UNIVERSITI PUTRA MALAYSIA

AN APPROACH IN INTEGRATING SAFETY AND USABILITY INTO AN AUTOMOTIVE NAVIGATION INTERFACE

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By

MUHAMMAD SYAFIQ SYED MOHAMED

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

AN APPROACH IN INTEGRATING SAFETY AND USABILITY INTO AN AUTOMOTIVE NAVIGATION INTERFACE

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MUHAMMAD SYAFIQ SYED MOHAMED

January 2017

Chair: Associate Professor Shamsul Bahri Mohd Tamrin, PhD
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Automotive navigation interface designs have the potential to cause distractions to drivers. The National Highway Traffic Safety Administration (NHTSA) crash data showed that 17 percent (an estimated 899,000) of all police-reported crashes involved some type of driver distraction in year 2010. Of those 899,000 crashes, distraction caused by instrumentations residing in the vehicle was reported in 26,000 crashes. It is important to address the issue of safety and usability in multimedia and navigation systems, in order to reduce the problem of driver's distraction. Common usability problems with automotive navigation user interfaces are legibility, cluttered interfaces, and the map design in general. This study contains three major components, namely to ascertain the automotive navigation user interface design elements, to integrate the needs of Malaysian drivers into the automotive navigation interface design and lastly to evaluate the proposed automotive navigation interface design for Malaysian drivers.

Relevant design elements for an automotive navigation interface were studied using content analysis of an online Malaysian GPS forum. As many as 235 comments were analyzed. Following the conclusion of the content analysis method, the Kansei Engineering approach was utilized to integrate safety and usability in an automotive interface design, after which a new prototype of an automotive navigation interface was developed. A usability testing was conducted to evaluate the new automotive navigation interface prototype.

Results from the content analysis showed that several important design elements were noted such as "Points of Interest", "3D Buildings", "Maps" as well as "Driving Safety". In the second phase of the study, the Kansei Engineering results were analyzed with Principal Components Analysis (PCA) as well as Partial Least Squares (PLS) method. Equations relating Kansei words of safety and usability were obtained. A finalized list of design specifications was

developed and the design specifications were then used to develop a new automotive navigation interface design, in the form of an animated prototype.
During the usability testing, a Wilcoxon signed-rank test showed that the newly proposed automotive navigation interface design performed better than the existing automotive navigation interface design in terms of the Kansei usability survey (Z=-2.386, P=0.017), number of driving errors (Z=-4.989, P <0.00), and task completion times (Z=-3.015, P=0.003) whereas the System Usability Scale (SUS) scores showed no significant difference (Z=-0.990, P=0.322), although the SUS score for the new automotive navigation interface design was slightly higher (66.625) compared to the existing automotive navigation interface design (62.625). As a conclusion, the Kansei Engineering approach worked very well in integrating the safety and usability requirements for an automotive navigation interface design.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGINTEGRASIAN ASPEK KEBOLEHGUNAAN DAN KESELAMATAN DI DALAM ANTARAMUKA NAVIGASI AUTOMOTIF

Oleh

MUHAMMAD SYAFIQ SYED MOHAMED

Januari 2017

Pengerusi: Profesor Madya Shamsul Bahri Mohd Tamrin, PhD
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Reka bentuk antara muka navigasi mempunyai potensi untuk menyebabkan gangguan pemandu. Data kemalangan dari *National Traffic Highway Safety Administration* (NHTSA) menunjukkan bahawa 17 peratus (kira-kira 899,000) daripada semua kemalangan polis dilaporkan melibatkan beberapa jenis gangguan pemandu pada tahun 2010. Daripada jumlah itu 899,000 kemalangan, gangguan yang disebabkan oleh instrumentasi di dalam kenderaan itu dilaporkan dalam 26,000 kemalangan. Isu gangguan pemandu adalah penting untuk menangani isu keselamatan dan kebolehgunaan dalam multimedia dan navigasi sistem, untuk mengurangkan masalah gangguan pemandu. Masalah kebolehgunaan dengan antara muka navigasi automotif adalah kebolehbacaan, rekabentuk yang berserabut , dan reka bentuk peta yang kurang sesuai. Kajian ini mengandungi tiga komponen utama, iaitu untuk memastikan komponen unsur-unsur reka bentuk antara muka automotif yang penting, untuk mengintegrasikan keperluan pemandu Malaysia ke dalam reka bentuk antara muka navigasi automotif dan akhir sekali untuk menilai reka bentuk antara muka navigasi yang dicadangkan untuk pemandu Malaysia.

Elemen reka bentuk yang berkaitan untuk antara muka navigasi automotif telah dikaji dengan menggunakan analisis kandungan forum GPS di Malaysia. Sebanyak 235 komen telah dianalisis. Setelah tamatnya kaedah analisis kandungan, pendekatan Kejuruteraan Kansei telah digunakan untuk mengintegrasikan keselamatan dan kebolehgunaan dalam reka bentuk antara muka automotif, selepas itu prototaip baru antara muka navigasi automotif telah dibangunkan. Satu ujian kebolehgunaan telah dijalankan untuk menilai antara muka navigasi automotif prototaip baru.

Keputusan daripada analisis kandungan yang menunjukkan bahawa beberapa elemen reka bentuk yang penting diperhatikan seperti "Tempat Menarik", "Bangunan 3D", "Peta" dan juga "Keselamatan Memandu". Dalam fasa kedua kajian ini, keputusan Kejuruteraan Kansei dianalisis dengan Analisis Principal Components (PCA) dan juga kaedah PLS. Persamaan berkaitan kata-kata

Kansei keselamatan dan kebolehgunaan diperolehi. Senarai dimuktamadkan spesifikasi reka bentuk telah dibangunkan dan spesifikasi reka bentuk kemudiannya digunakan untuk membangunkan reka bentuk antara muka navigasi baru, dalam bentuk prototaip animasi.

Semasa ujian kebolehgunaan, ujian Wilcoxon menunjukkan bahawa reka bentuk antara muka navigasi baru yang dicadangkan lebih baik berbanding navigasi reka bentuk antara muka yang sedia ada dari segi kajian kebolehgunaan Kansei ($Z = -2,386$, $P = 0.017$), jumlah kesilapan memandu ($Z = -4,989$, $P < 0.00$), dan jumlah masa memandu ($Z = -3,015$, $P = 0.003$) manakala skor (SUS) Sistem Usability Skala tidak menunjukkan perbezaan yang signifikan ($Z = -0,990$, $P = 0,322$), walaupun skor SUS untuk reka bentuk antara muka navigasi automotif baru adalah lebih tinggi sedikit (66,625) berbanding reka bentuk antara muka navigasi sedia ada (62,625). Kesimpulannya, pendekatan Kejuruteraan Kansei berjaya dengan baik dalam mengintegrasikan keperluan keselamatan dan kebolehgunaan bagi reka bentuk antara muka navigasi automotif.

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I certify that a Thesis Examination Committee has met on 6 January 2017 to conduct the final examination of Muhammad Syafiq bin Syed Mohamed on his thesis entitled "An Approach in Integrating Safety and Usability into an Automotive Navigation Interface" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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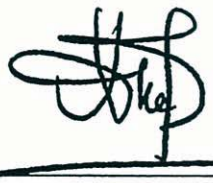

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

KE	Kansei Engineering
GPS	Global Positioning System
PND	Personal Navigation Devices
ISO	International Organization for Standardization
CTAM	Car Technology Acceptance Model
MIROS	Malaysia Institute of Road Safety Research
NHTSA	National Highway Traffic Safety Administration
HCI	Human Computer Interaction
UMTRI	University of Michigan Transportation Research Institute
JAMA	Japan Automobile Manufacturers Association
SAE	Society of Automotive Engineers
EU	European Union
MEC	Means End Chain
QFD	Quality Function Deployment
SMB	Semantic Environment Description
CA	Conjoint Analysis
SD	Semantic Differential
EEG	Electroencephalography
EMG	Electromyography
KES	Kansei Engineering System
QT 1	Quantification Theory Type 1
PLS	Partial Least Squares
KEM	Kansei Engineering Modeling

CHAPTER 1

INTRODUCTION

1.1 Introduction

According to the Malaysian Automotive Association the total sales of passenger cars in Malaysia in 2015 was 591,298 (Malaysia Automotive Association, 2016). This is a 109% increase from 2000, which indicates that more Malaysians are dependent on their cars as effective means of personal mobility. Malaysians now have access to many foreign car brands with so many options to choose from.

Cars in the Malaysian market now are equipped with advanced driver assistance systems such as collision warning, automatic braking, and blind spot assist, as well as automotive navigation systems (GPS). Interacting with an automotive navigation system is a common task for many drivers when navigating through an unfamiliar route. Drivers often have to juggle between engaging with the navigation system while keeping their eyes on the road.

According to a study by Frost&Sullivan, a market research company, automotive navigation devices, or known as GPS commanded 93% of the market share, and the trend is expected to continue in the future (Chia, 2013). Automotive navigation usage is expected to continue in the future, along with the rise of smartphone sales globally. Usage of automotive navigation is expected to be the norm for drivers worldwide, and this new phenomenon potentially leads to a safety ramification of driver distraction.

1.2 Problem Statement

Road accidents in Malaysia have been showing an increasing trend since the past few years. In year 2000, a total of 250,429 road accidents were recorded, and in the year 2010 as many as 414,421 road accidents were recorded (as indicated in Figure 1.1). According to the MIROS director general Prof. Dr. Wong Shaw Voon road accidents will continue to climb in Malaysia unless certain interventions are made (Tamrin, 2013).

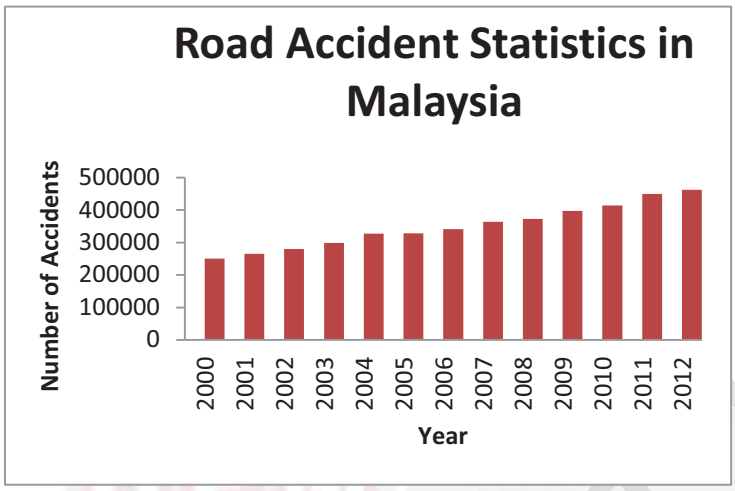

Figure 1.1: Road Accident Statistics in Malaysia
(Source : ("MIROS - Road Facts," 2014)

In-car instrumentation such as automotive navigation system can cause driver distractions. Wierwille & Tijerina (1996) reported that half of 2819 driver distraction related accidents were caused by distractions happening due to the interaction with multimedia and navigation systems. Furthermore, the National Highway Traffic Safety Administration (NHTSA) crash data indicated that seventeen percent of reported crashes involved a certain degree of driver distraction. The justification of selecting automotive navigation systems as the focus of the study has to be based on literature. Looking deeper into the various types of distraction involving automotive user interfaces, two previous studies, namely the NHTSA-sponsored 100-Car Naturalistic Driving Study, and the Federal Motor Carrier Safety Administration (FMCSA) collected naturalistic driving data related to the performance of secondary tasks while driving. Examples of secondary tasks are radio tuning, GPS destination entry, dialing or answering cell phones, and reaching for objects while driving. Part of study results included the estimated risk odds ratio values as shown in Table 1.1 below:

Table 1.1: Risk Odds Ratio Estimated Values
(Adapted from: NHTSA Driver Distraction Guideline, 2012)

Task / Activity	Risk Odds Ratio Estimation
Interacting with passenger	< 1.0
Talking/ Listening to hand held phone	1.1 to 2.0
Dialing cell phones	2.1 to 3.0
Reading	3.1 to 4.0
Reaching for moving object	9.1 to 10.0
Text messaging	> 23.0

Table 1.1 shows that the highest risk odds ratio are the task of text messaging on the cell phone, followed by reaching for moving object in the cabin, dialing cell phones in trucks, and reading. A positive risk odds ratio of 23 means that the driver is 23 times more likely to end up in car accidents compared to a risk odds ratio below one which indicates a protective effect of the secondary task (NHTSA Driver Distraction Guideline, 2012). Text entry is a visually demanding task, and therefore any secondary tasks involving text entry should be given a focused research effort. Examples of secondary tasks including text entry are GPS (Global Positioning System) destination entry and text messaging. According to the NHTSA Driver Distraction Guideline (2012) tasks which are visual-manual in nature tend to have high risk odds ratio, and automotive navigation system interaction clearly belongs to visual manual task which makes it a potential source of distraction with high risk odds ratio. As the task of interacting with the GPS system is primarily visual manual in nature, the usability of the automotive navigation user interface is highly crucial in influencing the levels of driver distraction. Common usability problems with automotive navigation user interfaces are legibility, cluttered interfaces, and the map design in general (Adam et al., 2004; Stanski-Pacis & de Voogt, 2011) Usability issues in an automotive navigation user interface can cause drivers to focus more time on the GPS screen instead of the road ahead, and this can lead to accidents. Hard to read maps and icons in the GPS screen makes it difficult drivers to make correct judgments when navigating unfamiliar roads. This is due to the fact that drivers often rely on the information supplied by the GPS navigation system to lead them to their destination correctly. Drivers do not have a lot of time figuring out what is being displayed on the GPS screen. Ideally, a couple of one to two second glances should be enough for drivers to figure out what is being displayed on the GPS screen (NHTSA Driver Distraction Guideline, 2012). Considering the urgency for having the best usability possible for automotive navigation user interface design, a suitable approach needs to be proposed in order to integrate usability as early as possible in the design stage. Currently, a huge gap exists between existing guidelines and standards (Green et al., 1993, 1995; ISO / TR 16352, 2005; ISO 15006, 2011; ISO 15007, 2014; ISO 15008, 2009; ISO 17287, 2003; ISO/TS 16951, 2004; Japan Automobile Manufacturers Association, 2000; Ross et al., 1996) and the actual design specifications of an automotive navigation user interface.

Therefore, this research takes on a different approach in integrating safety in GPS user interface design, by adapting the Kansei Engineering method. Kansei Engineering (KE) is a user- centric method, where the user plays an active role right in the beginning of the design process. In this way, the mismatch of expectations between users and designers can be minimized. In KE, users will be able to express their specific needs for safety and usability for automotive navigation interface designs, and KE will link those needs with exact technical design specifications which are clear and precise. The result from KE analysis will lead to the development of automotive navigation user interface design prototype which is safe and usable from the viewpoint of users.

1.3 Study Objectives

1.3.1 General objective

To integrate usability and safety in the design of automotive navigation user interface.

1.3.2 Specific objectives

- To ascertain the automotive navigation user interface design preferences among Malaysian drivers
- To integrate the needs of Malaysian drivers into automotive navigation user interface design.
- To evaluate the proposed automotive navigation user interface design for Malaysian drivers.

1.4 Research Scope and Limitations

In order to overcome the potential problem of driver distraction caused by automotive navigation interface design, a special approach is proposed and used in this research, which is the Kansei Engineering. The approach places a special emphasis on safety and usability. Therefore, in the Kansei Engineering approach, all the GPS interface design samples chosen featured complex road designs, urban roads, and only languages understood by Malaysians are chosen such as Malay and English. Only fourteen automotive navigation interface design samples were evaluated in this study since the design of the roads and language selection may influence the perception of usability by the participants. In this regard, the analysis in this study had produced several mathematical equations that describe safety and usability for automotive navigation interface design. Due to the fact that the equations were developed based on limited design samples and limited Kansei words, the generalizability of the equations may be limited. However, the same methodology can be applied to other components of the automotive user interface.

Testing the newly developed animated prototype requires a new usability testing method to be developed. Due to safety and ethical constraints, testing can only be carried out in a driving simulator as opposed to real world driving conditions. In order to ensure a certain level of validity, the short animated route consisted of closely spaced turns and unusual intersections. These two criteria were listed by Nowakowski et al.(2003) as the essential criteria to have while testing automotive navigation systems. Therefore, the usability testing method used in this study is only limited for validating the automotive navigation interface design prototypes.

1.5 Conceptual Framework

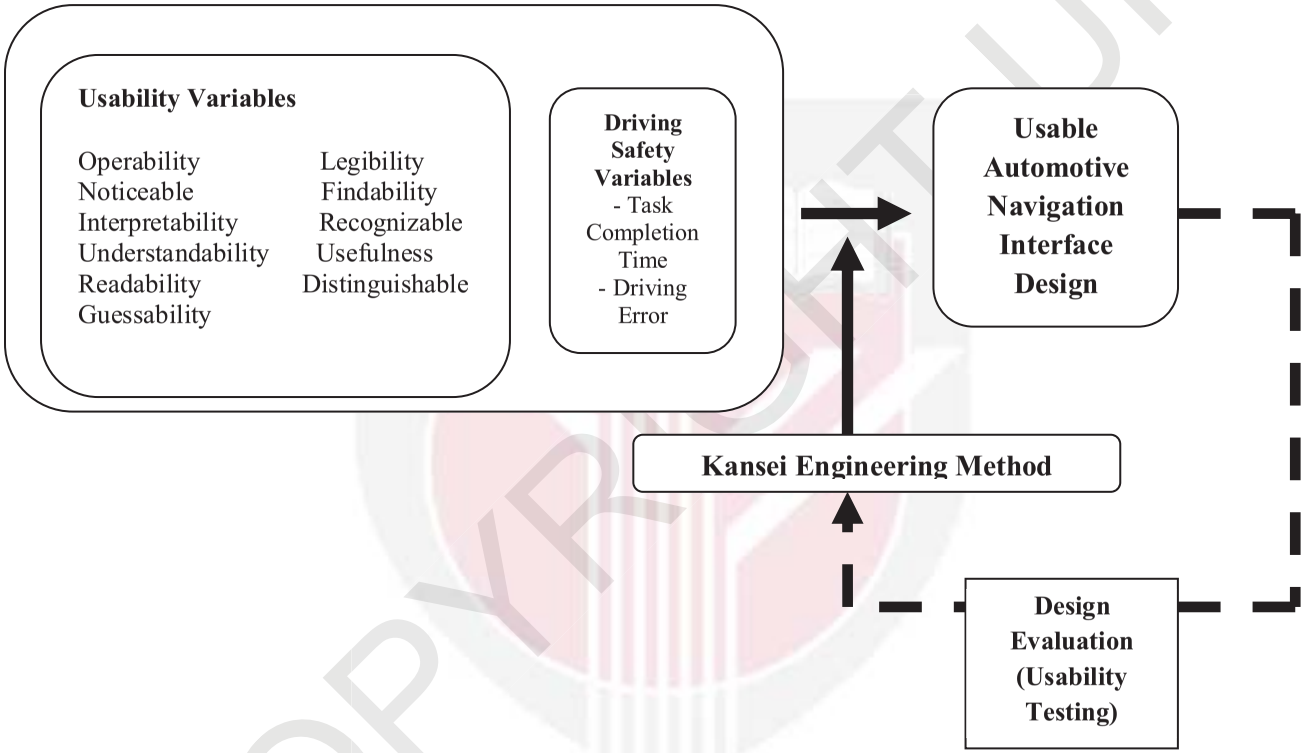

Figure 1.2 : Conceptual framework

A conceptual framework for describing the approach used to integrate safety and usability is shown in Figure 1.2. The concept of usability for automotive user interfaces was carefully defined from literature on the standards and guidelines related to the usability of automotive user interfaces. High levels of usability lead to better driving safety and vice versa. Poorly designed automotive interfaces may lead to driver distraction, which in turn can lead to accidents.

Driving safety variables are defined as task completion time and number of driving errors. All the usability variables from the current literature would then become the primary input in the development process of a usable automotive navigation interface prototype, using Kansei Engineering method.

The Kansei Engineering method was applied to suit the objective of this study i.e. to integrate safety and usability in the development of an automotive navigation interface prototype. Details of how the Kansei Engineering method was implemented were described in Chapter 3, section 3.3. In the evaluation process, the newly developed automotive navigation interface was tested using a driving simulator, where the Kansei survey, modified System Usability Scale (SUS), task completion time and number of errors were used to compare the newly developed GPS user interface design with the current design.

1.6 Terms and definitions

Table 1.2 lists some of the key concepts and terms which have a special meaning in this study.

Table 1.2: Conceptual definitions

Concept	Explanation
Automotive user interface	Refers to the area in the car interior (usually the center of dashboard) where the radio, climate control, navigation, Bluetooth and CD/DVD/MP3 player are located.
IVIS (In Vehicle Information System)	"Refers to specialized traffic information systems, cell phones, text messaging, email, vehicle diagnostics, and, in some situations, warning systems and emergency help systems." (Green et al., 1993)
Usability	''the effectiveness, efficiency, and satisfaction with which specified users can achieve goals in particular environments'' (ISO 9241-11, 1998)
Driver distraction	Specific type of inattention that occurs when drivers divert their attention away from the driving task to focus on another activity instead. (NHTSA Driver Distraction Guideline, 2012
Kansei Engineering	"Technology that unites Kansei (feelings and emotions) with the engineering discipline."
GPS	Global Positioning System
Automotive navigation interface	The graphical screen which comprises of icons and buttons of the navigation system
Regular drivers	Malaysians with driving ability who are not engaged in driving for the purpose of a paid occupation
Professional drivers	Malaysians who are engaged in a full-time job as drivers, driving passengers for a living.
Driving Safety	Optimal performance of the primary task of driving which is characterized as being free from driving errors

1.7 Thesis layout

The major focus of this thesis is on engineering usability and safety into the design of automotive navigation interface for Malaysians. Therefore, a user centered design approach of Kansei Engineering as well as content analysis was used to ascertain and engineer the safety and usability into the design of automotive navigation interface design. The newly developed design was then subjected to a usability evaluation. The layout of this thesis is presented below:

Chapter 1 provides the background of the problem as well as the objectives, scope and limitations of this study.

Chapter 2 provides a detailed discussion on the relevant theories and concepts related to automotive user interfaces, as well as the suitable design approaches.

Chapter 3 describes the methodology in detail for the study objectives. The methods for content analysis, Kansei Engineering and usability evaluation were described in detail.

Chapter 4 presents the findings and discussions related to the relevant design elements of an automotive navigation interface for Malaysians, results and analysis for the Kansei Engineering, as well as the findings from the usability evaluation.

Chapter 5 discusses the conclusion for each objectives of this study as well as the way forward for future research.

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