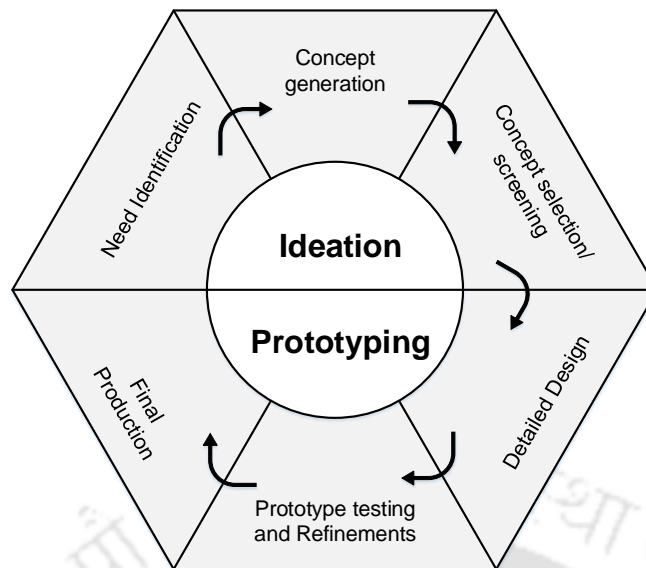


Figure 5.1: A generic product development process (Adapted from Ulrich and Eppinger (2016)).

5.2 Need/ requirement of a mobile-holder for car

During the initial survey of MABTS drivers, all the positions used for keeping mobile phone was exhaustively determined. Ranking of the positions was done to find out the most preferred position (details in chapter 3). Placing the mobile phones on the steering wheel was not found during the survey and got a lower rating from the drivers. A virtual ergonomic evaluation of the mobile phone placed at all the different positions using CATIA-DELMIA as a DHM tool was carried out to determine the biomechanical load of viewing and easy hand-reach (details in chapter 4). The results revealed that in-vehicle mobile phone positions, which are less eccentric from the line-of-sight, are more suitable (positions on the steering wheel and behind the wheel on the dashboard). A market survey showed, non-existence of mobile-holder, which could be mounted on the steering wheel and simultaneously keep the mobile phone in a vertically upright position even when the steering wheel rotates.

Hence, to empirically examine the most suitable in-vehicle mobile phone position for navigation purposes, a mobile phone holder was needed to be developed. The developed mobile phone holder should facilitate easy mounting on the steering wheel and keep the mobile phone in a steady-state, even when the steering wheel is rotated.

5.3 Methodology adopted

For this study, the following steps were followed:

- (i) Field survey: Initially, semi-structured interview (consisting of both closed and open-ended questions) was conducted with the drivers who were using the mobile-phone holder in their car.

- (ii) Concept generation: Concepts sketches of the mobile-phone holder were generated based on customer needs. Morphological chart was used for generating alternate concepts of the product.
- (iii) Concept selection/ screening: Different concept alternatives of the mobile-phone holder were compared, evaluated, and screened by the design team, using the Pugh concept selection matrix.
- (iv) Prototype development and field trail: A working prototype was developed. The CAD model was generated before physical prototyping.

Development process of the mobile-phone holder

According to Ulrich et al., a product development process is a set of activities which is employed to conceptualize, design, and commercialize a new product (Ulrich & Eppinger, 2016). The process of designing and developing a new product (mobile phone holder in this case) consists of two broad phases, each of which further divides into three sub-activities. These two phases are Ideation (consists of customer need identification, concept generation, and concept selection) and Prototyping (which consists of Detailed design, prototype testing & refinement, and final production). Generic product development process is shown in figure 5.1.

5.3.1 Customers' need identification

Careful assessment of market is needed for designing a successful new industrial products (Piegorsch, 2009). Keeney and Lilien (1987) in their work introduced Multi-attribute analysis, which they showed to have potential in aiding product design process (Keeney & Lilien, 1987). For the purpose of this study, to identify customer needs, a total of 107 male drivers were contacted. Semi-structured interview was conducted and their response was recorded. These covered the aspects about their usage pattern of the mobile-phone holder, relative placements around the steering wheel, cost, size etc. Their response was noted and the data was interpreted in terms of customer needs to formulate the design objectives. It helps in designing the concept of product. The key features of the design objective are that it manages and controls the design and is easily understood by both the client and designer.

5.3.2 Concept generation

Brainstorming session was conducted with a small design group to identify the suitable location for mounting mobile-phone on the steering wheel. Five possible location were identified (shown in figure 5.2).

- Location 'A': It is at the top periphery of the steering wheel; placing here would obstruct the view of the instrument cluster.

- Location 'B' and 'C': located at left and the right periphery of the steering wheel; there would be deviation from the straight forward line of sight.
- Location 'D': situated at the bottom periphery of the steering wheel; mobile-phone, if placed here, would increase the neck and eye movement.
- Location 'E': This position is at the center of steering wheel; there will be minimum deviation from the straight forward line of sight.

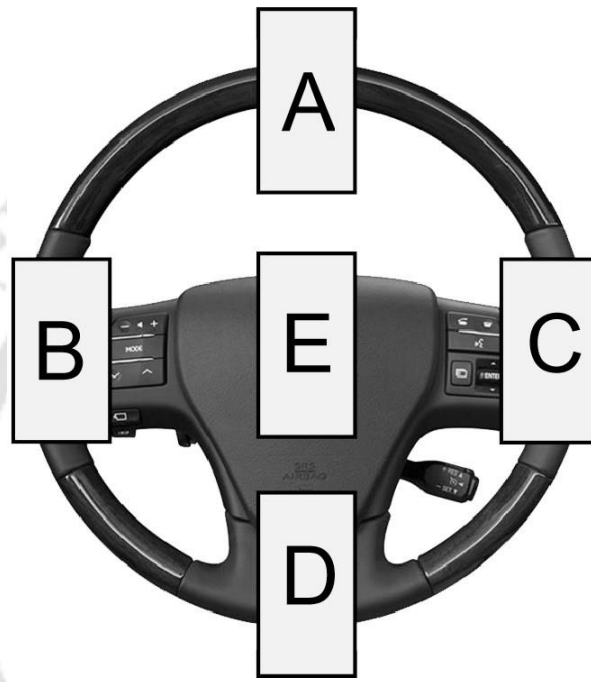


Figure 5.2: Possible location of mobile-phone on steering wheel.

Hence, it was decided to design a mobile-phone holder which could be mounted at the center of steering wheel, as there would be minimal deviation from the straight forward line of sight. Thereafter, to generate various concepts of mobile-phone holder, a matrix containing all the possible solutions called the Morphological chart (Norris, 1963) was prepared (shown in Table 5.1). For this study, the product was divided into the following five functions: 1) Fixing on the steering wheel, 2) Viewing angle adjustment, 3) Type of clamp opening, 4) Holding mechanism, 5) Rotating mechanism; and for each of the functions, five alternative options were made (shown in Table 5.1). Six alternative concepts of the mobile-phone mounting device were prepared by using one option for each of the function.

5.3.3 Concept selection

Concept selection is a critical stage in the product development process. After various concepts were developed, appropriate concept was selected or screened out based on the design objective described earlier. The design team evaluates the concept alternatives and gives scoring based on

Table 5.1: Morphological chart for Mobile-phone holder for car

Functions	Options				
	1	2	3	4	5
(a) Fix to steering-wheel	Vacuum suction	Magnet	Sticking	Clamping	Screw to base
(b) Adjust viewing angle	Ball and socket	Swan neck wire			
(c) Attaching and detaching	Both-side open	One-side open	Bottom open		
(d) Holding mechanism	Clipping	Spring loaded	Rack and pinion	Elastic band	Screw
(e) Rotation mechanism	Gyroscope (electronic)	Ball bearing (mechanical)	Hand adjustment (manual)		

the design objectives. Different concepts of mobile phone holder were evaluated using the Pugh chart (Otto & Wood, 2001; Pugh, 1991) method for concept selection, and a decision matrix is prepared. Selecting the DATUM or the reference is of utmost importance in this method. The design team voted, concept '2', be chosen as 'DATUM' or reference, with which other selected concepts will be evaluated. Concept alternative which received higher score is proceed further with prototype development.

5.3.4 Creation of virtual mock-up in CAD

A virtual mock-up of the selected mobile-phone holder concept was prepared before making the prototype. Three-dimensional, Solid CAD model was created using Solid-works (v16) software; various parts of the product was made and assembled using Solid-works platform. Two-dimensional drawing of all the part of mobile-phone holder with measurements (in mm) was drafted.

5.3.5 Prototype development

Various components of the mobile-phone holder were gathered and suitably modified in design studio as per the requirement of the conceptualized mobile-phone holder. The prototype consisted basically of three parts: (a) base (b) ball and socket (c) mobile-phone holder. Base was prepared using Thermoform plastic as material, by Vacuum forming process. A miniature ball bearing (No. 698zz) was procured from the market. This ball bearing was used to prepare the mold of the base and was finally fixed inside the base, such that it does not skip out. The

second part is the ball with a small stick, made of nylon. It was prepared by turning process in lathe. For procuring the third part of the mobile-phone holder, which is the holder mechanism, 'Jugaad' (Agnihotri, 2015; Prabhu & Jain, 2015) technique was used and was taken from an already existing product in the market.

5.3.6 Usability testing and user feedback

User feedback was collected to check the efficacy of developed product. Fifteen driver volunteered to participate in the study. Demonstration was given about fixing of the mobile-phone holder on the hub of steering wheel, and it's working during navigation and driving tasks. Table 5.2 shows the questionnaire for feedback. Usability of the novel mobile-phone holder was evaluated using System Usability Scale (SUS) (Brooke J. & Brooke, 1996). Fifteen driver volunteered to participate in usability testing and SUS was administered to them after they interacted with the mobile-phone holder prototype. The SUS scores was interpreted in terms of adjective rating and acceptability Bangor, Kortum, and Miller (2009, 2008), shown in Table 5.3.

Table 5.2: Questions used during user feedback.

Sr. No.	Feedback questions	Low (1-2)	Middle (3)	High (4-5)
1.	How likely is there that you will use this product ?			
2.	Based on the material and design aspects do you feel the cost of \$5 justified ?			
3.	How likely do you feel that this product is helpful to you ?			
4.	Do you think that the mobile mounting device is innovative in nature ?			
5.	How will you rate the Aesthetics of the developed product ?			
6.	How likely is there that you will refer this product to your family members/relatives/ friends ?			

5.4 Observations

5.4.1 Insights from the field survey

To understand the customer needs, a semi-structured interview was conducted. A total 107 driver took part in this survey process. Their responses were noted down, and data was interpreted.

Table 5.3: SUS scores with corresponding adjective and acceptability rating.

SUS Score	Adjective rating	Acceptability
89—100	Best Imaginable	
84—88	Excellent	Acceptable
71—83	Good	
50—70	OK	Marginal
32—49	Poor	
20—31	Awful	Unacceptable
00—19	Worst Imaginable	

The relative percentage of drivers and their preference regarding the cost of mobile-phone holder they use is shown in figure 5.3.

About 50% of the drivers used, mobile-phone holder which ranged from \$ 3.5 to \$ 7 (approx. ₹250 – ₹500); whereas, 36.45% preferred to use mobile-phone holder, which are below \$ 3.5 (approx. ₹250). For the question, what size of mobile-phone they use for navigation purpose in their cars, about 24.3% of drivers used mobile-phone having a screen size of 4.5-in. Some other mobile-phone screen sizes being used by the drivers, recorded during the survey were 4.7-in (19.6%), 5-in (15%), 5.5-in (13.1%), 5.2-in and 5.3-in (each 9.35%). figure 5.4, shows the frequency curve of mobile phone size, and their relative usage percentage by drivers during the survey.

Apart from this the drivers were also asked about their preferred position of keeping the mobile phones (left, right or center). About, 57.9 % preferred keeping their mobile phone on left side, whereas 36.4 % said they like to keep it on right side, a very small percentage, and 5.6 % said they keep it at center. It was also noted that everyone said that they would like to operate and install the mobile- phone holder with minimum effort and without any assistance. Hence, following design objectives are formulated based on customer needs:

1. *Size:* The mobile-holder easily mounts at the center of steering wheel without hindering its free movement.
2. *Installation:* It should be easy to install on the steering wheel.
3. *Adjustability:* The mobile-holder should provide for a change in the angle of viewing of mobile phone and keep the phone in upright even while steering wheel movement.
4. *Universal:* It should be able to adjust to accommodate mobile phones of different size.
5. *Cost:* The mobile-phone holder is lower in cost than the existing competitors' products.

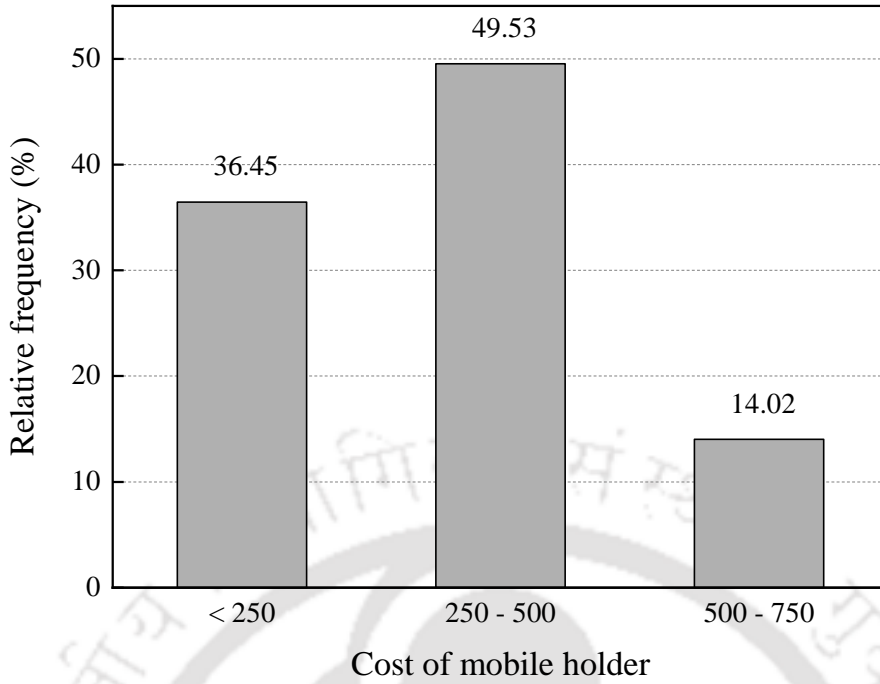


Figure 5.3: Relative frequency of the mobile-phone holder cost

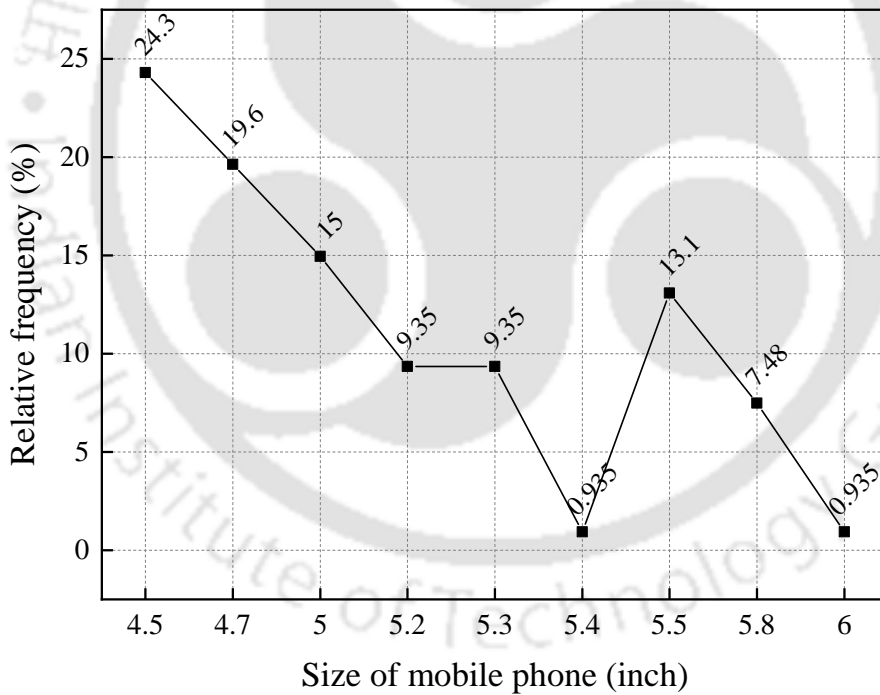


Figure 5.4: Relative percentage of mobile phone size

5.4.2 Generated concepts and their descriptions

Morphological chart was used for generating concepts. Table 5.1, shows the morphological chart of mobile-phone holder for car, with various options as column, and different functions as each row. By using the Morphological chart, many concepts were generated (by choosing one option for each function of the product), out of which the design team selected six concepts which

were found to be feasible. The design objectives obtained from customer needs, formulated the functionality of the novel product. Thus, each of the concept is obtained from combination of one option for each function; these combinations for each concept is given below in figure 5.5.

These concepts of mobile-phone holder is shown in figure 5.5 (a – f). A brief description of each concept is given below:

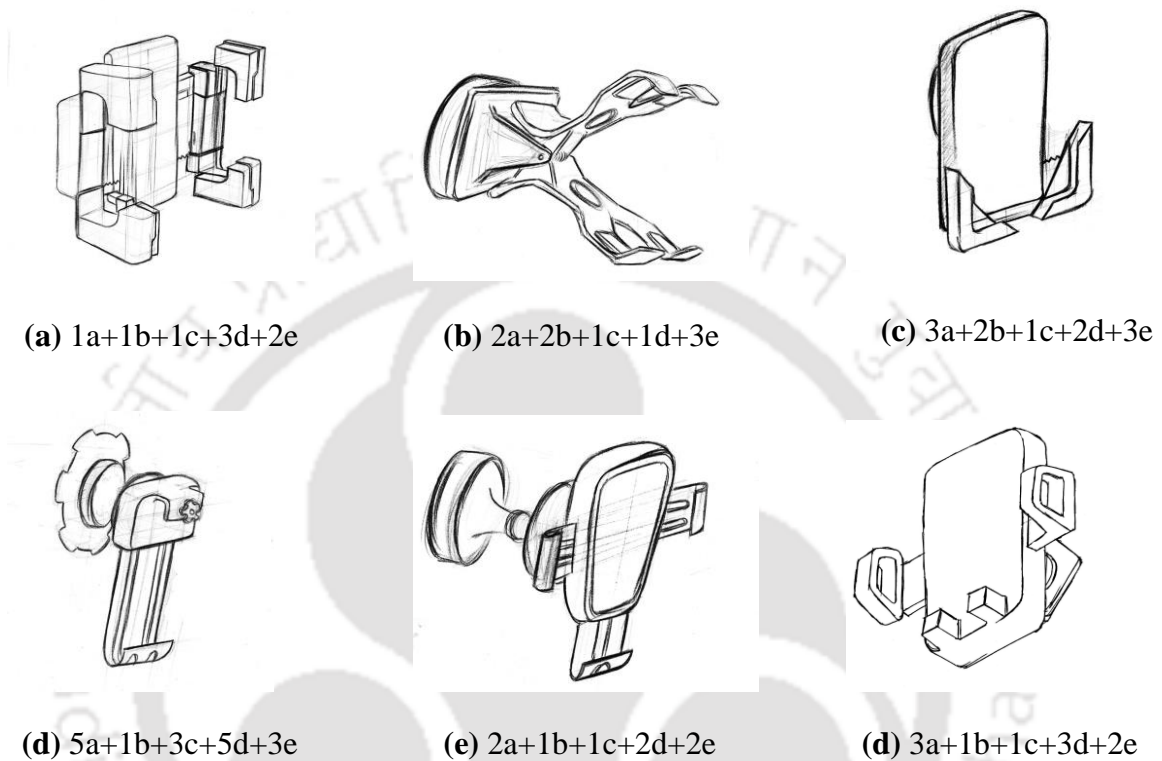


Figure 5.5: Different concepts of mobile-phone holder developed.

1. *Concept 1:* In this concept, the phone is held from the sides, by the arms of the holder, which come out uniformly by use of rack and pinion mechanism. The phone can be tightly fixed by pressing the arms of the holder with the phone. A ball bearing is attached at the back, which in-turn is attached to the steering wheel by stick pad. Hence, the holder can rotate and stay in an upright position even when the steering is rotated. Shown in figure 5.5(a).
2. *Concept 2:* The sketch is shown in figure 5.5(b). The phone can be held from top and bottom by clipping mechanism. The back side of this is attached to the bearing through the pivot of the clip. Hence, the angle of the phone can also be adjusted. The bearing can be attached to steering wheel by stick pad.
3. *Concept 3:* In this concept, the phone is held from the bottom corners. The jaws open by a rack and pinion type mechanism. By pressing the jaws we can tighten the mobile-phone. A bearing is attached at the back of the holder which can be fixed at the centre of the

steering wheel by a stick pad. The position of the bearing attachment is not at the center of the holder but above the horizontal axis — shown in figure 5.5(c).

4. *Concept 4:* In this the phone is held from the top and bottom. The mobile-phone fits in by extending the bottom jaw of the holder, which is spring loaded. At the top, a screw can be tightened to fix the position of mobile-phone. A bearing is attached at the back which is again attached to the steering wheel stick pad — shown in figure 5.5(d).
5. *Concept 5:* This concept is shown in figure 5.5(d). This holder consists of three jaw system- 2 sideways and 1 at bottom. A ball bearing is attached at the back, which can be fixed to the steering wheel by stick pad. The center of this holder is above the horizontal axis, to maintain the phone weight to bottom.
6. *Concept 6:* In this concept (shown in figure 5.5(e)), the mobile phone is held by two jaws of the mobile holder which opens simultaneously by the press of a button, by rack and pinion mechanism. The jaws can be closed by pressing them together. A rotating mechanism is provided with the help of a miniature bearing which maintains the mobile holder in an upright position when the steering wheel is rotated. The center of this bearing is attached to the ball and socket joint which provides the facility of changing the angle of the mobile when it attached to the mobile holder. The entire assembly can be easily fixed at the center of steering wheel.

5.4.3 Final concept based on Pugh chart score

Based on Pugh chart matrix, the scores of different concepts is shown in Table 5.4. Out of all the alternatives, concept '6' received the highest score of '5' and it was further taken-up for physical prototype development.

Table 5.4: Pugh concept selection matrix for a mobile-phone holder for car

	Weights	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
Size	1	–	D	+	+	–	+
Installation	1	+	A	+	+	+	+
Adjustability	2	–	T	–	–	–	+
Universal	2	+	U	+	+	+	+
Cost	1	–	M	+	0	–	–
$\Sigma+(P_i)$		+3	0	+5	+4	+3	+6
$\Sigma-(N_i)$		–4	0	–2	–2	–4	–1
Σ		–1	0	+3	+2	–1	+5

5.4.4 Generated CAD model and final physical prototype

Three-dimensional solid CAD modeling of different part was made and then assembled in SOLIDWORKS (v.16) platform. The different views of the product's CAD model is shown in figure 5.6. An exploded view of the mobile-phone holder is shown in figure 5.7. The physical prototype of the conceptualized mobile-phone holder is shown in figure 5.8. It consists of three parts: (a) mobile-holder (b) ball and socket (c) base. The approximate cost of the developed prototype is between \$4 to \$5 (approx. ₹290 – ₹350). The two-dimensional drafting (with measurements in inches) of the mobile-phone holder concept is shown in figure 5.9, detailed drafting is given in Appendix A.7 (measurements in mm).

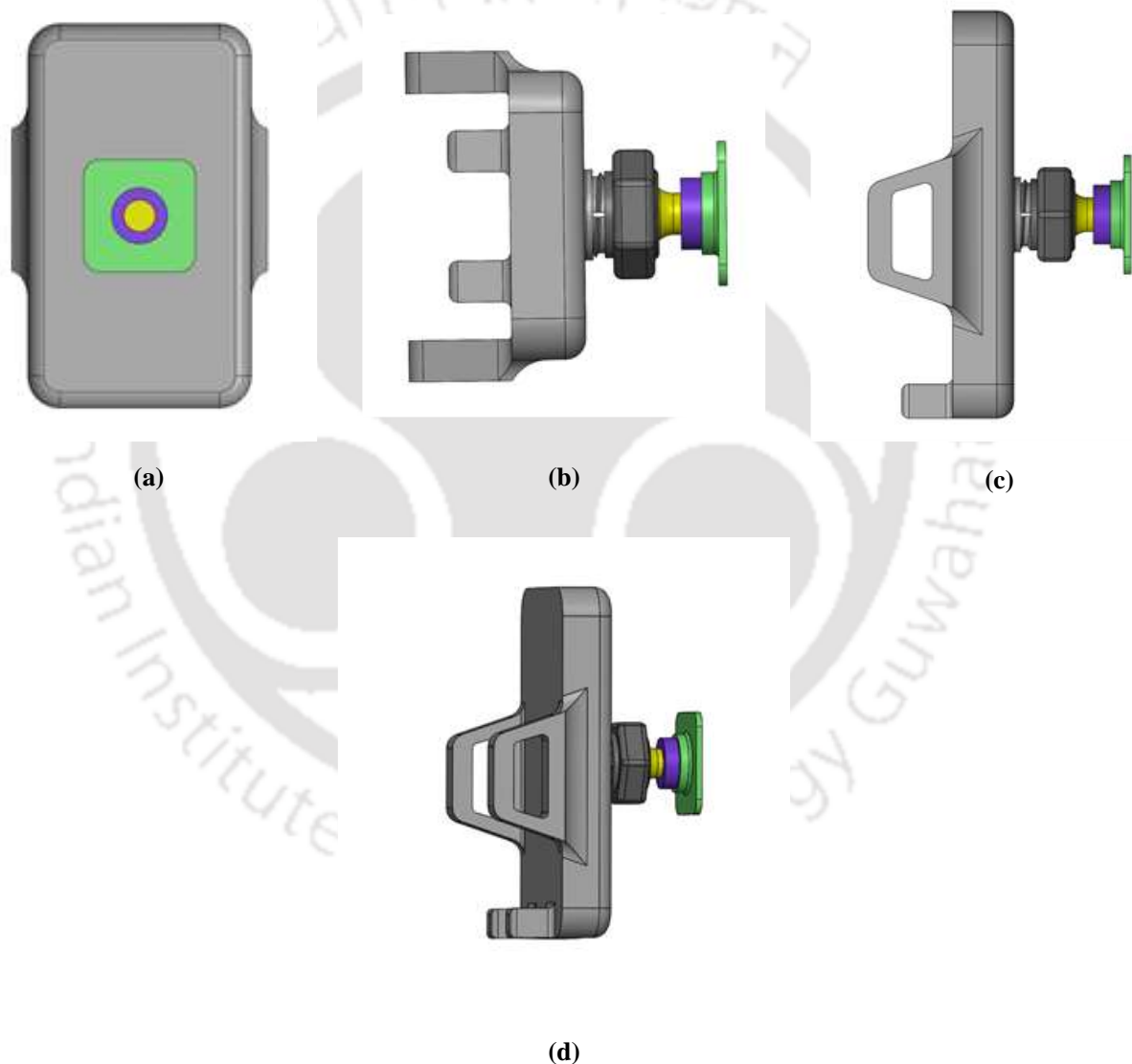


Figure 5.6: Different views for the CAD model of mobile-phone holder; (a) rear-view, (b) top-view, (c) side-view, and (d) perspective view

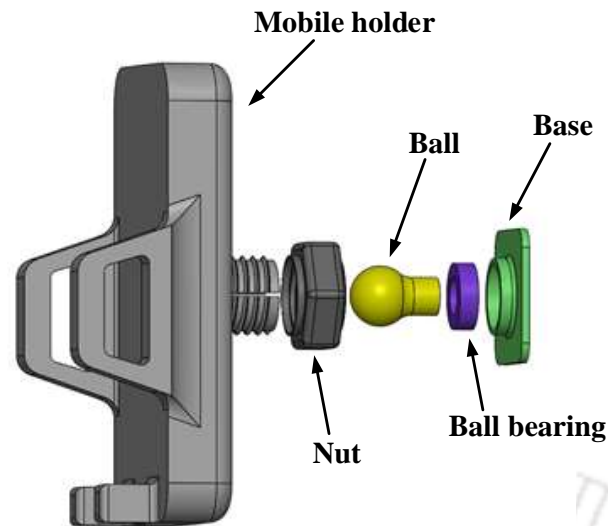


Figure 5.7: Exploded-view of mobile-phone holder

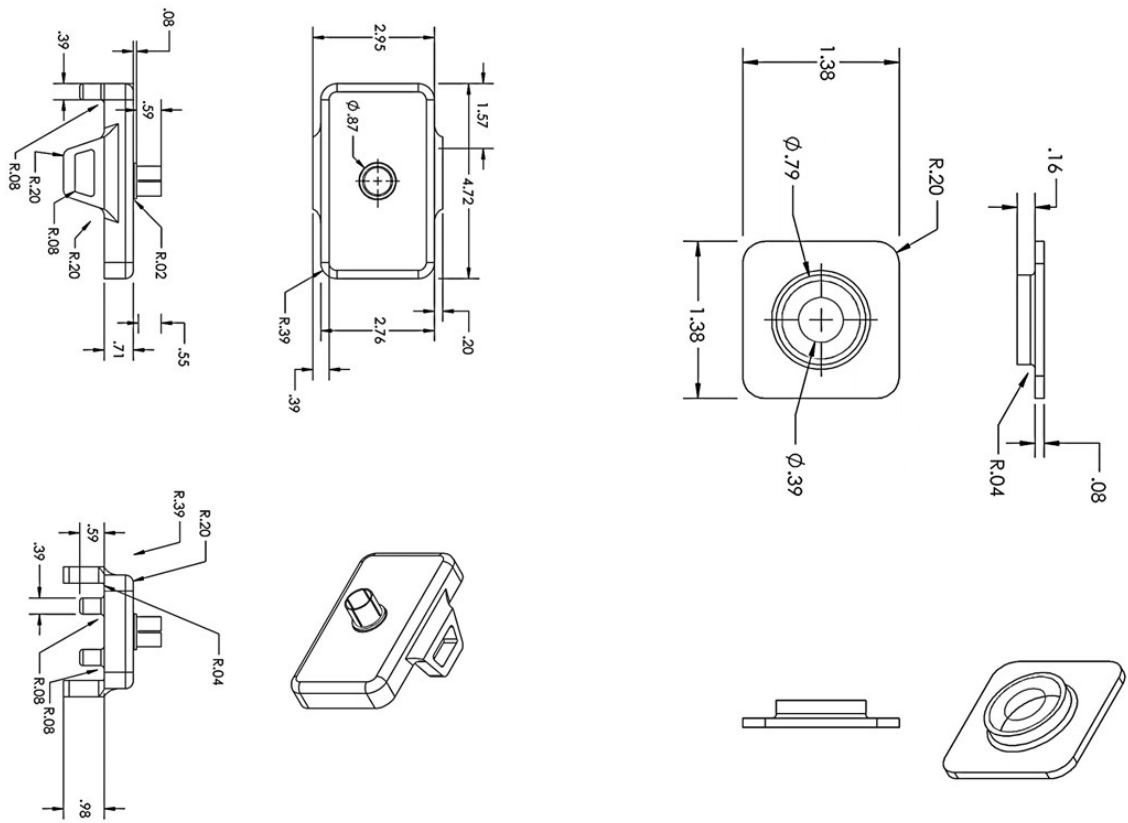


Figure 5.8: Different views of prototype mobile holder.

5.4.5 Insights from usability testing and user feedback

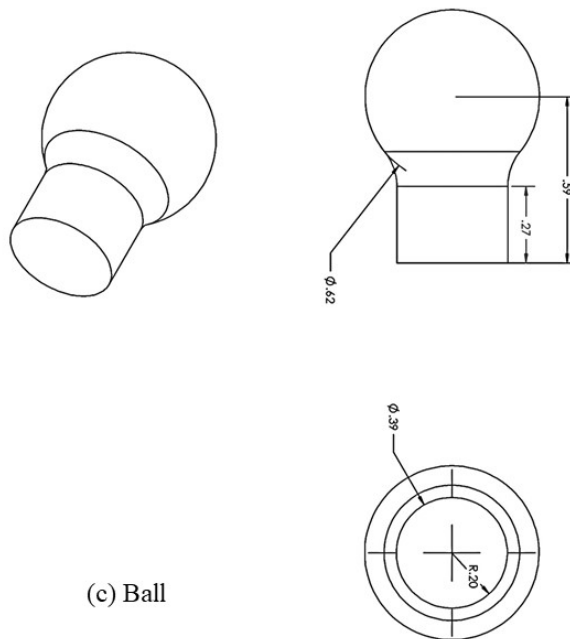
Fifteen drivers volunteered for usability evaluation and rate the product on System Usability Scale (SUS) after they were shown and interacted with the product prototype. A SUS score value of 83.67 was obtained which shows “good” and “acceptable” usability rating, according to the adjectives shown in Table 5.3. The ratings for various items of SUS is shown in Table 5.5. Figure 5.10 and figure 5.11 show the ratings for these odd and even-numbered questions respectively, in a pictorial form. It was observed that, for odd-numbered questions (positively phrased), the responses were mostly ‘agree’ and ‘strongly agree’; in-contrast to even-numbered questions (negatively phrased), were high responses percentages lied mostly between ‘disagree’ and ‘strongly disagree’.

The feedback of the users was recorded using the questionnaire (shown in Table 5.2). The mean ratings by the users is shown in figure 5.12. Overall feedback score of 4.46 out of 5 was obtained. A horizontal line at ‘3’, indicated the median value, the mean score for all the questions were above it. This indicated the overall positive feedback by the users. The smart-phone mounting device was tested under naturalistic driving condition and was observed to move/ rotate about 10° – 15° under sudden jerks and motion (due to rotation of the steering



(a) Holder

(b) Base



(c) Ball

Figure 5.9: Two Dimensional drafting of the mobile-phone holder

wheel) and it returned to its initial vertical position within 600 to 700 milliseconds, after the sudden motion subsides.

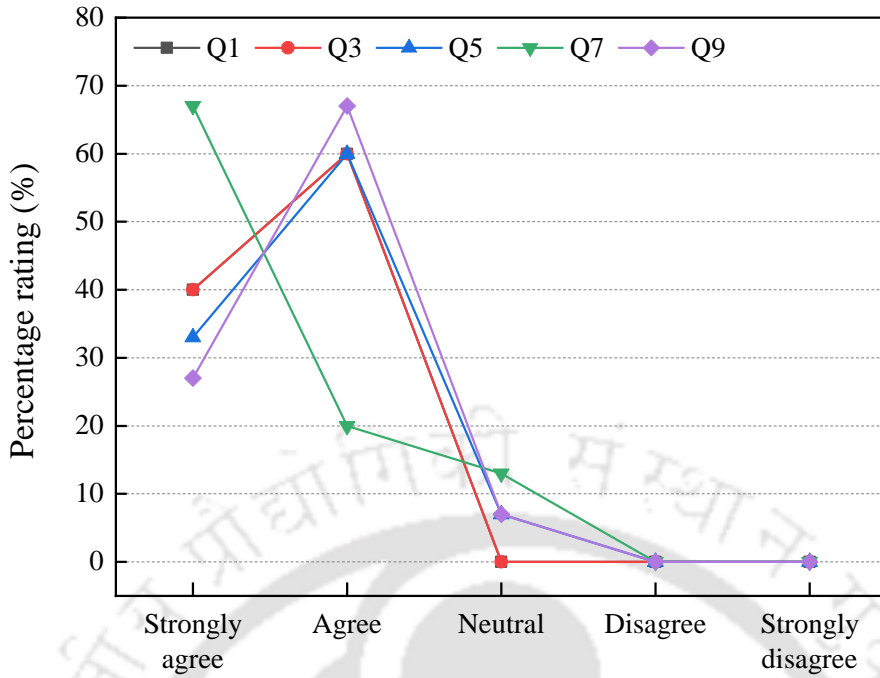


Figure 5.10: Percentage ratings for questions 1, 3, 5, 7, 9 of SUS

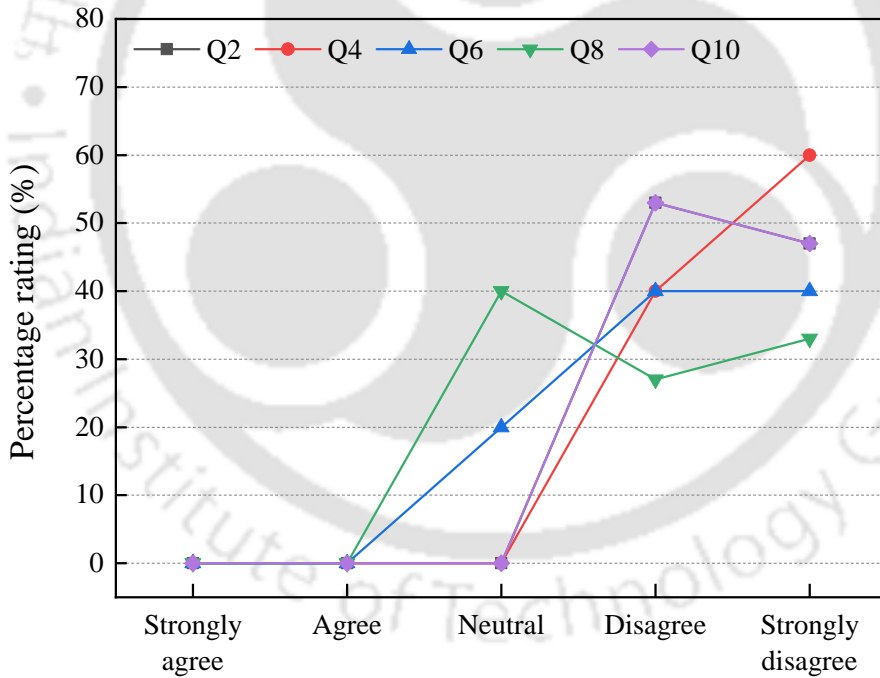


Figure 5.11: Percentage ratings for questions 2, 4, 6, 8, 10 of SUS

5.5 Discussion

Literature shows that placing visual displays nearer to the straight forward line of sight (which have smaller viewing angles), results in improved performance of drivers by reducing the glance time as well as reaction-time to visual display and consequently reduces driver distraction (Wittmann et al., 2006; Zheng et al., 2016). Therefore, mounting the mobile-phone as an

Table 5.5: System Usability Scale items and their ratings

Sr. No.	System usability scale questions	Ratings, % (n), total n =15				
		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1.	I think that I would like to use this product frequently.	00 (0)	00 (0)	00 (0)	60 (9)	40 (6)
2.	I found the product unnecessarily complex.	47 (7)	53 (8)	00 (0)	00 (0)	00 (0)
3.	I thought the product was easy to use.	00 (0)	00 (0)	00 (0)	60 (9)	40 (6)
4.	I think that I would need the support of a technical person to be able to use this product.	60 (9)	40 (6)	00 (0)	00 (0)	00 (0)
5.	I found the various functions in the product very well integrated.	00 (0)	00 (0)	07 (1)	60 (9)	33 (5)
6.	I thought there was too much inconsistency in the product.	40 (6)	40 (6)	20 (3)	00 (0)	00 (0)
7.	I would imagine that most people would learn to use the product very quickly.	00 (0)	00 (0)	13 (2)	20 (3)	67 (10)
8.	I found the product very cumbersome to use.	33 (5)	27 (4)	40 (6)	00 (0)	00 (0)
9.	I felt very confident using the product.	00 (0)	00 (0)	7 (1)	67 (10)	27 (4)
10.	I need to learn a lot of things before I could get going with this product.	47 (7)	53 (8)	0 (0)	0 (0)	0 (0)

in-vehicle navigation device close to the straight forward line of sight must improve the driving performance. Middle of the steering wheel for positioning mobile-phone was planned as it is presumed beneficial. It allows lesser viewing angle and less obscuration of the forward on-road view field as well as instrument cluster located back-side of steering wheel. Although, based on earlier research related to position of in-vehicle displays/ navigation screen, it is presumed that middle of the steering wheel is the best suited location for mounting mobile-phone but the superiority of selected location should be empirically established. Objective methods of experimentation using eye-tracking (De Lumen et al., 2019), driving simulator (Doi et al., 2019), and neck angle (flexion, extension and lateral movement) measurement should be done for this purpose.

Although there is negligible horizontal/ lateral eye and/or neck movement to visualize the

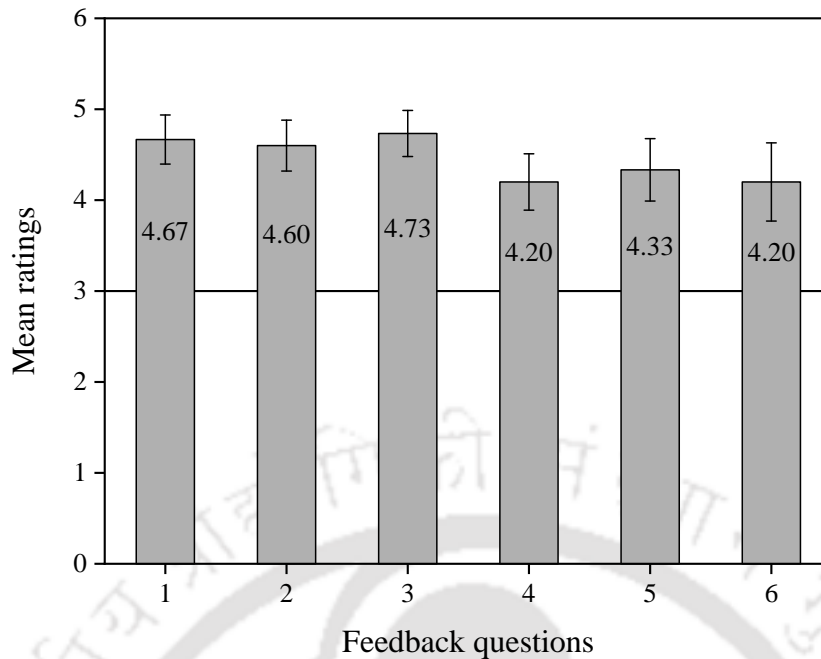


Figure 5.12: Mean rating for different feedback questions.

display of the smart-phone positioned on the hub of steering wheel, there is still requirement of downward eye and/or neck movement. To avoid this downward eye and/ or neck movement, mobile-phone could be alternatively positioned on the dashboard or hanging from the windshield, but these positions lead to obscuration of forward view-field. Another alternative to avoid downward eye and/ or neck movement is the use of Head-Up Display (HUD), but there are various limitations of HUD as stated by earlier researchers (Bhise, 2012). Moreover, HUD are costly, and it is not compatible for various navigation applications. The developed product (device for mounting smart-phone on steering wheel hub) is innovative in nature due to novelty in its features as compared to those already existing in the market. The novel features of the mounting device include (a) provision for fixing the phone/ navigation device at the hub (center) of the steering wheel, (b) use of ball and socket joint which allows for adjustment of angle of mobile-phone for better viewing experience (drivers can easily adjust the viewing angle of the mobile-phone to reduce the glare and better visibility), (c) application of ball bearing system to the mounting device to facilitate upright position of the mobile-phone even when the steering wheel is in rotation, (d) lightweight (approx. 200 gm). In the current research, detailed product development methodology starting from conceptualization to prototype development has been covered and the adopted methodology is in corroboration to other innovative product development techniques (Otto & Wood, 2001; Ulrich & Eppinger, 2016).

Brainstorming session with the designers' group was instrumental in generating optional ideas for each of the sub-functions of the mounting device. Using Morphological analysis/ chart, large number of concepts was possible in the given time. Additionally, the designers were able to improve the overall quality of product by a slight change in components to address

the same function, because all the data is in front of them in the chart (Dandavate & Sarje, 2012). Similar scientific endeavors where morphological analysis were used for generating results in the fields of smart furniture design (Dragomir, Banyai, Dragomir, Popescu, & Criste, 2016), education (Ritchey, 2010), automotive components (Mansor, Sapuan, Zainudin, Nuraini, & Hambali, 2014) and architecture (Amorim, 2009). The best solution among the generated concepts of the mounting device was determined using the Pugh matrix. It is simple and has been effectively used in comparing the alternative concepts in the diverse product domain of electrical appliance (Lin & Hsiao, 2019), packaging/ containers (Wu & Hsiao, 2019). For measuring the perceived usability of the system, multiple standardized questionnaires are available. Effective use of System Usability Scale (SUS) can be found in evaluating usability of the system in domains relating to mobile-app development (Kaya, Ozturk, & Gumussoy, 2019; Kortum & Sorber, 2015), healthcare device (Liang et al., 2018), automobile (Deng et al., 2019) and hand-tool design (Dianat, Asadollahi, & Nedaei, 2017). In current research, SUS was adopted for checking the usability of the mounting device as this tool were reported to be the most reliable option even with small number of participants (Tullis & Stetson, 2004). One of the visible limits of the study is that it takes into account the opinion and feedback only from male drivers. However, in the future study female drivers may also be included to have a better understanding of the scenario. Secondly, the final prototype was made using 'Jugaad' technique. Future studies could fruitfully explore different material as well as manufacturing technology for mass production and making the product much affordable. Business plan to commercialize the developed mounting device are beyond the scope of current study and can be taken up further. Additionally, as the product is innovative and has market potential, initiative for protecting the Intellectual property rights (IPR) is needed.

5.6 Conclusion

Following the current research, an innovative smart-phone mounting device was developed through systematic user-centered product design approach. The developed product is in-expensive, light-weight, easy to use and has the potential to become a marketable product.

The developed mobile phone holder has a self adjusting feature which can be mounted in the center of the steering wheel. It is expected that positioning of smart-phone at the hub of steering wheel with the help of developed mounting device would reduce biomechanical effort of neck and/or eye movement for information access from the screen and thereby reduction of driver distraction. However, further experimental study involving this developed mobile-phone holder in a simulated environment is required to validation this statement.



— Optimism is the faith that leads to achievement. Nothing can be done without hope and confidence.

Helen Keller

6

Experimental validation of the preferred in-vehicle mobile-phone position

Abstract

This chapter presents an empirical study conducted to evaluate the most suitable in-vehicle mobile phone position. This study uses the construct of lane changing test (LCT) in a simulated driving environment. The driver has to simultaneously perform secondary task on the mobile phone and lane changes on a simulated track. Lane change indications are presented to the drivers on the simulator monitor. Eye-tracking variables were also measured to identify the total number of glances away from the road and eyes-off-road duration during the simulated driving condition while performing the secondary task on the mobile phone placed at different positions. The subjective workload of the drivers was assessed using driver activity load index (DALI). Results, discussion, limitations, and conclusion of the study are presented at the end in this chapter.

6.1 Introduction

Globally, road traffic accidents are the 8th leading cause of fatalities and injure. An estimated 1.35 million people die due to road traffic accidents annually (WHO, 2018). Driver distraction is one of the causes of road accidents, and one of the reasons for driver distraction is the use of mobile phones while driving. Mobile phone use in our daily life has also increased. According to “Ericsson’s mobility report”, the total number of mobile subscriptions worldwide was around 7.9 billion in Q3 of 2018; it also estimated 8.9 billion subscribers by 2024 (Ericsson, 2018). Advancements in communication and information technologies have led to mobile phone use as an in-vehicle information system (IVIS) (Horrey et al., 2006). These mobile phones, used as IVIS, provide drivers with more information about driving and non-driving tasks (navigation, vehicle status, weather, and entertainment). It is frequently discovered that drivers place the mobile phone inside the vehicle at various locations (on the dashboard/ windshield close to

the central console, close to the base of A-pillar) (Verma & Karmakar, 2020). The use of mobile-phone-based IVIS is often being associated with inattention to driving, causing driver's distraction, thereby impairing road safety (ISO, 2010). According to Ranney et al. (2001), driver distraction is "any activity that takes a driver's attention away from the task of driving." Any distraction from rolling down a window, over adjusting a mirror, tuning a radio to using a cell phone can contribute to a crash. It is worthwhile to point out that De Lumen et al. (2019), in their study, found that the drivers have no idea about the safe and efficient location to mount their navigation devices.

6.1.1 In-vehicle display position in the driving context

Previous research have evaluated the effect of in-vehicle display positions on various aspects of driving (De Lumen et al., 2019; Doi et al., 2019; Ganesh et al., 2015; Radakrishnan et al., 2016; Verma & Karmakar, 2020; Wittmann et al., 2006; Zheng et al., 2016).

Studies have focused on positioning of the infotainment screen inside the vehicle for better visual experience, emphasis was given to parameters like vision angle, avoiding any obscuration due to vehicle components, avoiding in-vehicle reflections and avoiding ambient reflections (Radakrishnan et al., 2016), and cluster packaging process flow for in-vehicle visual hindrance free instrument cluster position (Ganesh et al., 2015). Some other researchers have conducted empirical studies to determine the optimal location of in-vehicle displays. In their study, De Lumen et al. (2019) measured the driver's visual distraction level by conducting a peripheral detection test on three locations around the steering wheel to determine the ideal location for placing mobile navigation device. Further, researchers have also used digital human modeling to identify the suitable location for mobile navigation device. Verma and Karmakar (2020), measured head rotation, flexion/extension of the manikins (5th, 50th, and 95th percentile), when mobile phones are placed at nine different locations around the steering wheel. It is evident that there is a lack of rules or guidelines for the optimal position of mobile phone-based IVIS. Further, formulating driver distraction policy is an incremental process as bringing the empirical and theoretical knowledge is a complex process (McGehee, 2011). However, some countries have enacted laws to prevent distracted driving. One such country is the Philippines, which has implemented the Anti-Distracted Driving Act (ADDA, RA 10913). It proposes a safe zone for placement of mobile phone-based IVIS (LTO, 2017).

Further, the research conducted by Wittmann et al. (2006), hypothesized that the primary task of driving would have a strong degrading effect as the eccentricity of display and workload condition of secondary task increases. They reported an exponential decrease in driver's performance as a function of the distance between the line-of-sight and on-board display position. Also, the empirical study of Zheng et al. (2016) evaluated the suitability of display positions based on eye-gaze tracking of drivers, when navigation systems were placed at different locations around the dashboard. The findings suggest that in-vehicle display positions

with small visual angles have significantly shorter glance time compared to displays with larger visual angles.

A few researchers have conducted studies to investigate the positioning of mobile data terminals (MDT) used by the police force for assistance during patrolling duties (Hampton & Langham, 2005; McKinnon et al., 2012) as an influencing factor for distraction. Hampton and Langham (2005), have investigated the requirements of MDT installed inside the police vehicle in terms of safety and the requirements of systems design. McKinnon et al. (2012) conducted studies on five MDT locations and two types of seats (standard and modified) to find the best possible MDT locations in terms of reduced physical discomfort. Results reveal that self-selected MDT locations, along with modified driver seats, reduced the physical discomfort compared to the traditional arrangement. Some researchers have also studied the effect of display positions on driving performance, when Camera Monitor System (CMS) replaced side-view mirrors (Beck et al., 2017; Doi et al., 2019; Large et al., 2016). Studies conducted by Large et al. (2016) also evaluated five types of layouts for three in-vehicle displays (two side-view and one rear-view), in comparison to the existing mirror system. Results revealed that layouts that were similar to the existing mirror locations were subjectively more preferred. Further, the empirical study conducted by Beck et al. (2017) compared three CMS layouts to the traditional side-view mirror system. It was concluded that the CMS display position that was closer on either side of the steering wheel was relatively better in terms of reduced mean eye-off-road time, higher preference, and perceived safety. The results of the study conducted by Doi et al. (2019) were in agreement with the previous results, with accurate and faster reactions to rearward situations when CMS displays were located at a smaller view angle. Even though previously mentioned studies have evaluated and provided insight to the in-vehicle display positions, they have some limitations. These studies have mainly considered the position of the rear-view or side-view mirrors, which were replaced by CMS. The drivers did not perform any visual-manual task (dual-task scenario) on these displays. Although a few researchers have studied the interaction of IVIS at different locations, these results can not be generalized for smaller (in-vehicle mobile phone display). Even the studies conducted on MDTs did not consider eye-movement while performing tasks on MDTs at different locations. Since more than 90% of the information to the drivers is gathered from the visual senses, evaluation of eye-movement becomes an important agenda in driver behavior studies. Also, the tasks performed on MDTs are different from those on mobile phones. Moreover, these studies did not consider the drivers' visual behavior in a dual-task driving scenario. Hence, we conducted the present study to evaluate the driving performance and the drivers' visual behavior when in-vehicle mobile phone are placed at different positions in a dual-task simulated driving condition.

6.1.2 Lane change test for assessing driver distraction in dual-task paradigm

Lane change test (LCT) is a simple inexpensive, reliable, and standardized test tool for measuring demand of in-vehicle information system (IVIS) (Mattes, 2003). In the past, several studies have employed the lane change test (LCT) to successfully examine the effect of performing secondary tasks on driving performance. Specific focus was given to reaction time (Fofanova & Vollrath, 2011), driver and task characteristics (complexity) (Rodrick et al., 2013), and gender (Petzoldt et al., 2009). The LCT driving simulation consists of a 3 km test track having three lanes with 18 lane change signs along the track. The participants have to perform lane change manoeuvres while maintaining the vehicle at a constant speed of 60 km/hr. The mean distance between the signs was approximately 150 m, having a mean duration of 9 s in between subsequent lane changes. It took approximately 180 s to complete each test track. During the LCT, the primary driving performance measure is called the mean lateral deviation (M.Dev). There was no surrounding traffic in the driving scenario. The participants have to perform the lane change manoeuvres in a deliberate, quick, and effective manner when they were able to identify the signs.

6.1.3 Research objective

The objective of the current study was to evaluate the effect of mobile phone position on the driving performance (measured by lane change test), the visual behavior (measured by eye-tracking), and the perceived driving workload. We expected that as the eccentricity of mobile phone position increases from the normal line-of-sight, there would be difficulty in maintaining the lane (higher mean deviation) and thus would also influence the visual behavior. It was hypothesized that better lane-keeping would result in lower driving workload scores by the participants.

6.2 Methods and materials

6.2.1 Participants

Thirty participants took part in the study. The participants' age was 21 to 45 years ($M = 27.67$ years, $SD = 5.03$), having a mean driving experience of 6.93 years ($SD = 3.94$). All of them declared they had a valid Indian driving license and had prior experience of interacting with the mobile phone while driving. They were healthy and were not suffering from any musculoskeletal disorders. The participants were informed that they could choose to leave (without any consequences) at any stage if they felt uncomfortable during the experiment. The study objective and the experimental procedure was clearly explained to the participants. Written informed consent was obtained from each participant before starting the study. The

entire data collection was performed following the declaration of Helsinki (Association, 2001). Since most of the subjects were not well-versed with English, they were explained the questions in their vernacular language and data were filled in by the interviewer. The inclusion criterion for participating in the study was: good general health, regularly driving with valid driver's license, and having experience of using a mobile phone while driving. Each of them had normal or corrected to normal vision, and those having glasses were not included in the study.

6.2.2 Apparatus

We used a low-fidelity driving simulator for the experiment. It comprised a separate 42 – inch display screen, resolution: 1024×768 pixels (SAMSUNG, Model No. PS42A410C1) and a Logitech G29, racing wheelset (a force-feedback steering wheel, brake pedal, and accelerator), shown in figure 6.1. The viewing distance between the LCD monitor and the participant was kept at 70–75 cm depending upon the participant's stature. The participants could adjust the position and degree of the seat backrest as per their comfort. It is essential to note that the simulator set up was for the right-handed driving vehicle. Simulated driving was performed using the lane-change test (LCT) software (ISO, 2010) installed on the computer system.

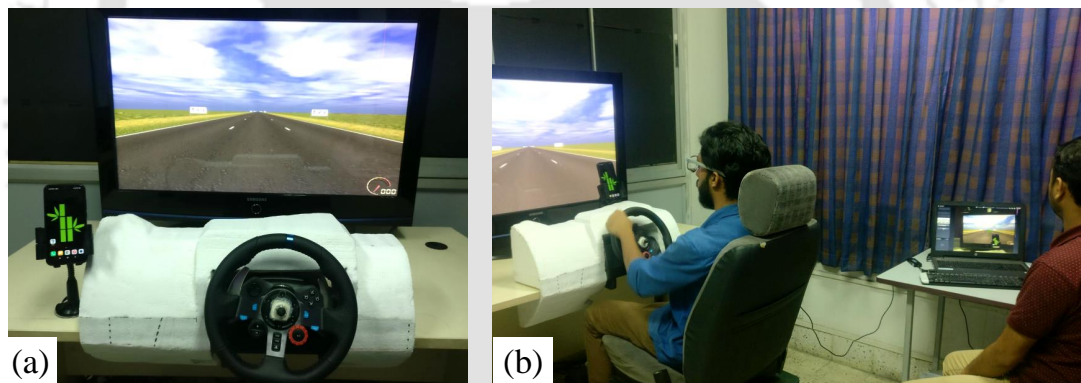


Figure 6.1: *Experimental Setting; (a) Driving simulator (front-view), (b) Experimenter monitoring the participant*

A binocular eye-tracker glass, SMI iView X software, and SMI BeGaze (v 3.7) software by SensoMotoric Instrument (SMI) were used to acquire and analyze eye-movement data on a separate computer system. The eye-tracking device was calibrated using a one-point calibration technique and was later checked with a laser-pointing device per driving session, per participant. A 6.3 — inch (diagonally measured) touch screen mobile-phone was used to perform the secondary task in a dual-task scenario. This mobile-phone was mounted at different positions (see Table 6.2) using a mobile-holder. Comfortable room temperature and ideal ambient illumination of about 24 °C (75 °F) and 500 lux, respectively, were maintained during the experiment (Bridger, 2017).

6.2.3 Experiment design

The study used a within-subject design to measure the driving performance: one baseline driving (only lane change test), and four dual-task driving (lane change + secondary task, when mobile-phone is at left, right, front, and middle of the steering wheel). Every participant was subjected to all the five driving conditions. During each of the five simulated driving sessions, the participants were instructed to perform the lane change deliberately as-soon-as they saw the lane change sign-board. The participants had to maintain the vehicle's speed to 60 km/hr. The participant had to perform the secondary task on the mobile phone without removing it from the mobile holder. A visual representation of the experimental design is shown in figure 6.2. The rest period between the driving session is represented by 'R'; it was approximately 5 min and used to collect DALI subjective rating data. Baseline and dual-task driving sessions took 3 min each.

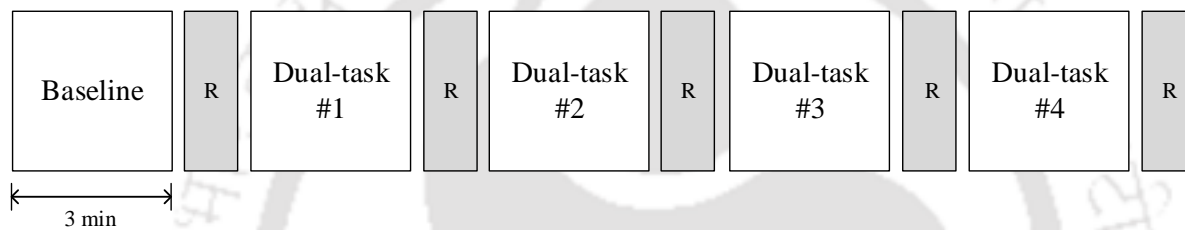


Figure 6.2: Visual representation of experimental design

6.2.4 Driving task

The driving performance was measured using the lane change test (LCT). The LCT is a simple and low-cost tool used to measure the distracting capabilities of the secondary task performed during driving. It consists of a 3000 m straight roadway. The driving speed was limited to a maximum of 60 km/hr, and participants were asked to maintain it, thereby completing the simulated run in approximately 3 min. There was no traffic or pedestrians. The drivers had to change the lane purposely as soon as they saw the lane change sign that appeared on both sides of the road. An image of the simulated road environment is given in figure 6.3.

6.2.5 Secondary task

During each of the four dual-task driving sessions, the participants performed four (4) secondary tasks (description in Table 6.1). Participants performed these tasks after the experimenter gave a clap signal to start the secondary task. The sequence of these tasks was counterbalanced for each dual-task driving sessions to reduce the learning effect. The task chosen to perform during the experiment resemble the typical tasks that are being performed by the drivers during their day to day activities.



Figure 6.3: A screenshot of the simulated roadway

Table 6.1: Descriptions of the secondary task

Task	Category	Description
1	Dialing	Call a pre-saved number by the name Demo '1'
2	Dialing	Call a pre-saved number by the name Demo '2'
3	POI Address	Open google map and finding a POI (point of interest) address (for ATM, petrol pump, restaurant) and start navigation
4	Dialing	Open the telephone dialer and dial your own phone number (ten digit number)

6.2.6 Position of the mobile phone

During the initial field survey many positions of in-vehicle mobile phone were identified. However, four positions (left, right, center and front of steering wheel) were shortlisted for this empirical study which utilized eye-tracking/ driving simulator. Out of the four, two positions (middle and front) were chosen based on the results of the DHM study, and the remaining two (left and right) were chosen because they were the most preferred among the drivers (in the current study), as found from the field study.

Since the simulator setup was for a right-handed driving vehicle, all the mobile phone positions were accordingly demarcated. The mobile phone was placed at each of the four positions: left, right, front, middle of the steering wheel. The position of mobile phone w.r.t. steering wheel is shown in figure 6.4. The dashboard shown represents half of the car's actual dashboard, and the left position of the mobile phone is at the center of the actual dashboard. Dots represent the center of the mobile phones in the figure. The relative positions (shown in Table 6.2) of the mobile phones are calculated w.r.t. the center of the middle position.

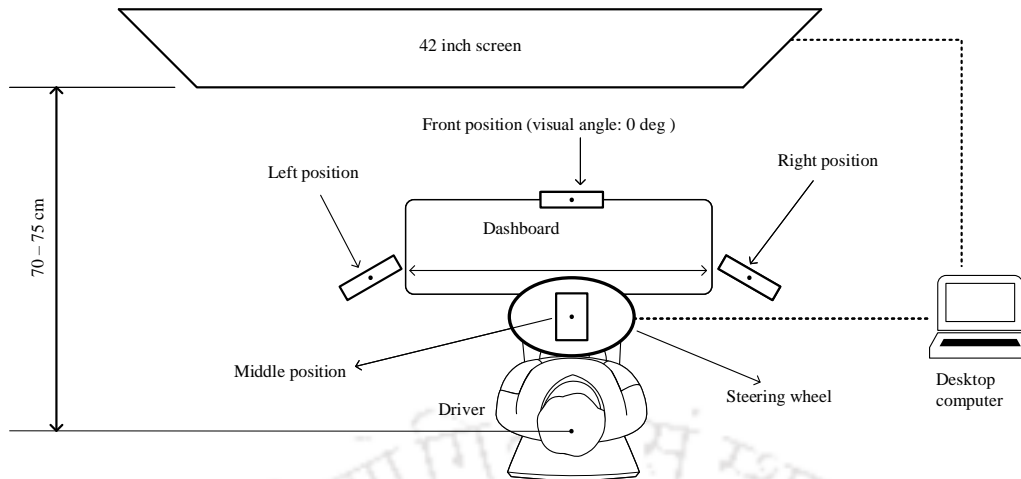


Figure 6.4: Diagram showing different positions of the mobile phone w.r.t. the driver

Table 6.2: Descriptions of mobile phones positions

Position	Description	
	Distance w.r.t. middle (mm)	Horizontal visual angle ($^{\circ}$)
Left	410	58
Right	310	50
Front	260	0
Middle	0	0

6.2.7 Experimental procedure

The experiment was divided into three sessions: screening and briefing, practice, and experimental session. Upon arrival of the participants in the experiment area, they were allowed to rest for 5 min. Then they were screened and tested for fitness (for physical pain or discomfort), visual acuity (using Snellen chart) (Snellen, 1868), and color blindness (using Ishihara color-blindness type test) (Ishihara, 1917). Subsequently, they were given a brief introduction about the study and informed about the experimental protocol. Before starting the session, all participants answered demographic questions regarding their age, gender, driving experience, license, and visual status. Each of them signed a consent form to participate in the experiment. After the screening and briefing session, the participants practiced on the driving simulator with single and dual-task driving. The practice session ended once the participants were comfortable with the simulated driving environment and completely understood the task to be performed. In the experimental session, the participant's driving performance and eye-movement data were recorded. The participants drove as per the experiment design (mentioned in 6.2.3). After each driving session, the participants rested for 5 minutes and filled a subjective rating questionnaire using the driving activity load index (DALI). The entire session

took approximately 60 minutes. A flowchart showing the procedure adopted for the study is given in figure 6.5. Upon completion of the experiment, participants were given refreshments and a remuneration amount of ₹ 200 to compensate for their time and effort required for taking part in the experiment. The entire experimental protocol was approved by the Institute Human Ethics Committee (IHEC) (see Appendix A.8).

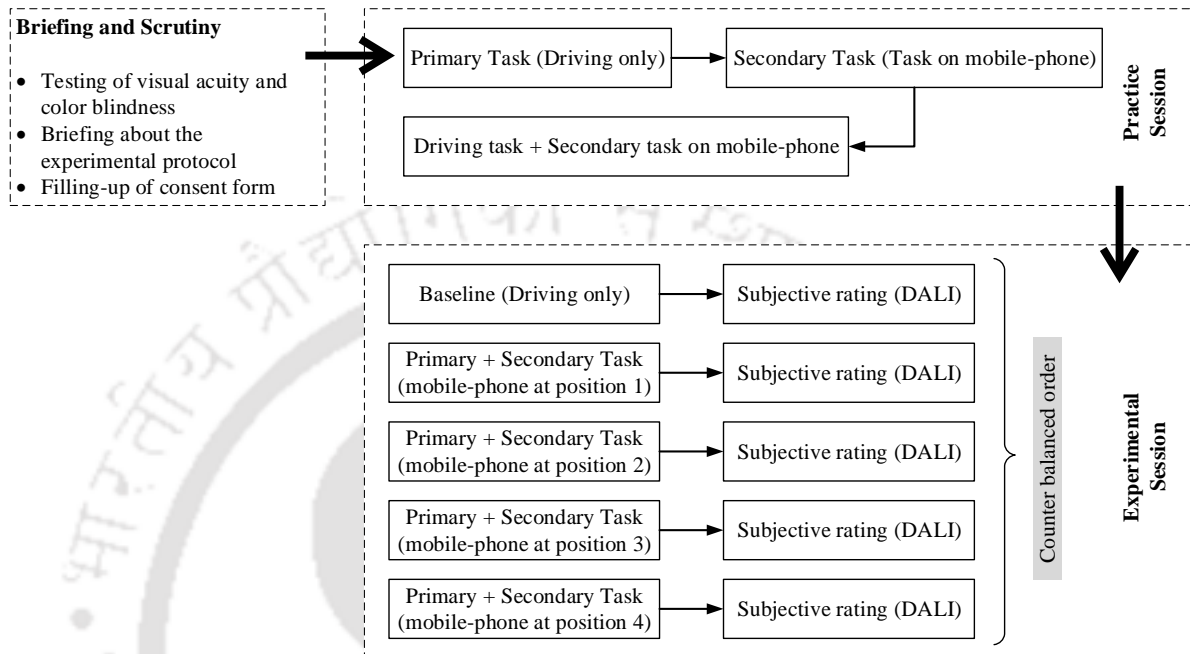


Figure 6.5: Flowchart of the experimental procedure

6.2.8 Experiment variables

In this study, the independent variable was the position (spatial arrangement of the mobile phone around the steering wheel), which had five levels: baseline (no mobile phone), and mobile phone at left, right, front, and middle of the steering wheel. The dependent variables were: Mean deviation (M.Dev), lane-change error, fixation (duration and count), glance (duration and count), Total eye-off road time (TEORT), and DALI subjective workload ratings. The Mean deviation (M.Dev) is defined as the mean deviation between the actual driving course and the position of normative model. It has been used by many researchers to evaluate driving performance (Burns et al., 2005; J. Harbluk et al., 2007; Petzoldt et al., 2009; Rodrick et al., 2013). Lane excursion is the errors performed during the lane change. It was measured using the LCT simulation software. Glance duration refers to the time duration for which the drivers looked at a particular area of interest (AOI), and the number of glances to a particular AOI is defined as glance count (Crundall, Large, & Burnett, 2016; Large et al., 2016; Yang et al., 2020). Fixation duration is the time duration for which fixation occurred at a particular area of interest (AOI); the number of fixations occurring at a particular AOI is defined as fixation count (Čegovnik, Stojmenova, Jakus, & Sodnik, 2018; Scialfa, McPhee, & Ho, 2000).

Total eye-off-road time is defined as the total time when the driver is not looking towards the road or time spent looking away from the road (Beck et al., 2017; Feng, Liu, & Chen, 2018). DALI subjective workload scale is a modified version of the NASA-TLX scale measuring the workload during the driving task. It has six sub-scales; attention, visual, temporal demand, stress, and interference (Pauzié, 2008).

6.2.9 Statistical analysis

A Shapiro—Wilk's test ($p > 0.05$) (Razali, Wah, et al., 2011; Shapiro & Wilk, 1965) and visual inspection of the histogram, normal Q-Q plot and box plots showed that the eye-movement variables (fixation and glance duration, fixation, and glance count), TEORT, and mean weighted DALI subjective rating scores were normally distributed for each of the individual groups. On the contrary, it was observed that Mean deviation (M.Dev) variable was not normally distributed. However, an inverse (reciprocal) transform was employed to make all the mean deviation groups normal for statistical analysis. A one-way repeated measures ANOVA was used to test statistical significance (if any) by comparing the means of each group in a within-subjects design (Hughes, Rudin-Brown, & Young, 2013). For controlling the inflation of type-I error, Bonferroni correction was used (Crundall et al., 2016). Whenever Mauchly's Test of Sphericity was violated, Greenhouse-Geisser correction was applied. The statistical analysis was performed using IBM SPSS 25.0 (SPSS Inc., Chicago, USA) software at a significance level of $p = 0.05$. The calculated effect size were reported as being large ($0.14 \geq \eta^2$), medium ($0.06 \leq \eta^2 < 0.14$), and small ($\eta^2 < 0.06$) (Cohen, 2013).

6.3 Results

The Mean and SD of the dependent variables are given in Table 6.3.

6.3.1 Driving performance

Mean deviation (M.Dev) of lane change from the normative path (in meters) and the number of lane change errors were used as a measure of driving performance. The value of M.Dev was lowest at 0.51 for the baseline and highest at 0.83 for middle position of mobile phone. A repeated measures ANOVA showed that there was a significant effect of driving condition ($F(4, 116) = 36.80, p < 0.05, \eta^2 = 0.559$, large effect size) on M.Dev values. A post hoc test using the Bonferroni correction revealed that there was a significant difference between the M.Dev values of baseline and all the dual-task driving scenario at $p < 0.05$. Also, significant difference in M.Dev values were observed between front and middle mobile phone position ($p < 0.05$). However, no significant difference ($p > 0.05$) were observed in M.Dev values for; left vs right, left vs front, left vs middle, right vs front, and right vs middle position of steering

Table 6.3: Descriptive of the dependent variables for different test conditions

Measure	Test conditions				
	Baseline	Left	Right	Front	Middle
M.Dev (m)	0.51 (0.26)	0.81 (0.38)	0.76 (0.30)	0.68 (0.30)	0.83 (0.44)
LC error (n)	2.53 (2.37)	4.10 (3.02)	3.83 (2.57)	3.50 (3.10)	4.10 (3.18)
Fixation duration (s)	N.A.	19.20 (8.42)	18.00 (6.13)	24.64 (5.40)	17.32 (6.82)
Fixation count (n)	N.A.	73.23 (29.55)	71.93 (23.15)	90.26 (22.20)	72.97 (26.23)
Glance duration (s)	N.A.	24.67 (10.55)	23.57 (7.89)	31.06 (6.60)	23.47 (9.20)
Glance count (n)	N.A.	23.10 (7.88)	24.50 (7.10)	32.70 (8.90)	22.13 (6.53)
TEORT (s)	N.A.	27.93 (11.62)	26.86 (8.42)	33.93 (7.09)	25.78 (9.53)
DALI (0 – 100)	23.33 (5.04)	39.24 (7.42)	36.73 (5.69)	30.35 (5.47)	40.97 (4.97)

*Mean (SD); M.Dev – mean deviation, LC – lane change, TEORT – total eye-off road time, DALI – driver activity load index, N.A.– not applicable.

wheel.

The errors performed during lane change were minimum for baseline (M=2.53), and maximum for left and middle (M=4.10) positions of the mobile phone. A Friedman test revealed that there was a significant effect of driving condition ($\chi^2(4) = 14.09, p < 0.05$) on lane change errors. A post hoc analysis with Wilcoxon signed-rank test was conducted with Bonferroni correction applied, resulting in a significance level set at $p < 0.005$. The result revealed that a significant difference exist in lane-change error for mobile phone at middle vs baseline driving ($Z = -3.212, p = 0.001$). Median (IQR) error in lane change for baseline, left, right, front, and middle of steering wheel are shown in Table 6.4. The M.Dev and error in lane change values for different driving condition is shown in figure 6.6.

Table 6.4: Descriptive of error in lane change at different condition

Condition	Mean (SD)	Percentile		
		25th	50th (median)	75th
Baseline	2.53 (2.41)	1	2	4
Left	4.1 (3.07)	2	3	6
Right	3.83 (2.61)	1.75	4	5.25
Front	3.5 (3.16)	1	3.5	5.25
Middle	4.1 (3.23)	1.75	3	5.25

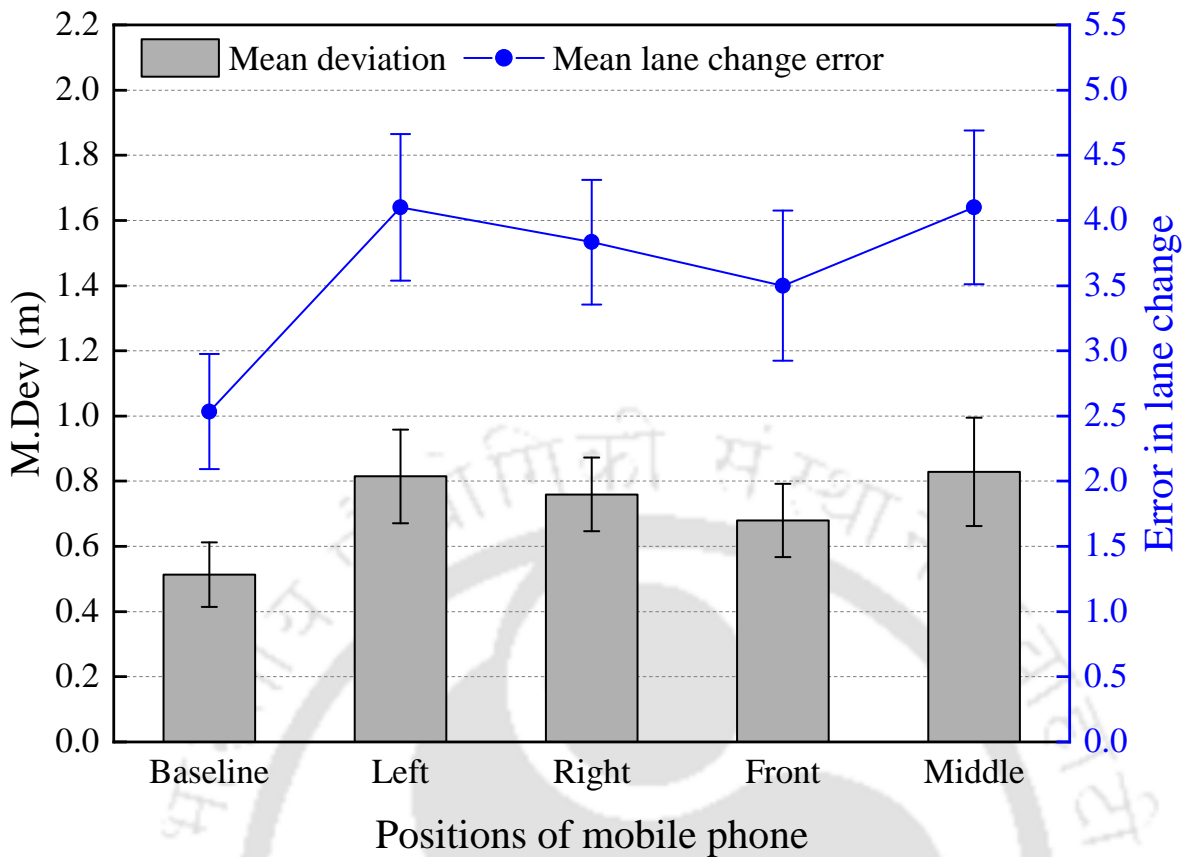


Figure 6.6: Mean deviation of lane change at different positions

6.3.2 Visual behaviors

Glance (duration and count), fixation (duration and count), Total eye-off road time (TEORT), and Mean eye-off road time were used as a measure of visual behavior.

Glance duration and count

The longest glance duration value was observed for front mobile phone position ($M = 31.06$ s, $SD = 6.60$). A repeated measures ANOVA with Greenhouse-Geisser correction revealed that the difference in glance duration values between the different positions of the mobile phone was statistically significant ($F(2.528, 73.304) = 10.339, p < 0.05, \eta^2 = 0.263$ large effect size). Post hoc test with Bonferroni correction determined significantly higher total glance duration for mobile phone at the front position than left ($p = 0.01$), right, and middle ($p < 0.05$).

The glance count values were minimum for middle mobile phone position ($M = 22.13$, $SD = 6.53$). A repeated measures ANOVA revealed that total glance count was significantly different for mobile phone position ($F(3, 87) = 23.078, p < 0.05, \eta^2 = 0.443$). Post hoc test with Bonferroni correction revealed that, the total glance count was significantly higher for the front position ($p < 0.05$) as compared to left, right, and middle position. The total glance duration and count for different mobile phone positions is shown in figure 6.7.

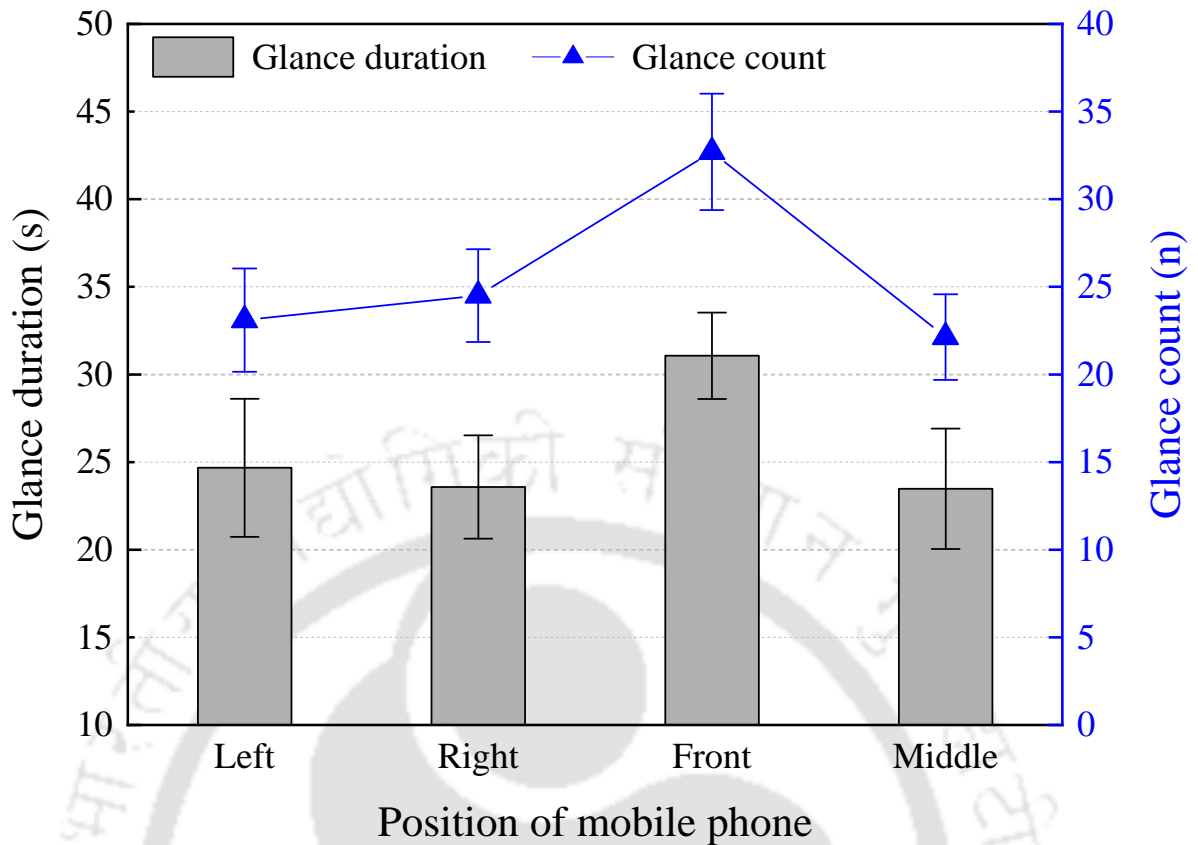


Figure 6.7: Glance duration and glance count at different mobile phone positions

Fixation duration and count

The minimum values for fixation duration were observed for middle mobile phone position ($M = 17.32$, $SD = 6.82$). A repeated measures ANOVA revealed that total fixation duration differed significantly between the positions of mobile phone ($F(3, 87) = 16.122$, $p < 0.05$, $\eta^2 = 0.357$, large effect size). Post hoc test with Bonferroni correction determined that, the total fixation duration was significantly higher for mobile phone placed at front as compared with left ($p = 0.005$), right ($p < 0.01$), and middle ($p < 0.01$).

Least fixation count was recorded for right mobile phone position ($M = 71.93$, $SD = 23.15$). A repeated measures ANOVA with Greenhouse-Geisser correction revealed that position of mobile phone had a significant main effect on fixation count ($F(2.503, 72.594) = 7.287$, $p < 0.05$, $\eta^2 = 0.201$, large effect size), post hoc test with Bonferroni correction showed that, the fixation count for front position of mobile phone being significantly higher than left ($p = 0.019$), right ($p < 0.01$), and middle ($p = 0.008$) positions of mobile phone. Fixation duration and count for different mobile phone positions is shown in figure 6.8.

Total eye-off-road time (TEORT)

The middle mobile phone position recorded the minimum value of TEORT ($M = 25.78$ s). A repeated measures ANOVA with Greenhouse-Geisser correction revealed that mobile

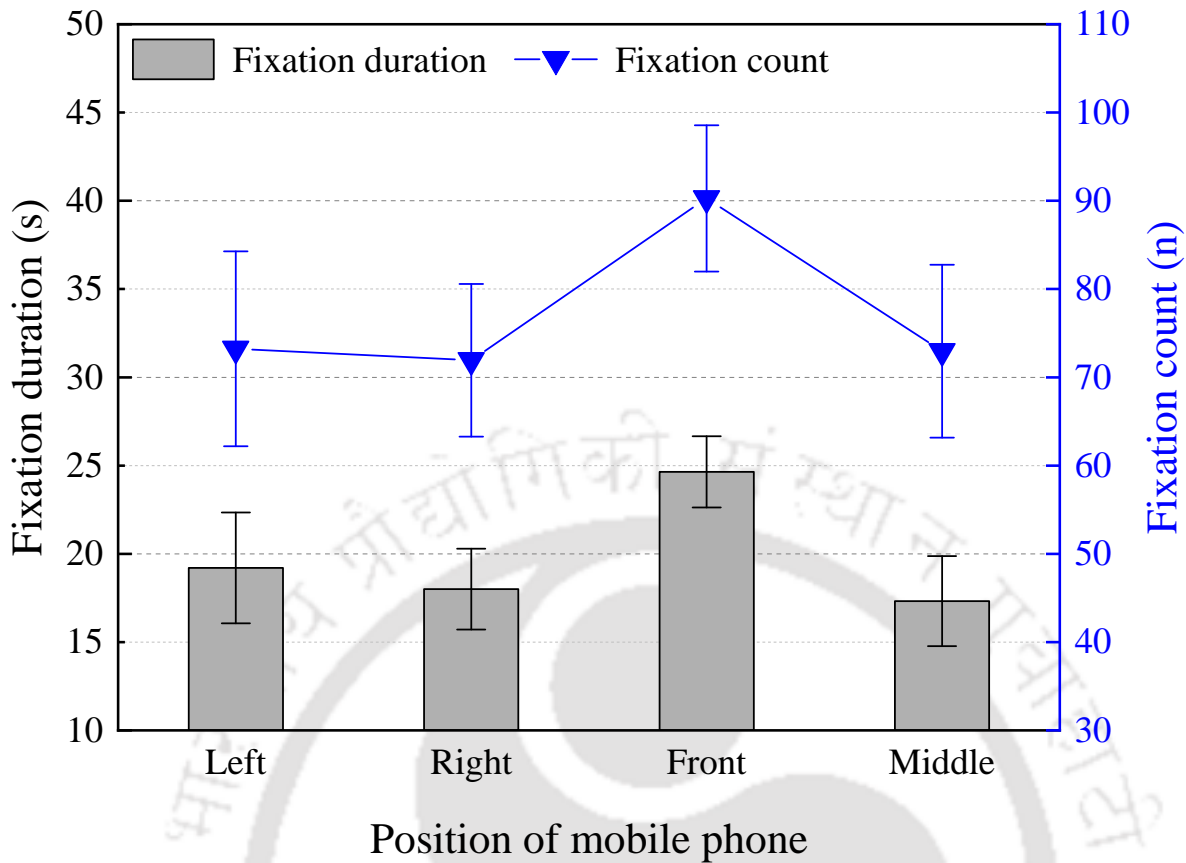


Figure 6.8: Fixation duration and count at different mobile phone positions

phone position had a statistically significant effect on TEORT ($F(2.508, 72.73) = 8.935, p < 0.05, \eta^2 = 0.236$, large effect size). A post hoc test with Bonferroni correction revealed that TEORT was significantly higher for front than left, right, and middle ($p < 0.05$) positions of mobile phone. The variation of Total eye-off-road time (TEORT) under different mobile phone position is shown in figure 6.9. For mean eye-off-road time, a log transformation was performed on the data set to make them normal. A repeated measured ANOVA revealed that mobile phone position did not have a statistically significant effect on the mean eye-off road time ($F(3, 87) = 1.974, p = 0.124, \eta^2 = 0.064$, low effect size).

6.3.3 Subjective workload assessment

The subjective workload measured using DALI was minimum for baseline task ($M = 23.33$), and maximum for middle mobile phone position ($M = 40.97$). A repeated measures ANOVA, revealed that position of mobile phone had a statistically significant effect on the subjective workload ratings ($F(4, 116) = 61.14, p < 0.05, \eta^2 = 0.678$, large effect size). A post hoc test revealed that the baseline driving condition was significantly different from left, right, front, and middle ($p < 0.05$). In addition, front position was found to be significantly different from baseline, left, right, and middle ($p < 0.05$).

The graph showing the DALI subjective assessment is shown in figure 6.10. The individual

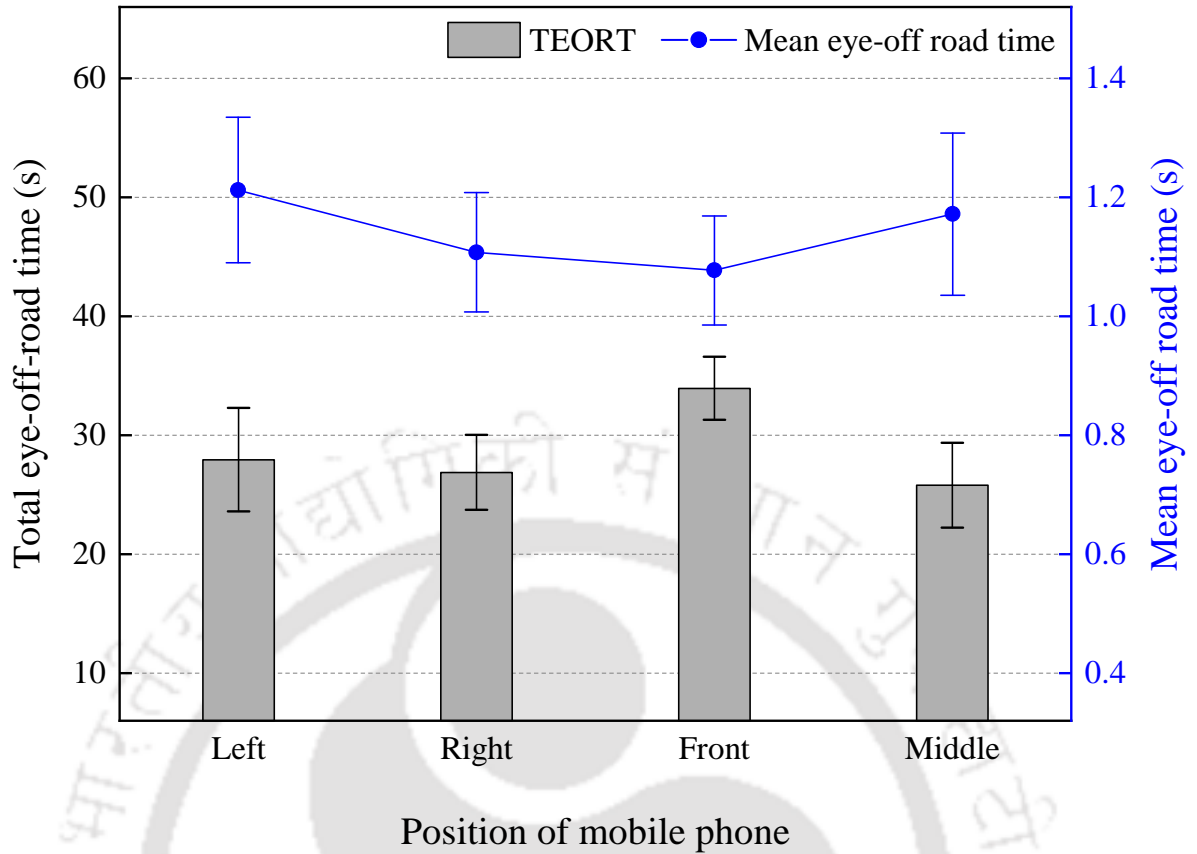


Figure 6.9: Total and mean eye-off-road time at different mobile phone positions

Table 6.5: Mean DALI scores for each task condition

Dimensions	Test conditions				
	Baseline	Left	Right	Front	Middle
Attentional	54.93	70.80	64.53	61.20	67.73
Visual	58.40	55.60	50.40	49.33	57.33
Auditory	04.00	06.93	09.20	01.33	08.67
Stress	11.87	34.40	32.40	21.73	36.53
Temporal	10.00	24.93	19.20	14.93	24.00
Interference	00.80	42.80	44.67	33.60	51.60

sub-scales of DALI for different test conditions is shown in figure 6.11. The mean values of DALI sub-scale for different driving condition is given in Table 6.5.

6.4 Discussion

In the present study, we empirically examined the influence of in-vehicle mobile phone positions on the driving performance and the drivers' visual behavior. The participants performed a

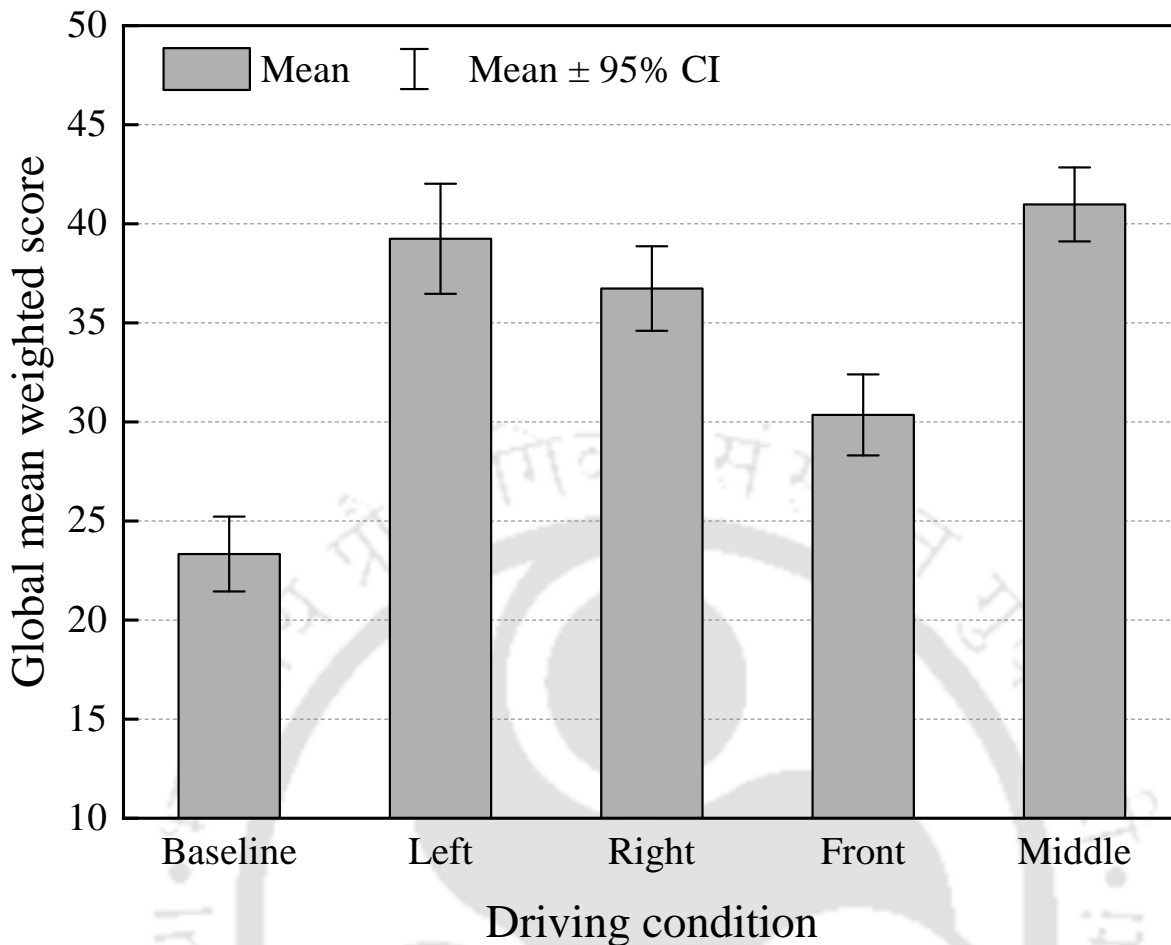


Figure 6.10: DALI subjective assessment scores

visual-manual task on the mobile phone and driving task in a simulated environment. The driving performance results were interpreted in terms of the mean deviation in lane change (M.Dev) and lane change errors. A smaller value of M.Dev indicates a good lane keeping (better driving) performance as compared to a larger value, which indicates a poor lane keeping (poor driving) (J. Harbluk et al., 2007; Mattes, 2003). The best values (M.Dev = 0.51) resulted during the baseline (only driving) session when compared to all the other driving scenarios, whereas the worst (M.Dev = 0.83) values were recorded when the mobile phone was placed at the middle (dual-task) of the steering wheel. When inspecting the dual-task sessions, the values of M.Dev were better for mobile phone placed at the front when compared to other dual-task scenarios. Previous studies conducted by Burns et al. (2005); J. Harbluk et al. (2007); K. L. Young, Lenné, and Williamson (2011) have shown that mean deviation values were smaller for cognitively and visually easier tasks compared to difficult tasks. The lane excursions (lane-change error) for dual-task driving were higher for middle and left positions whereas minimum for front position, indicating that better driving performance was achieved for front and worst for the middle mobile phone positions. It is important to note that the mobile phone placed on the left is the farthest from the normal line-of-sight and for looking at the middle position, drivers have

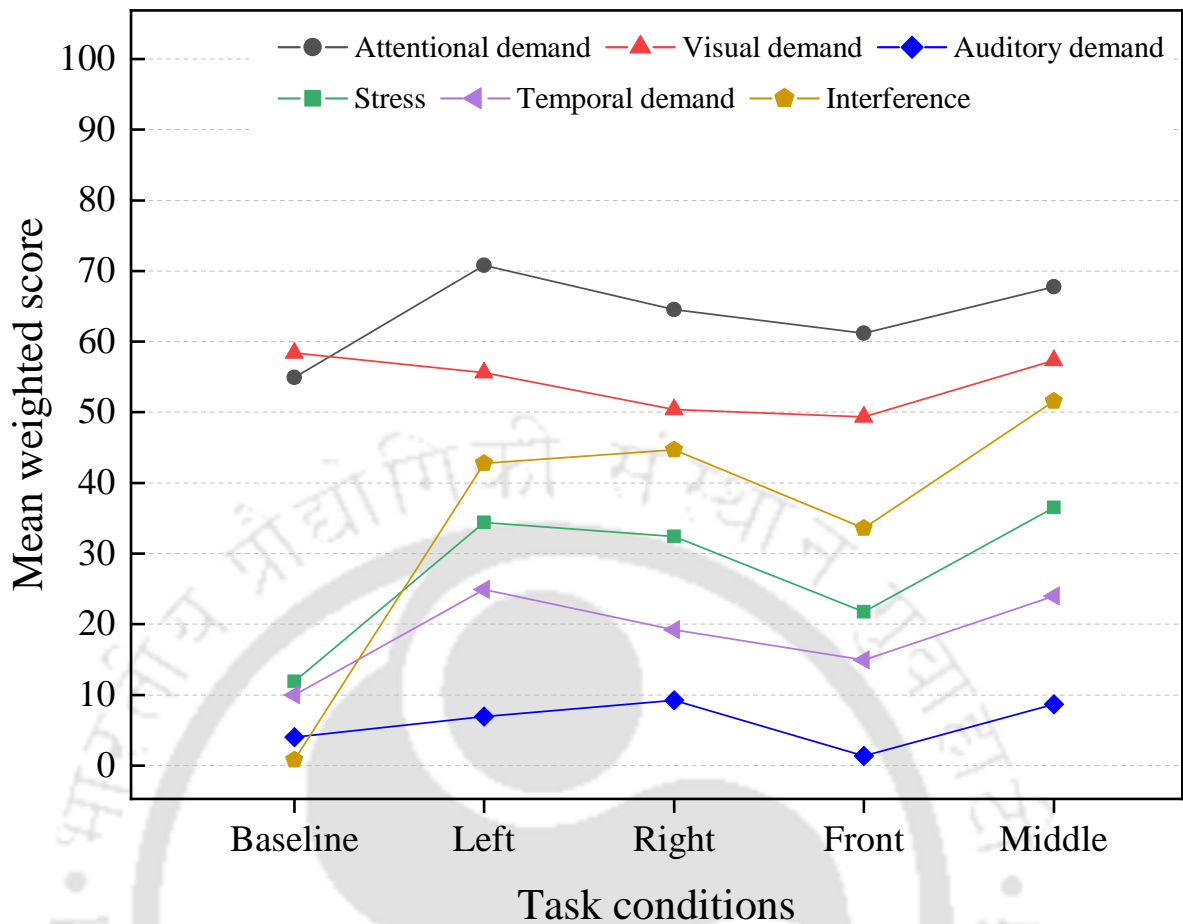


Figure 6.11: Sub-scales of DALI for driving conditions

to shift their attention from the driving scene to the mobile phone. Thus, in terms of driving performance we can say that the mobile phone positions at the front gave better results than others.

Further, observing the visual behavior interpreted in terms of the eye-movement measures (fixation, glance, and TEORT), we note that eye-movement measures were significantly affected by the in-vehicle mobile phone position.

The glance duration was most prolonged ($M = 31.06$ s) for the front and smallest ($M = 23.47$ s) for the middle position. Apart from the front and middle positions, the left position was the farthest, and right was the nearest from the normal line-of-sight horizontally. The hypothesis that farther the position of mobile phone away from the normal line-of-sight the longer is the eye-off-road time holds for left and right positions. Thus, the glance duration values were higher for left than right, but no significant difference was observed. On the contrary, with the mobile phone at the front position, the subjects may still use their peripheral vision to observe the on-road scene. Studies by Summala, Lamble, and Laakso (1998) show that drivers use peripheral vision for lane and distance keeping. Thus, using the peripheral vision for on-road monitoring, the drivers tend to spend more time off-road and still maintain better lanes. This argument holds for the front position where we observe a better mean deviation value and

a longer glance and eye-off road time. Similar conclusions were also drawn in the studies of Dukic, Hanson, Holmqvist, and Wartenberg (2005), where the button location closer to the normal line-of-sight resulted in longer eye-off-road time.

In the case of mobile phone at the middle position, the hypothesis mentioned above does not hold since it is farthest from the normal line-of-sight, located at the center of the steering wheel, and still has the shortest total eye-off-road time. A potential explanation for this result could be the driver's perception of risk. If the drivers have to look at the middle position at the steering wheel's center, they have to flex their neck, and they cannot use their peripheral vision to monitor the on-road scenario. Thus, implying that the drivers consider the middle position as dangerous, since they cannot look at the on-road situation and are impaired of their motion-detecting capabilities. Hence, they try to keep the visual off-road time to a minimum. Similar arguments were also given in the studies conducted by Dukic et al. (2005), for a button located near the gearbox, showing a shorter eye-off-road time.

The fixation duration for the middle mobile phone position was found to be minimum at 17.32 s, whereas the fixation count was 72.97. The longest fixation duration (24.64 s) was recorded for front mobile phone position. This can be explained because, while looking at the front position, drivers were able to monitor the on-road scenario with their peripheral vision and thus fixated for longer duration at the front mobile phone position, which was opposite in case of middle position. Similar results were also observed in the studies of Čegovnik et al. (2018), where the fixation duration decreased with the presence of increased cognitive load. Similarly, a study conducted by Scialfa et al. (2000), which examined the effect of a cellular phone conversation on the search of a traffic sign, also reported a reduction in fixation duration as the complexity/ clutter increased.

The DALI subjective workload rating score shows that the baseline task had the lowest workload score compared to the dual-task driving conditions. Among the dual-task driving conditions, the front position had the lowest workload compared to the middle position, which exhibited the highest workload. The above results could be justified because, for performing tasks on the middle mobile phone position, drivers have to continuously shift their attention from forward on-road view to the mobile phone located at the center of the steering wheel. Whereas, for the front position, the drivers did not have to move their heads and performed their tasks without the fear of committing any driving error, hence resulting in a lesser workload score.

Studies conducted by Pauzié (2008), have also shown a higher DALI global workload scores for complex guidance systems than the human co-pilot. Similarly, studies by K. H. Kim and Wohn (2011) also showed higher DALI workload values for an augmented reality navigation system than map navigation. Thus, concluding that a high demanding session/ situation corresponds to a higher value of DALI score.

Observing the details of individual DALI factors, it was noticed that a higher value of 'interference' was registered for the middle position compared to other dual-task conditions

since the mobile phone interfered in the unobstructed functioning of the steering wheel. 'Stress' was also rated high for middle positions as compared to other dual-task driving conditions. If we arrange the sub-scales according to their impact on dual-task driving, it was observed that attention and visual demands were highly rated. In contrast, temporal and auditory demands were rated low for each of the dual-task conditions. Thus, according to the results of the present study, in-vehicle mobile phone position at the front seems to be the most suitable in terms of better driving performance and a lesser amount of driving workload as compared to other dual-task conditions in the study.

6.4.1 Limitations

The present study is limited in its approach since it was conducted on a fixed-base driving simulator in a simulated environment where the drivers know that an error or fault in driving will not lead to an accident. Further, there was a lack of vibration and physical motion in the simulator vehicle, that may affect the visual and driving performance. Additionally, various other factors were unaccounted, which may have affected the drivers' driving and visual behavior. These factors include the drivers' characteristics (age, gender, comfort and skill of driving the simulator, driving experience), environmental characteristics (road condition (rural/ urban), traffic (high/ low)), and vehicle characteristics (right/ left-hand drive, type of vehicle). Although utmost care has been taken to match the experimental conditions (position of the mobile phone) with the real-world scenario, an accurate resemblance may not have been achieved. An experimental study conducted on an instrumented vehicle may have produced different outcomes.

This study was primarily aimed at interventions for MABTS drivers as mentioned earlier. Although DALI was used to measure the driving workload of the drivers, in the real environment, driver's behavior may also be affected by psycho-social and organizational factors/ policies. For example, driver behavior may be influenced by the urgent need for receiving/ booking calls from a customer while driving and meeting performance targets which is directly linked to financial factors/ incentives (of reaching the destination on time) which non MABTS drivers may not be influenced by. These constraints and expectations might put additional load on the MABTS drivers. Since such factors were not measured, this may be taken up in future research studies. Apart from the lacunas, as mentioned earlier, future studies should take up research on an instrumented vehicle and different classes of vehicles (trucks, buses, and auto-rickshaws) for producing more generalized outcomes.

Future research could also take a comparative study between MABTS drivers who use only mobile phone and those who use mobile phone with Bluetooth devices (or audio navigation), since audio input may also influence visual behavior while driving. Future scope also lies in understanding the optimum position for the mobile phone for drivers suffering from disorders such as low back pain etc. which is very common among professional drivers and its comparison

with healthy drivers (present study) and its implications for design.

6.5 Conclusion

In this study, we conducted a driving simulator-based experiment to examine the effect of in-vehicle mobile phone position on the driving performance and the visual behavior of the drivers. Results showed that the in-vehicle mobile phone position had a statistically significant effect on drivers' driving performance and visual behavior. Placing mobile phones at a smaller visual angle from the normal line-of-sight resulted in better driving performance and lesser driving workload scores. However, the drivers' glance and fixation duration increased, and they spent more time performing tasks on mobile phones because they felt safer compared to other in-vehicle mobile phone positions. This study's observations can be utilized by the policy-makers and mobile-application-based taxi rental companies to formulate guidelines for better and safer use of in-vehicle mobile phones. The knowledge gained from the study about visual and driving behavior could be used by the designers and the ergonomics team for developing safer and user-friendly in-vehicle displays. Additionally, the industrial designers can also use the knowledge to design mobile holders/ space integrated with the dashboard, keeping in mind smaller visual angle for safety and usability (to guide the driver to place the mobile device in the correct position).

7

General discussion and conclusion

Abstract

This chapter summarizes and presents an overall discussion of the research work, which is being taken up. Salient findings of the present research, fulfillment of the objective, hypothesis testing, and the present research's key contributions are presented in this chapter. Future research directions based on the limitations of the study have been furnished along with the conclusion at the end.

7.1 Overall discussion of the research work

The present research tried to find the most suitable in-vehicle mobile phone (as a navigational device) position for navigation purposes in terms of head rotation, flexion/ extension, reachability, driving performance, visual distraction, and driving workload. The overall framework of the current research was divided into five phases: problem identification; questionnaire survey of MABTS drivers; DHM based study of mobile phone positions; development of a novel mobile phone holder to be mounted at the center of the steering wheel; and empirical evaluation of the in-vehicle mobile phone positions in a driving simulator. Phase – I was the problem identification stage, where a review of literature related to the study of this thesis was carried out, followed by identification of the research gap. During this phase, research questions were raised, aim & objectives were set, and hypothesis were formulated for conducting the research.

In the phase – II, a questionnaire based survey was conducted to understand the drivers' involvement/ engagement in distracting activities/ tasks and their preference location for placing in-vehicle mobile phones for navigation purposes. The study involved MABTS drivers (n = 188). The questionnaire was found to be reliable with a Cronbach's alpha (α) = 0.72. Inferences drawn from the outcome of the survey concluded to some interesting findings. The majority of drivers (48.8%) preferred to keep their mobile phones on the steering wheel's left side for navigation purposes. It was also observed that 40.4% of drivers reported that they kept mobile

phones on the steering wheel's right side, near the A-pillar. A small percent (10.1%) of drivers mentioned that they change the position of their mobile phones during night/ evening, and keep it below the dashboard. Additionally, about 22.3% of drivers reported that they reduce the mobile phone's screen's brightness during the night. These behaviors could be seen as an act of counter measuring glare from the mobile device during night/ evening. A total of 'nine' in-vehicle mobile phone positions (on & around the dashboard and the steering wheel) were used in this study (details in chapter 3, see figure 3.1, for visual representation). The outcome of the ranking of various mobile phone positions as rated by the drivers revealed that position '6' (left of steering) had a mean rank of 1.77, and was the most preferred position, whereas, position '4' (right of steering) was the second most preferred position (mean rank = 1.90). Similar observations were reported in the previous studies conducted by Alconera et al. (2017); however, the participants of this experiment were Filipino drivers who were driving 'left-handed vehicles'.

Further, in phase – III digital human modeling (DHM) based virtual simulation study was conducted using the CATIA-DELMIA software to identify the head movement (rotation, flexion/ extension), torso movement, reach-ability required to access information from the different mobile phone positions. Head movement (rotation and flexion/ extension), and reach-ability for all the different mobile phone positions identified during the questionnaire survey were measured, using manikins (5th, 50th, and 95th percentile) with male Indian anthropometric body dimensions. This experiment showed the influence of mobile phone position on the head movement. Kee and Karwowski (2001), defined a comfortable angle for neck, with 4° flexion, 7° extension, 17° rotation, and 13° lateral bending in a sitting posture. An overview of all the in-vehicle mobile phone positions in the car interior is given in figure 3.1. The minimum head rotation was recorded for the positions '8', '5', and '2', which were on the same vertical line and close to the line-of-sight. Negligible head rotation (1°, 1°, 1°), and head flexion (5°, 7°, 8°) was also recorded for position '5', for the three different percentile manikins. These values are within the comfortable range as given by Kee and Karwowski (2001) for visualizing display. Earlier studies, by Wittmann et al. (2006), showed that display position closer to line-of-sight of drivers had a better driving performance. Although, the least head rotation was recorded for position 8, head flexion (17° – 19°) were outside the comfortable range suggested by Kee and Karwowski (2001). Position 8 had a better hand reach than others, and it did not obstruct the forward vision of the drivers.

Following DHM study (details in chapter 4) it was noticed that placing in-vehicle mobile phone at a straight forward location nearer to normal line-of-sight would reduce the neck/ eye movement and subsequently reduce distraction. Previous studies by Wittmann et al. (2006); Zheng et al. (2016) also supported the same. Hence, placing in-vehicle mobile phone at position '5', and '8' would benefit MABTS drivers in-terms of improved driving performance. However, no mobile phone holder which could be easily mounted at the steering wheel's center, could be found in the automobile accessories market. Hence, the process of developing a

steering-wheel-mounted self-adjusting mobile phone holder was carried out in phase – IV. This novel product's primary requirement was, (a) it could be mounted in the center of the steering wheel, (b) it should self-adjust and remains vertically upright even when the steering wheel rotates. A systematic product development process was followed, which included – customer needs identification, concept generation, concept screening, prototyping, customer feedback. The entire process is discussed in detail in chapter 5.

To empirically examine the effect of in-vehicle mobile phone position on the drivers' driving performance and visual behavior, a simulated driving study in a laboratory setup was conducted in phase – V. In this study, four highly preferred in-vehicle mobile phone positions (left, right, front, and middle of the steering wheel) were used (details in chapter 6). The experiment was conducted in a within subjects design, and the study subjects had to drive in a simulated road environment, under five driving conditions (one baseline – only driving, and four dual-task driving – driving + secondary task on mobile phone located at one of the positions mentioned earlier). The subjects performed four secondary tasks under each of the four dual-task driving condition (details in chapter 6).

The visual behavior was measured using an eye-tracker, and the lane-change test (LCT) in a simulated environment measured the driving performance. The driving performance results were interpreted in terms of the mean deviation in lane change (M.Dev) and lane change errors. A smaller value of M.Dev indicates a good lane keeping (better driving) performance as compared to a larger value, which indicates a poor lane keeping (poor driving) (J. Harbluk et al., 2007; Mattes, 2003). To find out the difference (if any) in M.Dev values among the different driving conditions statistical analysis was performed. A repeated-measures ANOVA showed that there exists a significant difference in M.Dev values among the different driving conditions ($F(4, 116) = 36.80, p < 0.05, \eta^2 = 0.559$, large effect size). In the post hoc test, significant difference in M.Dev value was observed for the driving condition when the mobile phone was placed at the front and middle of the steering wheel ($p < 0.05$).

The errors performed during lane change were maximum for left and middle (M=4.10) mobile phone positions. A significant difference in lane change error among the different driving conditions ($\chi^2(4) = 14.09, p < 0.05$) was observed. Visual behavior was interpreted in terms of glance (duration and count), fixation (duration and count), total eye-off road time (TEORT), and mean eye-off road time. The total glance duration (for all the four tasks) for mobile phone placed at left, right, front, and middle of the steering wheel was 24.67 s, 23.57 s, 31.06 s, and 23.47 s. A repeated-measures ANOVA revealed that the total glance duration differed significantly among the positions of the mobile phone ($F(2.528, 73.304) = 10.339, p < 0.05, \eta^2 = 0.263$, large effect size). Similar results were also achieved for fixation duration, glance count TEORT. The drivers' subjective workload was measured after each of the simulated driving sessions using the questions of driver activity load index (DALI). A repeated-measures ANOVA revealed that position of the mobile phone had a statistically significant effect on the subjective workload ratings ($F(4, 116) = 61.14, p < 0.05, \eta^2 = 0.678$, large effect size). The front position was

found to be significantly different than baseline, left, right, and middle ($p < 0.05$).

For the mobile phone display positioned in front of the driver on the dashboard, the drivers may still use their peripheral vision to observe the on-road scene. Studies by Summala et al. (1998) showed that drivers use peripheral vision for lane and distance keeping. Thus, using the peripheral vision for on-road monitoring, the drivers tend to spend more time off-road and still maintain better lanes. This argument holds for the front position where a better mean deviation value was observed along with a longer glance and eye-off road time. Similar conclusions were also drawn in the studies by Dukic et al. (2005), where the button location closer to the normal line-of-sight resulted in longer eye-off-road time. The mobile phone at the middle position (located at the steering wheel's center) is farthest from the normal line-of-sight, and still has the shortest total eye-off-road time. A potential explanation for this result could be the driver's perception of risk. If the drivers have to look at the middle position at the steering wheel's center, they have to flex their neck/ glance downwards, and they cannot use their peripheral vision to monitor the on-road scenario. This, implies that the drivers might consider the middle position as dangerous because they cannot look at the on-road situation and are impaired of their peripheral-detection capabilities for moving objects. Hence, they try to keep the visual off-road time to a minimum. Similar arguments were also given in the studies conducted by Dukic et al. (2005), for the button located near the gearbox, showing a shorter eye-off-road time.

Observing the individual DALI factors, it was noticed that higher values of 'interference' were registered for the middle position compared to other positions since the mobile phone some times interfered with easy maneuverability of steering wheel. 'Stress' was also rated high for middle positions as compared to other dual-task driving conditions.

Thus, according to the present research, the mobile phone display positioned at the front seems to be the most suitable (among the driver preferred mobile phone positions) for better driving performance and a lesser amount of driving workload than other dual-task conditions at different mobile phone locations under study.

In relation to usability of the methodology being adopted in the present study, the literature survey identified the advantages/ merits of the various methodologies, and for solving the research problem, the lane changing task (LCT) was utilized since it is a reliable, inexpensive, and standardized test tool for measurement of in-vehicle infotainment system (IVIS) demands. Eye-movement recorder was used to measure the visual demand/ attention of the drivers while driving. The study was performed in a low fidelity driving simulator in the laboratory environment, since, a variety of driving conditions/ environment can be easily and safely evaluated in the driving simulator. The digital human modeling (DHM) software was used for virtual ergonomics evaluation of various in-vehicle mobile phone position, since physical mock-ups and consequent trails with real human beings is expensive and time-consuming. In DHM software, digital human (manikin) model of varying body types and dimensions (mostly 5th, 50th, 95th percentile) can be created which interacts with a CAD generated product in a virtual environment. Thus, the above mentioned methods were utilize in the present study.

7.1.1 Summary of findings

The following are salient findings of the study regarding mobile applications-based taxi service (MABTS) drivers, their engagement in distracting tasks, and their placement of in-vehicle mobile phones around the dashboard and steering wheel.

- Involvement of the MABTS drivers in a wide variety of distracting activities while driving was explored in the field study.
- Drivers' preference of the location for placing in-vehicle mobile phone for navigation and justification of their behavior was established.
- The drivers showed a behavioral change between day and night-time. They either placed the in-vehicle mobile phone below the dashboard or reduced the screen brightness during night-time, depicting a mitigation strategy for glare from the mobile devices during night-time.
- With the digital human modeling study, the association between head movement (flexion/extension and rotation) and in-vehicle mobile phone location was established.
- Mobile phone located near the gearbox required the driver to turn/ rotate their head and the trunk/ torso to operate them. The mobile phone located on the dashboard in front of the steering wheel required minimum head movement (rotation, flexion/ extension), however, it obstructed the forward view-field. The mobile phone placed at the center of the steering wheel required minimum head rotation and provided un-obscured visibility of forward view-field and instrument cluster through the steering wheel.
- The DHM based study established that placing mobile phone at the center of the steering wheel would minimize head movement. Hence, an innovative, self-balancing mobile phone holder was developed using a systematic product design and development approach. The new product could be mounted at the center of the steering wheel.
- An empirical study in a laboratory setup established a statistically significant difference in driving performance (measured using lane change task on a driving simulator) and visual behavior (measured using eye tracker) for the in-vehicle mobile phone positions.
- Experimental observations established the superiority of in-vehicle mobile phone at the front of the steering wheel (on the dashboard) compared to other locations (left, right, and middle of the steering wheel).

7.1.2 Summary of objectives fulfillment

Objective 1: To identify the various methodologies currently practiced for measurement of driver distraction.

Various existing methodologies for measuring driver distraction were identified (details in Chapter 2) by surveying the current driver distraction literature. **Thus, objective – 1 of the research was fulfilled.**

Objective 2: To identify the factors influencing driver to distract attention from primary task of driving.

Objective 3: To identify various in-vehicle locations/ positions which are commonly practiced by MABTS drivers for navigation purpose.

A questionnaire survey was administered to the MABTS drivers to identify the various activities that distract the attention of drivers from the primary task of driving. The questionnaire survey also identified the various locations where the MABTS drivers keep their mobile phone devices for navigation purposes. **Thus, research objectives – 2 and 3 of the study were fulfilled.**

Objective 4: To identify the position/ location preferred by the majority of MABTS drivers for keeping mobile phones for navigation purposes, using questionnaire survey.

During the questionnaire survey, the MABTS drivers rated their most preferred location for mounting mobile phones for navigation purposes. **Thus, objective – 4 of the research was fulfilled.**

Objective 5: To identify the optimal/ most preferred in-vehicle position for placing mobile phone for navigation purpose in terms of minimizing the bio-mechanical effort.

A digital human modeling (DHM) based virtual simulation was performed to identify the optimal position of mobile phone location. Digital manikins with body dimensions of 5th, 50th, and 95th percentile Indian male population was prepared and interfaced with the car dashboard's CAD model. Head (rotation, flexion/ extension, and reachability) movement of each of the 5th, 50th, and 95th percentile manikins were observed at all the different mobile phone locations identified during the questionnaire survey (details in chapter 3). The virtual simulation values were validated by measuring head movements for drivers representative of 5th, 50th, and 95th percentile male population. An optimal position for placing a mobile phone for navigation purposes was identified in terms of minimal biomechanical effort. **Thus, research objective – 5 of the study was fulfilled.**

Objective 6: To identify the most suitable in-vehicle position in terms of reduced driver distraction and less affected driving performance for mounting the mobile phone (as navigational device), among the various preferred positions by MABTS drivers.

To empirically examine the suitable position of in-vehicle mobile phones, we conducted a driving simulator based experiment in a laboratory setup. Drivers'

visual behavior and driving performance were measured using an eye-tracking system and simulated driving (lane change test) environment, respectively. **Thus, research objective – 6 of the study was fulfilled.**

7.1.3 Testing of hypothesis

Hypothesis 1: Driver distraction due to use of mobile phone for navigation can significantly be reduced by identifying optimal/ most preferred position of the mobile phone considering minimal obstruction of external view field, minimal eye/ neck movement (to visualize the screen) and easy reach for navigational purpose.

The DHM study's outcome revealed that the minimum head movement (rotation: 1° , flexion: $5^\circ - 8^\circ$) was achieved for in-vehicle mobile phone placed at the front position of the steering wheel for 5th, 50th, and 95th percentile manikins. The outcome of the driving simulator-based experiment revealed that the driver distraction (in-terms of driving performance) was minimum for front position of in-vehicle mobile phone. A repeated measures ANOVA was conducted to find the difference (if any) in the M. Dev values, among the dual-task driving conditions. The results of repeated measures ANOVA revealed that there is a significant effect of driving condition ($F(4, 116) = 36.80, p < 0.05, \eta^2 = 0.559$, large effect size) on M.Dev values. Further, a post hoc test using bonferroni correction revealed that significant difference in M.Dev values exist between front and middle mobile phone positions ($p < 0.05$). Among the dual-task driving scenario, the mean deviation (M.Dev = 0.68) value was minimum for the front mobile phone position. In terms of driving workload, the front mobile phone position was rated to be the least loading ($M = 30.35$). Since the front position of the in-vehicle mobile phone was least distracting and drivers had a high perception of safety for this position, the fixation ($M = 24.64$ s) and glance ($M = 31.06$ s) duration of the drivers was longest at front mobile phone position. Hence, we can say that the front mobile phone position with minimum head rotation, and easy arm reach, has the least distracting effect (better driving performance and visual behavior). **Thus, establishing the hypothesis – 1 of the research.**

Hypothesis 2: Reduced driver distraction due to most suited position of mobile phone for navigation purpose significantly increases the driving performance.

The simulated driving experiment revealed that the driving performance depends on the position of in-vehicle mobile phones used for ride-booking, navigation, checking fare, and calling by the MABTS drivers. A repeated measures ANOVA showed that M.Dev values differed significantly among the different driving

conditions ($F(4, 116) = 36.80, p < 0.05, \eta^2 = 0.559$, large effect size). The best lane keeping performance (low value of mean deviation) was achieved when an in-vehicle mobile phone was placed at the front position ($p < 0.05$) compared to the other dual-task driving scenario. For lane change error, a Friedman test revealed that there was a significant effect of driving condition ($\chi^2(4) = 14.09, p < 0.05$) on lane change errors. The least amount of lane change error ($M = 3.50$) was also observed for the front position among the different mobile phone positions. **Hence, the hypothesis – 2 of the research work was established.**

7.1.4 Novelties (key contributions) of the present research

The current research work promotes the existing knowledge of the visual ergonomics and cognitive ergonomics in the applied domain of driver distraction to identify the most suitable/most preferred location for in-vehicle positioning of mobile phone as navigation device. The key novelties of this research are pin-pointed hereunder.

Contribution to the body of knowledge (ergonomics/HFE)

It has been observed from field-survey that the in-vehicle positioning of mobile phone as navigational device by MABTS drivers are varied. They generally mount at different locations on and around the dashboard and steering wheel, as per their convenience. Neither there is a guideline by the service providers, nor there are specific locations followed by the MABTS drivers for mounting their mobile for navigation purpose. Following the literature review, clear research gap has been identified regarding lack of guideline/ standard in national/ international scenario for optimal positioning of mobile phone (as portable navigation system) to minimize distraction. Present research has successfully addressed this prominent research gap through systematic empirical studies. Current research has utilized field survey, virtual simulation, and driving simulator based laboratory experiments involving LCT, eye-tracking and subjective workload assessment to identify the most preferred location of mobile phone for navigation purpose, among various highly preferred/ regularly practiced locations by MABTS drivers.

The current research has not only investigated the commonly practiced locations for positioning the mobile phone (as in-vehicle navigation device) by the MABTS drivers in Indian scenario but also attempted to identify the most preferred position in terms of minimal driver distraction and less affected driving performance. The research work undertaken is probably the first of its kind that explores the distracting effect of the usage of mobile phone as in-vehicle navigation device by MABTS drivers in Indian scenario.

The process of ergonomic designing of product (special mobile phone holder for mounting mobile phone on the hub of the steering wheel) has been described in detail. This research work has also lead the identification of the most suitable in-vehicle mobile phone position based

on lowest bio-mechanical effort (in-terms of minimum head rotation/ flexion/ extension and reachability) by applying virtual ergonomic evaluation using digital human modeling software. Apart from physical ergonomic aspect of reduced bio-mechanical load, suitable in-vehicle mobile phone position has also been identified based on driver's cognitive workload (DALI questionnaire), driving performance (Lane-changing task), and eye-movement study.

Methodological perspective

The present dissertation work demonstrated a systematic research approach from the review of existing literature, field survey to establish the rationale of research, and formulate the problem statement. Following laboratory-based experimentation in driving-simulator, current research has identified the most preferred location of mobile phone (as navigation purpose) in terms of reduced driver distraction and less impact on driving performance. Current research has employed field survey to understand the MABTS drivers' behavior and their common practice to position the mobile phone as navigation device. A systematic product development strategy developed an innovative self-adjusting steering wheel-mounted mobile phone holder, need analysis, concept generation using the morphological chart, concept selection via the Pugh matrix, and user feedback was applied. Use of digital human modeling (DHM) techniques for evaluating comfortable head movement (flexion/extension and rotation), and reach to various in-vehicle mobile phone locations was unique and brings novelty in driver distraction research. The eye-tracking was used for recording drivers' visual behavior during performing dual-tasks in a driving simulator in a laboratory setup to understand drivers' driving performance and level of driver distraction due to the different mobile phone locations. Drivers' subjective workload was measured using the driving activity load index (DALI) questionnaire. Statistical analysis (repeated measures ANOVA) was performed to identify, significant difference (if any) in the driving performance (M. Dev and lane change error), visual behavior (fixation, glance, TEORT), and driving workload, among the different in-vehicle mobile phone positions.

The research methodology followed in the present research work might be the foremost of its kind towards exploration from visual and cognitive ergonomics perspective in Indian MABTS scenario. Researchers, Designers and Engineers involved in design, development of mobile phone holder or any other in-vehicle control-display unit may adopt a similar strategy to come up with innovative product design with due consideration of cognitive aspects of the drivers during real-driving scenario. The standardized methodology as described and adopted in the present research could serve as the research manual for future researchers.

The complete methodology (starting from identification of research gap and formulating research problem to providing appropriate solution) used in the present research may be reproduced by emulating similar control-display scenario to minimize distraction from the primary task(s) in a scenario of working condition with high demand of attention and thereby cognitive load.

Contribution to society

The current research work deals with the widespread problem of visual distraction and inattention faced by professional (taxi/ cab/ auto-rickshaw) drivers in particular and personal automobile drivers in general, during their use of mobile phone as navigation device. The problem of distraction and there by possibility of accidents or near to accidents can be minimized by optimal position of in-vehicle navigation/ infotainment system like mobile phone. Suitable position of navigation device/ display would not only reduce the driver distraction largely by minimizing off-road glances to access information from the display or by decreasing interaction-time with the device. Moreover, appropriate positioning of navigation/ infotainment system would minimally affect the driving performance. Findings of the current research can be utilized by the policy-makers/ road-transport authorities for formulating guidelines for efficient and safe use of in-vehicle navigation device. It is anticipated that the outcomes of this research would be beneficial to the wide spectrum of drivers (both personal and professional) driving a variety of vehicle classes (auto, truck, buses, etc.), by giving them a clear perspective on the placement of in-vehicle mobile phones. Thus, mitigating the problem of driver distraction and increasing road safety for drivers and other road commuters.

Contribution to the industry

Current research through systematic research methodology has identified the most preferred location of mobile phone for navigation purpose, among various highly preferred/ regularly practiced locations by Indian MABTS drivers. The outcome of the research can be utilized by the MABTS companies to develop guidelines and standard operating procedures (SOP) for the drivers for placement of their mobile phone or any other navigation device. Further, the automobile companies can use the outcome from the present research for judiciously placing the in-vehicle displays for reduced driver distraction. The knowledge gained from the study about visual and driving behavior could be used by the designers and the ergonomists for developing safer and user-friendly in-vehicle displays. Additionally, the industrial designers can also use the knowledge to design mobile holders/ space integrated within the dashboard, keeping in mind smaller visual angles for safety and usability (to guide the driver to place the mobile device in the correct position).

7.2 Scope for future research based on limitations

Although the researcher tried to follow the best possible experimental design and thereby execution of research as per the set objectives, the overall research is not devoid of limitations. The inevitable loop-holes and limitations of current research could be taken for further exploration as the future research scope.

- The study in chapter 3, was mainly self-reported, which is biased by social desirability issues. Due to this bias, difficulty in viewing/ operating mobile phones while driving, health problems, engagement in distracting tasks, and chances/ possible occurrence of crash/ accident may be under-reported.
- India's MABTS driver population predominantly consists of males; data from the female drivers were not feasible due to their unavailability. Apart from this, the survey respondents were driving right-handed vehicles (hatchback/ sedan); some preferences regarding the placement of mobile phones might vary for left-handed vehicles, which are mainly used in the western world. Future studies could consider taking responses and data from the female population and drivers of left-handed vehicles.
- The study in chapter 4 is based on virtual ergonomic assessment using CATIA-DELMIA software. This study considers only biomechanical effort in terms of head (rotation and flexion/ extension) movement, comfort range of motion, and reachability. It does not consider the subjective evaluation of comfort under prolonged driving conditions.
- The manikins used in the study (chapter 4) were representative of the adult Indian male population. The results may vary a little and may not apply to the female population. Moreover, the evaluation was based only on the comfort of head movement (flexion/ extension and rotation), and reachability required for the different in-vehicle mobile phone positions, using percentile manikins (5th, 50th, and 95th). Use of boundary manikins may have produced different results. Future studies could build upon these shortcomings and carry out research to overcome these lacunae.
- Although the researchers have taken the utmost care to match the experimental conditions (position of the mobile phone) with the real-world scenario (for both DHM and simulated study), an accurate resemblance may not have been achieved. Further, the empirical study in chapter 6 used a fixed-base driving simulator in a laboratory environment where the drivers know that their error/ fault in driving would be inconsequential towards an accident. An empirical study on an instrumented vehicle on a real road/ traffic condition may produce a more realistic outcome. The study could further be extended by using dynamic simulator or in real road conditions.
- Additionally, in the study of chapter 6, various other factors were unaccounted, which may have affected the drivers' visual behavior and driving performance. These factors include the drivers' characteristics (age, gender, comfort and skill of driving the simulator, driving experience), environmental characteristics (road condition (rural/ urban), traffic (high/ low)), and vehicle characteristics (right/ left-hand drive, type of vehicle). Future research can be planned to study the impact of all these variables in identifying most preferred mobile phone position.

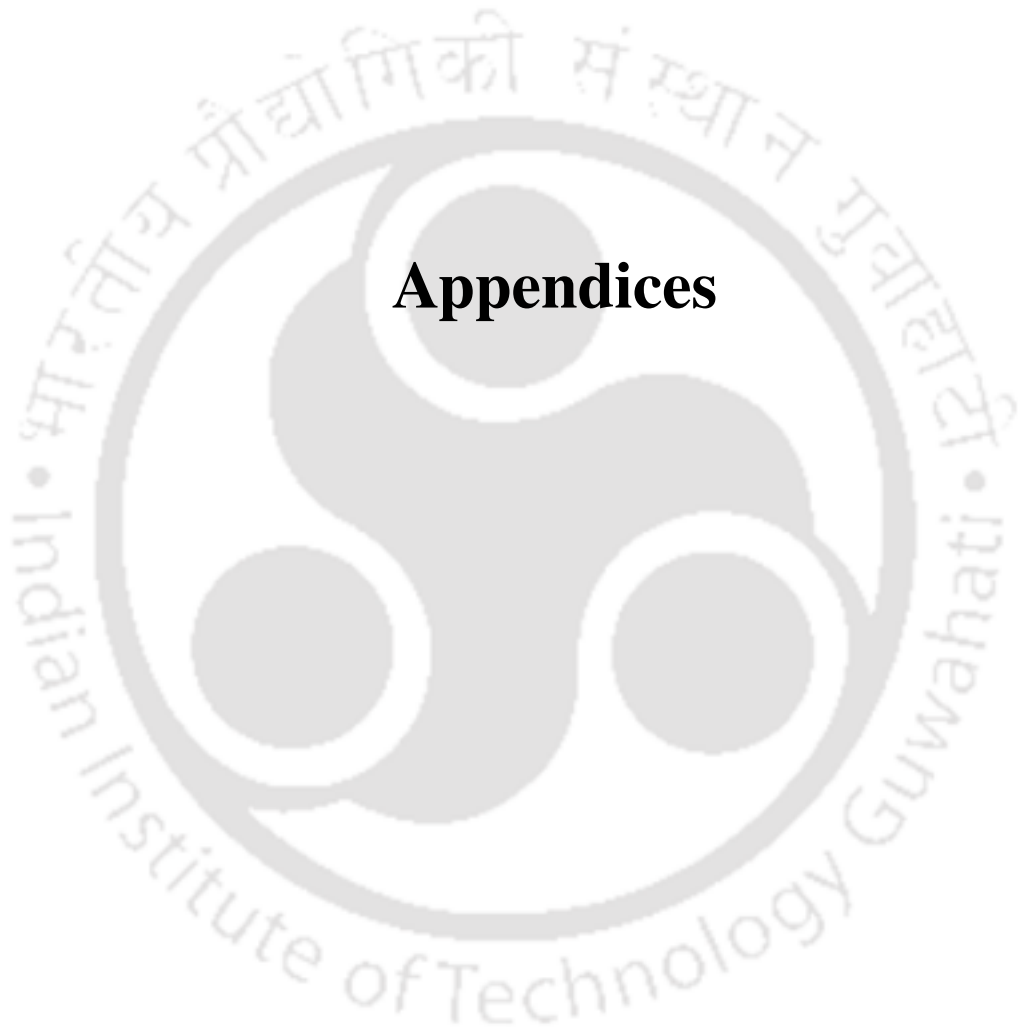
- The present study measured driving workload using the DALI scale in a laboratory setup; however, the driver's workload may be affected by psycho-social and organizational factors/ policies. There may be constraints and expectations on the MABTS drivers, such as meeting the performance targets, directly linked to financial factors/ incentives (of reaching the destination on time) which don't influence the non-MABTS drivers. Since such factors were not measured, there is a scope for future research.
- Future studies should take up research on an instrumented vehicle and different classes of vehicles (trucks, buses, and auto-rickshaws) for producing more generalized outcomes. The future scope also lies in understanding the optimum position for mobile phones for drivers suffering from low back pain, which is very common among professional drivers, its comparison with healthy drivers (present study), and its implications for design. Future research could also take a comparative study between MABTS drivers who use only mobile phones and those who use mobile phones with Bluetooth devices (or voice based user interface), since audio input may also influence visual behavior while driving.

Indian MABTS drivers mainly employ mobile phones for rendering their services (car booking, navigation, and fare). Complete elimination of mobile phone's use by them while driving is not possible since it is an essential part of taxi services. There is no guideline by the service providers, nor are there specific locations followed by the MABTS drivers for mounting their mobile for navigation purposes. MABTS drivers generally mount their mobile phones at different locations on and around the dashboard and steering, as per their convenience. Thus, self-justified positioning of the mobile phone by MABTS driver might cause greater visual distraction, higher biomechanical effort (neck/ eye movement, reachability, etc.), and reduced driving performance leading to an increased chance of error and accident. Thus, the need of the hour is to address the issue of identifying the most preferred/ best suitable position of the mobile phone (as a navigation device). The current research has successfully investigated the commonly practiced locations for positioning the mobile phone by the MABTS drivers in the Indian scenario and identified the most preferred position out of the various commonly practiced positions by the MABTS drivers, in terms of minimal driver distraction and less affected driving performance. Although the current research has various limitations, it is probably the first of its kind that explores the distracting effect of mobile phone usage as an in-vehicle navigation device by MABTS drivers in the Indian scenario. The automobile companies can use the present research outcome for judiciously placing the in-vehicle displays for reduced driver distraction. MABTS companies can develop guidelines and standard operating procedures (SOP) for the drivers for placement of their mobile phone or any other navigation device for mitigating driver distraction caused by inappropriate positioning of mobile phone for their services. The policy-makers/ road-transport authorities could utilize the findings of the current research for formulating guidelines for the efficient and safe use of in-vehicle navigation devices. The designers and ergonomists could use the knowledge gained from driving simulator-based

laboratory experiments involving LCT, eye-tracking, and subjective workload assessment for developing safer and user-friendly in-vehicle displays.







Appendices



A.1 Detailed questionnaire used in field survey

PARTICIPANT INFORMED CONSENT

Project Title: Driver Distraction Questionnaire
Researcher's Name: Indresh Kumar Verma
Supervisor's Name: Dr. Souagata karmakar

DECLARATION BY THE PARTICIPANT

I hereby declare that

- I have received information about this research project.
- I understand the purpose of the research project and my involvement in it.
- I understand that I may withdraw from the research project at any stage.
- I understand that whatever information gained during the study may be published, I will not be identified and my personal results will remain confidential.

Participants under the age of 18 yrs. require parental consent to be involved in research. The consent form should allow for those under the age of 18 yrs. to agree to their involvement and for a parent to give consent.

Name: _____ **Signed:** _____ **Date:** ___/___/201__
Education: _____ **Corrected Vision:** ____ (____) **Age / Sex:** ____ yr. / ____
Address: _____

DECLARATION BY THE RESEARCHER

I hereby declare that I have provided requisite information about the research participant; and confirmed that s/he has understood the experimental details and his / her role therein.

Researcher's Name: *Indresh Verma* **Signed:** _____ **Date:** ___/___/201__

Demographic Questions

Name: _____ Age: _____ Gender: _____
 Height (cm) _____ Driving Experience: _____ in yrs
 Type of vehicle you drive: a.) Personal Vehicle b.) Others vehicle professionally
 License type: a.) learners license b.) Commercial LMV c.) Commercial HMV license
 Have you met with an accident while driving (period – past 1 / 2 / 3 / 5 etc yr)
 a. Yes, (if yes, give details) b. No
 Vehicle you drive is: Hatchback / Sedan / SUV
 Driving Speed Range
 < 40 kmph 40 – 60 kmph 60 – 80 kmph > 80 kmph

Physical Fitness Questions:

1. Have you at any time during the past 12 months had trouble (ache, pain, discomfort) in:
 - a. Neck Yes / No
 - b. Shoulder
 - i. Right Shoulder Yes / No
 - ii. Left Shoulder Yes / No
2. Have you undergone some kind of surgery / operation of shoulder or neck in the past 12 months Yes / No
3. Are you under some kind of Medication / Drug Yes / No
4. Do you have a spectacles, if yes
 - a. For Long Distance
 - b. For Short distance
5. Do you have problem in recognising the colours Yes / No
6. Do you have undergone any kind of eye operation in the past 12 months Yes / No

Section A

1. Please select from the list of following activities you do while driving
 - a. Use of navigation system
 - b. Use of Radio/ Music system
 - c. Use of Environment control in vehicle
 - d. Use of mobile phone
 - e. Looking to the in-vehicle meters
 - f. Interaction with passengers
 - g. Adjusting the seat.

2. On a scale of 1 to 5 please rate the level of distraction you feel when performing these activities along with driving.

Least most

1 2 3 4 5

- a. Talking on phone
- b. Radio/ music system
- c. Environment control (AC / Heater)
- d. Looking to in-vehicle meters
- e. talking with passengers
- f. using navigation system
- g. seat adjustment

Section B

(Strongly disagree – Strongly agree)

1. It is easy for me to adjust Radio/ music system while driving
2. I have no difficulty in looking at in-vehicle meters while driving
3. It is comfortable for me to talk to the passenger and drive at the same time.
4. When driving I can easily adjust the environment control system (AC / Heater)
5. It is easy for me to drive and use navigation system at the same time
6. I have no difficulty in adjusting seats while driving my car
7. I can comfortably use my mobile phone while driving

Section C

1. The location of Radio / music system is at a comfortable position in my car.
2. I do not use navigation system in my cars as it is at an uncomfortable position.

Section D**Questions related to Display and Visual exploration of the display**

1. Where do you generally place the mobile device for navigation purpose while driving?
-

2.

a. How often do you look at the navigation display during a trip (known destination)

Never	Rarely	Sometimes / Occasionally	Almost every time	every time

b. How often do you look at the navigation display during a trip (un-known destination)

Never	Rarely	Sometimes / Occasionally	Almost every time	every time

3. Display visible from the normal operating posture.

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

4. Display located in the expected region?

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

5. Head or Head- torso movements are required to see the display.

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

6. There is visual discomfort in viewing the target area / device, leading to distraction?

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

7. There is discomfort with more than one visible interference, leading to distraction?

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

Display Location

8. Which Region do you prefer to keep the mobile phone when you are using it for navigation?

- Left Region of Steering Wheel
- Right Region of Steering Wheel
- Centre Region of Steering Wheel

9. Where do you generally place mobile for navigation in the car?

- Left Portion
- Right Portion
- Middle Portion
- No mobile holder

10. Do you change the position of the car mount mobile holder during different time of the day?

Yes / No

If Yes,

- Position at Day time _____
- Position at Night time _____

11. Rank the location (based on preference of use) of keeping the mobile device for navigation purpose (1 being most preferred and 9 is least preferred) as shown in picture.

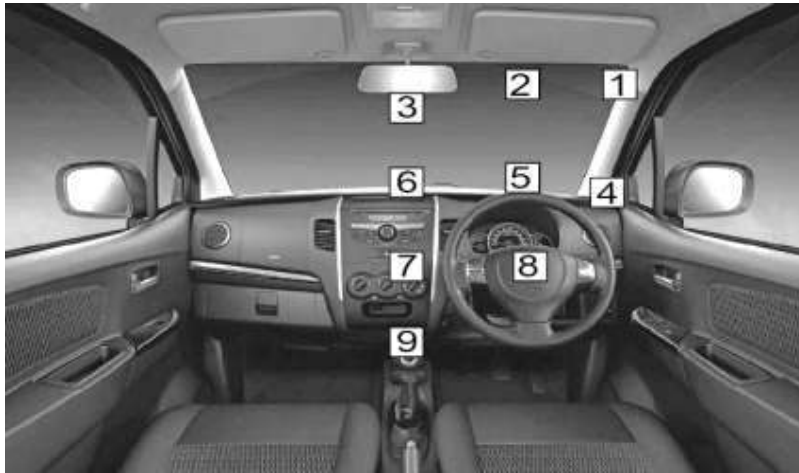


Fig 1

Position	1	2	3	4	5	6	7	8	9
Rank									

12. Do you somehow keep the mobile in any place other than those shown in Fig 1? Please share your views towards the same.

13. Display is located at a comfortable viewing distance.

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

14. Display is located close to the driver's Primary / binocular field of Sight.

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

15. Auxiliary display lead to distraction from driving.

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

16. To view the auxiliary display you have to distract from the primary visual area of driving.

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

17. Display confuse with other visible objects present laterally to the driving visual area.

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

A.2 Consent Form

Consent and Basic information Form

Experiment Id:	Name: রাসম	
Age: ১৭	Gender: মিঃ	Driving Experience:
<p>About the Experiment:</p> <ul style="list-style-type: none"> In this experiment, your driving performance will be tested under dual task scenario (performing secondary task along with the primary task of driving), in a fixed base driving simulator, when the mobile-phone is placed at four different locations. এই পরীক্ষায়, অপেক্ষাকৃত স্থায়ীভাবে দুটি দিকের ওপর যিবেশন হবে (দ্রুতগতির সাময়িক ক্রম এবং আনুষঙ্গিক তথ্য সৌন্দর্য্য)। Your eye-movement and gaze data will be recorded using the eye-tracking equipment. অপেক্ষাকৃত ক্রম চলমান এবং দৃষ্টিভঙ্গি ট্রেসিং সরঞ্জাম ব্যবহার করে রেকর্ড করা হবে। After completion of the driving test, subjective assessment of workload will be measured using Driver Activity Load Index (DALI) questionnaire. দ্রুতগতির পরীক্ষা শেষ হওয়ার পরে, দ্রুতগতির একাধিক লোড ইনডেক্স (DALI) প্রশ্নাবলীর সাহায্যে ক্রমের হেঁচক বিষয়গত অনুমান পাঠানো করা হবে। 		
<p>Confidentiality:</p> <ul style="list-style-type: none"> The data collected during the experiment will be used for research and education purpose. পরীক্ষার সময় সংগৃহীত তথ্য/ডাটা (data) গবেষণা আর শিক্ষার উদ্দেশ্যে ব্যবহৃত হবে। Your personal details will be kept confidential at all times and no part will be made public. অপেক্ষাকৃত ব্যক্তিগত বিবরণ সর্বদা গোপন রাখা হবে এবং তাৎক্ষণিকভাবে প্রকাশ করা হবে না। 		

Statement of Consent:

- Your signature indicates that you are at least 18 years of age.

আমোজনৰ স্বাক্ষৰেই ইংগিত দিছে যে আমোজনৰ বয়স
অধিকমেও ১৮ বছৰ।

- You have read this consent form along with purpose and procedure of the experiment.

আমোনি পাঠ্যক্ৰমৰ উদ্দেশ্য, কাল-পদ্ধতিৰ লগতে এই
সম্মতি-পত্ৰখনো পঢ়িছে।

Right to Withdraw and Questions:

- Your participation in this experiment is completely voluntary.

এই পাঠ্যক্ৰম আমোজনৰ উৎসাহেৰে সম্পূৰ্ণৰূপে লৈছে।

- You may choose not to take part at any time.

অনেকোৱাৰ সময়তে আমোনি যেনে নোহোৱাৰ সিদ্ধান্ত
লৈ যাব পাৰিব।

Signature and Date:

Signature: চৰী: _____

Date: ৱাৰিখ: _____

A.3 Driving Activity Load Index (DALI)

Driving Activity Load Index (DALI)

During the test you have just completed, you may have experienced some difficulties and constraints with regard to the driving task.

গাড়ি চলাই থকাৰ সময়ত হয়তো আপোনাৰ সময়সীমা হৈছে।

You are required to rate the experience through 6 different factors (described below). Please read each factor and its description carefully and ask the experimenter to explain anything you do not fully understand.

অনুপূৰ্ণি আপোনাৰ অভিজ্ঞতাক ভিত্তি কৰি বিভিন্ন বিলাসিতা সুলভায়ন কৰিব লাগিব। অনুভৱ কৰি প্ৰতিটো বিলাসিতা বেলকি পাঠিও তলত পৰীক্ষকক অনুৰোধ কৰিব নুবুজা বিলাসিতা বেলকি বুজাই দিবলৈ।

Participant Id _____ Track No. _____

Please rate each of the following factors according to the experience of your driving activity for this particular session on a scale of 0 (low level of constraint) to 5 (high level of constraint).

অনুভৱ কৰি এই নিৰ্দিষ্ট বৈশিষ্ট্য কৰণে আপোনাৰ ড্ৰাইভিং ক্ৰিয়াকলাপৰ অভিজ্ঞতা অনুভৱ কৰি প্ৰতিটো বিষয়ক ০ (সীমাবদ্ধতা নিম্ন স্তৰ) পৰা ৫ (সীমাবদ্ধতা উচ্চ স্তৰ) স্কেলত বেট দিব।

Attention demand:					
Think about the overall (mental, auditory, visual) demand required during the test to perform the whole activity.					
গোটেইখনি ক্ৰিয়াকলাপ সম্পাদন কৰণে পৰীক্ষাৰ সময়ত প্ৰয়োজনীয় মনোনিবেশ (মনোনিবেশ, শব্দ, চাক্ষুণ্য) চাহিদা সন্দৰ্ভে চিন্তা কৰক।					
Low 0	1	2	3	4	High 5

Visual demand:					
Think about the visual demand required during the test to perform the whole activity.					
<p>গোটেইখিনি ক্রিয়াকলাপ সম্পাদনৰ কৰণে পৰীক্ষাৰ সময়ত প্ৰয়োজনীয় ভিজুয়াল চাৰিমা সম্পৰ্কে চিন্তা কৰক।</p>					
Low 0	1	2	3	4	High 5

Auditory demand:					
Think about the auditory demand required during the test to perform the whole activity.					
<p>গোটেইখিনি ক্রিয়াকলাপ সম্পাদনৰ কৰণে পৰীক্ষাৰ সময়ত প্ৰয়োজনীয় শব্দৰ চাৰিমা সম্পৰ্কে চিন্তা কৰক।</p>					
Low 0	1	2	3	4	High 5

Stress:					
Think about the level of stress (fatigue, insecurity, irritation) during the test to perform the whole activity.					
<p>সম্পূৰ্ণ ক্রিয়াকলাপ সম্পাদন কৰাৰ বাবে পৰীক্ষাৰ সময়ত হেঁচাৰ দুৰ (শ্ৰান্তি, নিৰাশতাহীনতা, উত্তেজনা) সম্পৰ্কে চিন্তা কৰক।</p>					
Low 0	1	2	3	4	High 5

Temporal demand:					
Think about the pressure and specific constraint felt due to time pressure of completing task during the whole activity.					
সম্পূর্ণ সিনিয়রকাল্প সম্ভৱ কৰাৰ সময়ত মি হৈচা আৰু নিৰ্দিষ্ট সীমাবদ্ধতা অনুভূত হৈছিল, (সেই অক্ষৰে চিন্তাভাৱনা কৰক)					
Low 0	1	2	3	4	High 5

Interference:					
Think about disturbance to the driving task when completing secondary task.					
গৌণ বা আনুষংগিক কাম সম্পূৰ্ণ সম্পূৰ্ণ কৰাৰ সময়ত ড্ৰাইভিং কামত অসুবিধা বাৰী অক্ষৰে চিন্তা কৰক।					
Low 0	1	2	3	4	High 5

Pair Wise Comparison

<p>Attention demand মনোযোগ চাহিদা</p> <p>or</p> <p>Visual demand চাক্ষুস চাহিদা</p>	<p>Auditory demand আব্দন চাহিদা</p> <p>or</p> <p>Stress তৈঁচা</p>	<p>Attention demand মনোযোগ চাহিদা</p> <p>or</p> <p>Stress তৈঁচা</p>
<p>Auditory demand আব্দন চাহিদা</p> <p>or</p> <p>Interference হস্তক্ষেপ</p>	<p>Visual demand চাক্ষুস চাহিদা</p> <p>or</p> <p>Temporal demand সাময়িক চাহিদা</p>	<p>Attention demand মনোযোগ চাহিদা</p> <p>or</p> <p>Temporal demand সাময়িক চাহিদা</p>
<p>Attention demand মনোযোগ চাহিদা</p> <p>or</p> <p>Auditory demand আব্দন চাহিদা</p>	<p>Visual demand চাক্ষুস চাহিদা</p> <p>or</p> <p>Auditory demand আব্দন চাহিদা</p>	<p>Attention demand মনোযোগ চাহিদা</p> <p>or</p> <p>Interference হস্তক্ষেপ</p>
<p>Visual demand চাক্ষুস চাহিদা</p> <p>or</p> <p>Interference হস্তক্ষেপ</p>	<p>Auditory demand আব্দন চাহিদা</p> <p>or</p> <p>Temporal demand সাময়িক চাহিদা</p>	<p>Visual demand চাক্ষুস চাহিদা</p> <p>or</p> <p>Stress তৈঁচা</p>
<p>Temporal demand সাময়িক চাহিদা</p> <p>or</p> <p>Interference হস্তক্ষেপ</p>	<p>Stress তৈঁচা</p> <p>or</p> <p>Interference হস্তক্ষেপ</p>	<p>Temporal demand সাময়িক চাহিদা</p> <p>or</p> <p>Stress তৈঁচা</p>

A.4 Calculation of the DALI questionnaire

Computation of the Weighted DALI Score is calculated by Equation 1

$$W_i = \alpha_i \times R_i; \quad (1)$$

$$\alpha_i = C_i / (n - 1); \quad (2)$$

$$R_i = l_i \times 20; \quad (3)$$

where,

W_i = Weighted Score of each factor,

C_i = no. of times a given factor has been selected during the pairwise comparison;

$(n - 1)$ = no. of pairs for this factor, in this case its 5.

l_i = rating of each of the factor on a scale of 0 to 5.

The Global workload score for DALI is calculated as shown in equation 4

$$W_{global} = \left(\sum_{i=1}^6 \alpha_i R_i \right) / n \quad (4)$$

$n = 6$, in this case.

A.5 System Usability Scale (SUS)

System Usability Scale (SUS)

Project/Release/Study:	Date:
Participant:	

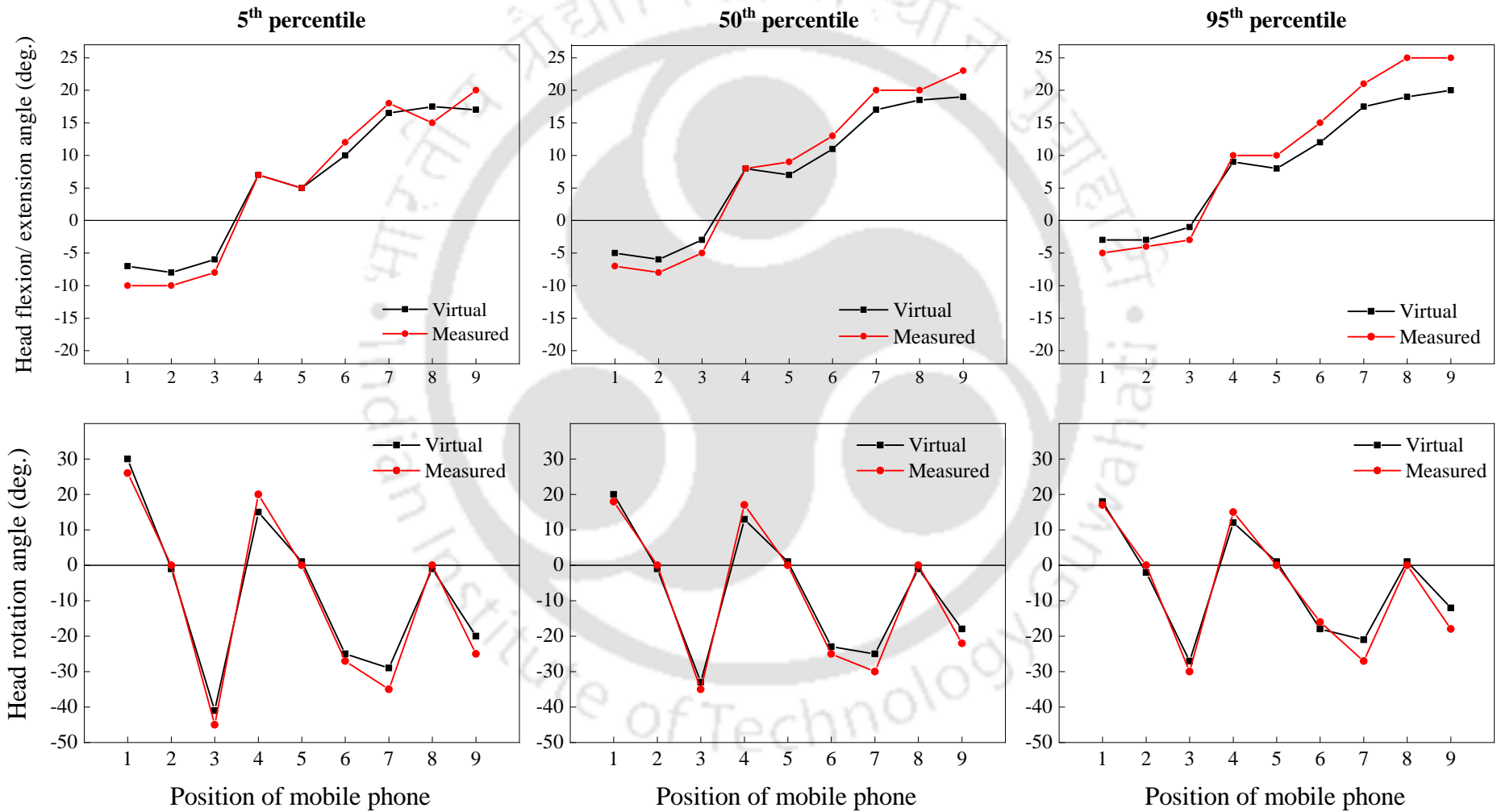
Instructions

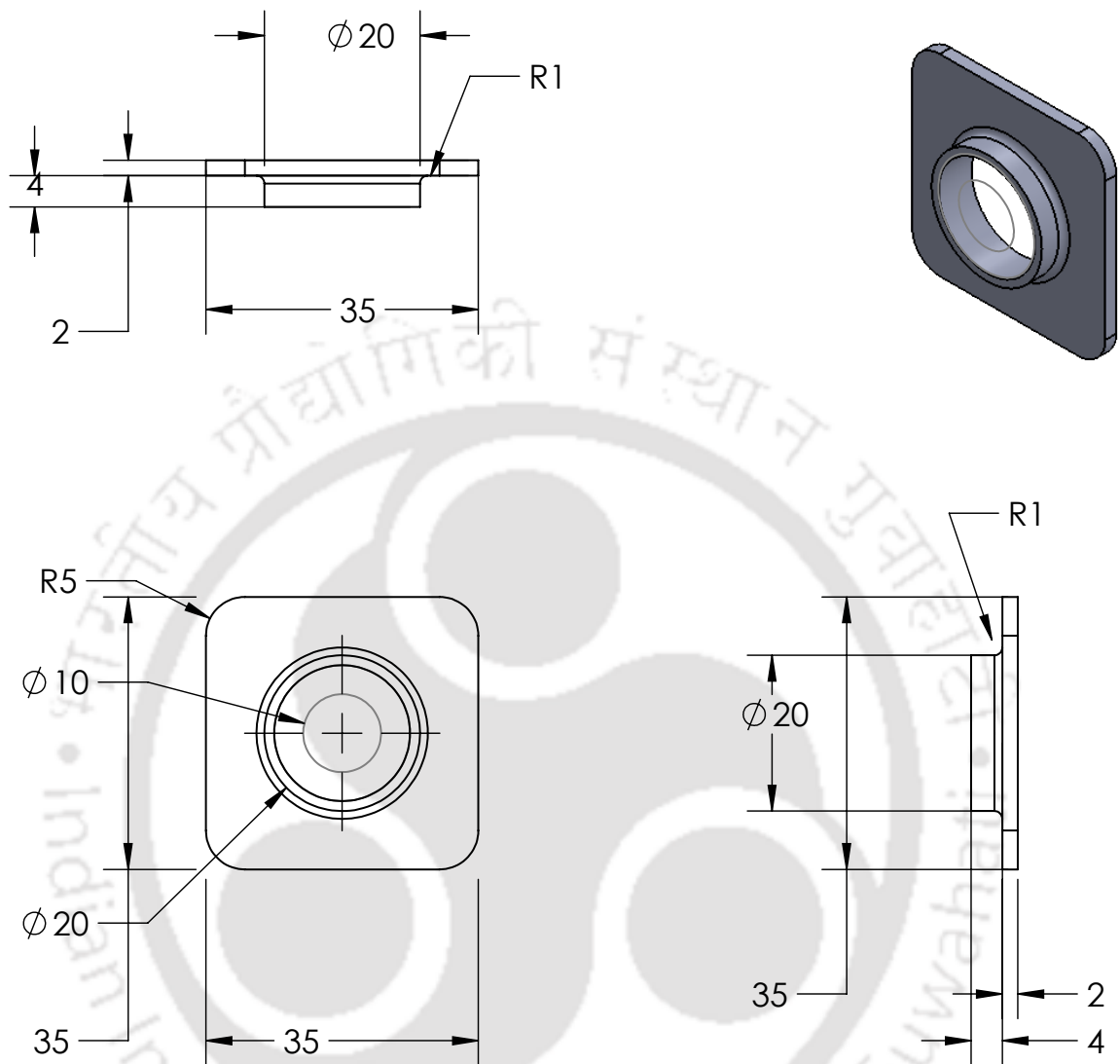
Based on your experience today, with the product, check the box that reflects your immediate response to each statement. Make sure you respond to every statement. If you don't know how to respond, simply check box "3".

		Strongly disagree				Strongly agree
		1	2	3	4	5
1	I think that I would like to use this product frequently.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	I found the product unnecessarily complex.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	I thought the Product was easy to use.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	I think that I would need the support of a technical person to be able to use this product.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5	I found the various functions in the Product were well integrated.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	I thought there was too much inconsistency in the Product.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	I would imagine that most people would learn to use the Product very quickly.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	I found the Product very cumbersome to use.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	I felt very confident using the Product.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10	I need to learn a lot of things before I could get going with this Product.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

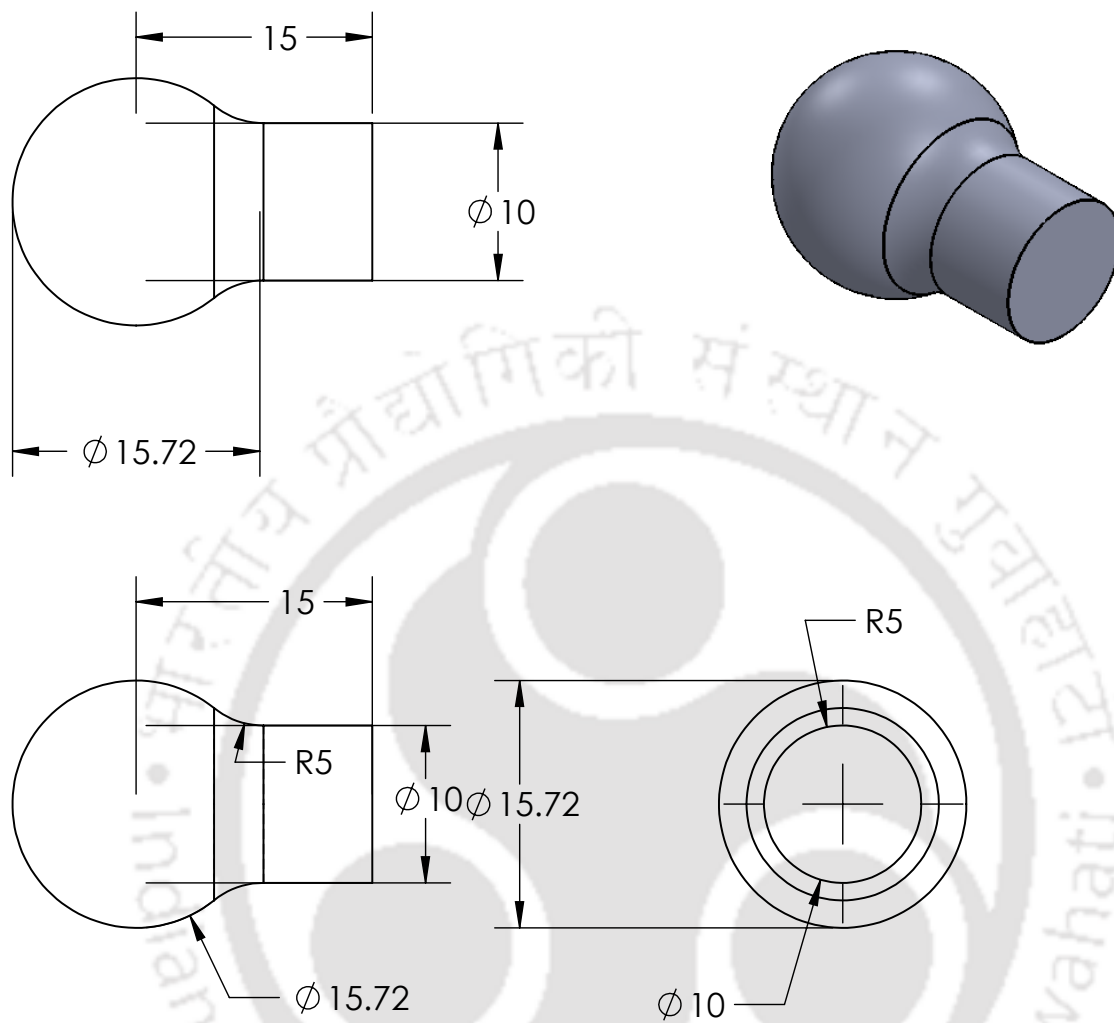
Comments:

A.6 Comparison between virtual and real measurements



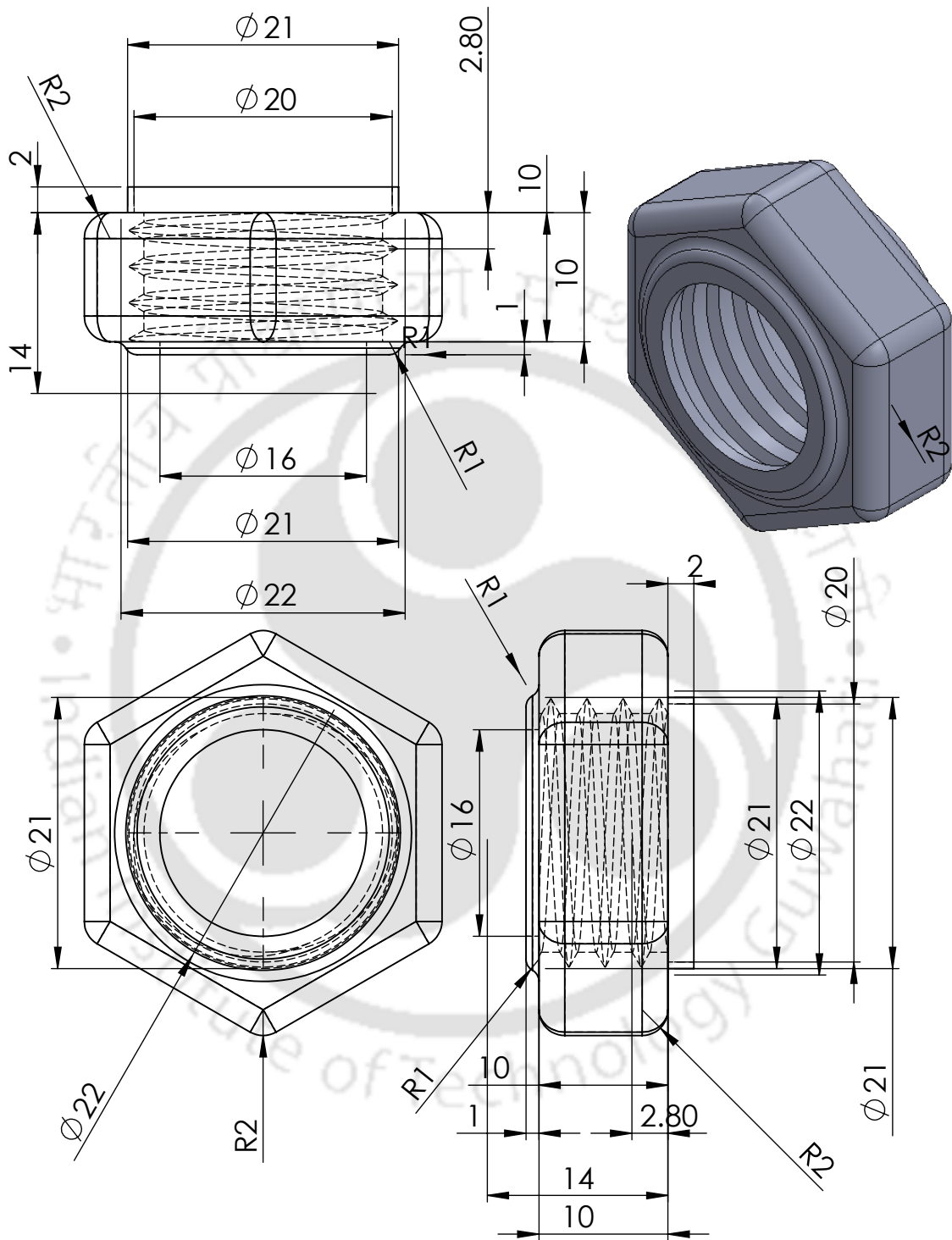
(b) Base

All measurements in mm.

(c) Ball

All measurements in mm.

(d) Screw



All measurements in mm.

A.8 Institute Human Ethics Committee approval letter



Institute Human Ethics Committee
INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
 North Guwahati, Guwahati – 781 039

Institute Human Ethics Committee Approval

The chair and the members of Institute Human Ethics Committee of Indian Institute of Technology Guwahati have considered the project titled “Study on identification of optimal position of mobile phone for navigation purposes in terms of minimizing distraction: a study on drivers of mobile application based taxi services (MABTS)” in the meeting convened on 28th February 2020 and given its approval for the same.

Prof. Vimal Katiyar
Deputy Chairperson of IHEC &
Dean R&D, IITG

संकायाध्यक्ष, अनुसंधान एवं विकास
 Dean, Research and Development
 भारतीय प्रौद्योगिकी संस्थान गुवाहाटी
 Indian Institute of Technology Guwahati
 गुवाहाटी-781039
 Guwahati-781039

A.9 List of publications

Conferences

1. **Verma, I. K.,** & Karmakar, S. (2017). Driver Distraction: Methodological Review. In A. Chakrabarti & D. Chakrabarti (Eds.), *Research into Design for Communities*, Volume 1. ICoRD 2017 (Vol. 65, pp. 849–859). Springer, Singapore. https://doi.org/10.1007/10.1007/978-981-10-3518-0_73
2. **Verma, I.,** Nath, S., & Karmakar, S. (2018). Research in Driver–Vehicle Interaction: Indian Scenario. In G. G. Ray, R. Iqbal, A. K. Ganguli, & V. Khanzode (Eds.), *Ergonomics in Caring for People* (pp. 353–361). Springer, Singapore. https://doi.org/10.1007/10.1007/978-981-10-4980-4_43
3. **Verma, I.,** & Karmakar, S. (2021). Subjective evaluation of driver-distraction caused during use of mobile phone for navigation purpose. In: *Proceedings of International conference on Humanizing Work and Work Environment, 2017. 8th – 10th Dec, 2017.*

Journals

1. **Verma, I.K.,** & Karmakar, S. (2020). Positioning of the Mobile Phone to Minimize Driver’s Biomechanical Effort During Navigation: DHM-Based Approach. *Journal of The Institution of Engineers (India): Series C*. <https://doi.org/10.1007/s40032-020-00580-9>
2. **Verma, I. K.,** & Karmakar, S. Mounting smart-phone on steering-wheel to facilitate ease of visibility of navigation screen: Systematic product design approach. *WORK: A Journal of Prevention, Assessment & Rehabilitation*. [Accepted]
3. **Verma, I. K.,** Nayak, B. K., & Karmakar, S. Effect of mobile-phone position on the visual and driving behavior: A LCT based study. *Human Factors*. [Communicated]

A.10 Patent filed

Design patent:

- Self-balancing mobile holder for steering wheels. [**FER Issued**]
Design Registration Number: 329864-001, Class: 08-08, Filed on 08th June, 2020.
Members: **Mr. Indresh Kumar Verma**, Dr. Sougata Karmakar, Mr. Gurdeep Singh

Utility patent:

- Design of steering wheel-hub mounted self-balancing universal mobile phone holder for reducing biomechanical effort for display-navigation by vehicle drivers. [**Published**],
Application No.: 202031030298
Date of Filing: 16th July, 2020, Kolkata
Published on: 14th August, 2020.
The Patent Office Journal No. **33/2020**
Members: **Mr. Indresh Kumar Verma**, Dr. Sougata Karmakar, Mr. Gurdeep Singh.

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