UNIVERSITI PUTRA MALAYSIA

INTEGRATION OF TRIZ, MORPHOLOGICAL CHART, AND PUGH MATRIX FOR REDESIGNING ERGONOMICS OF CAR INTERIOR FOR THE MOBILITY-IMPAIRED

SALAMI BAHARIAH BINTI SULIANO

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By

SALAMI BAHARIAH BINTI SULIANO

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

October 2021

To the memory of my late parents, Sufiah, and Suliano, may ALLAH s.w.t bless their soul. Without them, I won't go this far.
To my husband, Abdul Karim, for his love, time, effort, sacrifice, understanding, and the list goes on.
To my parents in-law, Mohd Daud, and Ku Fauziah, for their affection and steadfastness in prayer.
To my brilliant kids, Nurul Iman, Auni Athirah, and Muhammad Luqman.
To my sisters and brothers, for their help and support.

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

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Individuals with disabilities in Malaysia are among the most vulnerable of the minority group in the Malaysian population. According to the World Health Organization (WHO), 15% of the world's populations has some form of disability. According to *Jabatan Kebajikan Masyarakat Malaysia* (JKM), the number of registered disabled people is increasing, as recorded by their annual statistics. With a projected rise in the number, the number of referred groups that use the road also increases over time. Besides, they are the majority of those who have relied on private cars for their versatility. Adjustments and modifications in vehicle configuration are connected in some parts to the physical ailments frequently confronted by them. With incongruous design today in the market, disabled people faced difficulties to itinerant, as doing so contributed to the diminishing of physical and emotional impact on them. The objective of this research is to redesign an ergonomics interior of a car for the mobility-impaired using the Theory of Inventive Problem Solving (TRIZ), specifically function analysis, cause and effect analysis, and contradiction matrix. This redesign focuses on the driver's area of a compact car drove by upper limb disabled drivers, lower limb disabled drivers, or combined limb disabled drivers. Analysis from a set of questionnaires was conducted to list down the most sought-after needs of the mobility-impaired person for satisfaction of their ergonomics. It was then followed by a hybrid of TRIZ, Morphological charts, and Pugh Matrix to direct the solution and choices of design for the redesign. Redesigned parts initiated with a verification study of ergonomics impact towards the manikin. The results of the questionnaire have identified eight not-ergonomics parts in percentage scored by respondents handle door (53.3%), handle headliner (53.3%), door (53.3%), upholstery back (53.3%), upholstery bottom (53.3%), steering (53.3%), gear knob (56.7%), and pedals (53.3%). Accordingly, the aforementioned parts are subjected to TRIZ solution method, which results in the eight proposed Inventive Principles. At the end of the study, a model of an ergonomically redesigned car interior for mobility impaired people was developed to address mobility and exclusion issues, allowing them to improve their daily activities. A simulation in CATIA on design verification comparing current design and redesigned parts show virtuous scores of 1 and 2 for RULA and within guidelines range for Biomechanics Single Action Analysis. The post-questionnaire results show that product redesign has a positive impact on the listed part. Therefore, this research demonstrated the necessity of redesigning car interior and improving ergonomic features extensively, specifically for limb-disabled drivers.

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

INTEGRASI TRIZ, CARTA MORFOLOGI, DAN MATRIKS PUGH UNTUK MEREKA BENTUK SEMULA RUANG DALAMAN KERETA ERGONOMIK UNTUK GOLONGAN KELAINAN UPAYA

Oleh

SALAMI BAHARIAH BINTI SULIANO

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Individu kurang upaya di Malaysia adalah antara yang paling terdedah kepada kumpulan minoriti dalam populasi Malaysia. Menurut Pertubuhan Kesihatan Sedunia (WHO), 15% daripada populasi dunia mempunyai beberapa bentuk kecacatan. Menurut Jabatan Kebajikan Masyarakat Malaysia (JKM), jumlah OKU berdaftar semakin meningkat, seperti yang dicatatkan oleh statistik tahunan mereka. Dengan unjuran peningkatan dalam bilangan, bilangan kumpulan yang dirujuk yang menggunakan jalan itu juga meningkat dari semasa ke semasa. Selain itu, mereka adalah majoriti mereka yang bergantung pada kereta persendirian untuk fleksibiliti mereka. Pelarasan dan pengubahsuaian dalam konfigurasi kenderaan disambungkan di beberapa bahagian dengan penyakit fizikal yang sering dihadapi oleh mereka. Dengan reka bentuk yang tidak sesuai hari ini di pasaran, orang kurang upaya menghadapi kesukaran untuk mengembara, kerana berbuat demikian menyumbang kepada pengurangan kesan fizikal dan emosi terhadap mereka. Objektif penyelidikan ini adalah untuk mereka bentuk semula bahagian dalam kereta yang ergonomik untuk masalah mobiliti menggunakan Teori Penyelesaian Masalah Inventif (TRIZ), khususnya analisis fungsi, analisis sebab dan akibat, dan matriks percanggahan. Reka bentuk semula ini memfokuskan pada kawasan pemandu kereta kompak yang dipandu oleh pemandu kurang upaya anggota atas, pemandu kurang upaya anggota bawah atau pemandu cacat anggota gabungan. Analisis daripada satu set soal selidik telah dijalankan untuk menyenaraikan keperluan yang paling dicari oleh orang bermasalah mobiliti untuk kepuasan ergonomik mereka. Ia kemudian diikuti oleh gabungan TRIZ, carta Morfologi, dan Pugh Matrix untuk mengarahkan penyelesaian dan pilihan reka bentuk untuk reka bentuk semula. Bahagian yang direka bentuk semula dimulakan dengan kajian pengesahan kesan ergonomik terhadap manikin. Hasil soal selidik telah mengenal pasti lapan bahagian bukan ergonomik dalam peratusan markah oleh responden pemegang pintu (53.3%), pemegang kepala (53.3%), pintu (53.3%), upholsteri belakang (53.3%), upholsteri bahagian bawah

(53.3%), stereng (53.3%), tombol gear (56.7%) dan pedal (53.3%). Sehubungan itu, bahagian yang disebutkan di atas tertakluk kepada kaedah penyelesaian TRIZ, yang menghasilkan lapan Prinsip Inventif yang dicadangkan. Pada akhir kajian, model dalaman kereta yang direka bentuk semula secara ergonomik untuk orang yang mengalami masalah mobiliti telah dibangunkan untuk menangani isu mobiliti dan pengecualian, membolehkan mereka menambah baik aktiviti harian mereka. Simulasi dalam CATIA pada pengesahan reka bentuk yang membandingkan reka bentuk semasa dan bahagian reka bentuk semula menunjukkan skor yang baik iaitu 1 dan 2 untuk RULA dan dalam julat garis panduan untuk Analisis Tindakan Tunggal Biomekanik. Keputusan pasca soal selidik menunjukkan bahawa reka bentuk semula produk mempunyai kesan positif pada bahagian yang disenaraikan. Oleh itu, penyelidikan ini menunjukkan keperluan mereka bentuk semula dalaman kereta dan menambah baik ciri ergonomik secara meluas, khususnya untuk pemandu yang kurang upaya anggota badan.

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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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Date: 9 June 2022

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research and the writing of this thesis were done under our supervision;
- supervisory responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2015-2016) are adhered to.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AL	Action Limit
CATIA	Computer Aided Three-dimensional Interactive Application
CAD	Computer Aided Design
CL	Compression Limit
DHM	Digital Human Modelling
DOSM	Department of Statistics Malaysia
DOSW	Department of Social Welfare
EC	Engineering Contradiction
EDA	Ergonomics Design & Analysis
ES	Engineering System
IDC	Inclusive Design Cube
IEA	INTERNATIONAL ERGONOMICS ASSOCIATION
IF	Improving Factor
ITS	Intelligent Transport systems
JKEUPM	*Jawatankuasa Etika Universiti Untuk Penyelidikan Melibatkan Manusia*
LI	Lifting Index
MAIF	Maximum acceptable initial force
MASF	Maximum acceptable sustained force
MAW	Maximum Acceptable Weight
MI	Material Investigation
MPL	Maximum Permissible Limit
NHTSA	National Highway Traffic Safety Administration
NIOSH	National Institute for Occupational Safety and Health
PDS	Product Design Specification

PLPP	*Pusat Latihan Perindustrian dan Pemulihan*
PUSPAKOM	*Pusat Pemeriksaan Kenderaan Berkomputer*
RTD	Road Transport Department
RULA	Rapid Upper Limb Assessment
RWL	Recommended Weight Limit
SL	Shear Limits
TRIZ	Theory of Inventive Problem Solving
T2B	Top 2 Box
WF	Worsening Factor
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

This chapter presents the basis for a research idea on redesigning car interiors for mobility-impaired people. There is an absence of ergonomics elements in product adaptation and modification for disabled driver's cars. At the end of this chapter, the research problem statements, research objectives, and research scopes concerned in this evaluation study are clarified.

1.1 Research Background

Based on data from the Department of Statistics Malaysia (DOSM), Malaysia's population has reached 32.66 million (DOSM, 2021) an increase of 16.13% from 2015, as reported by Rosli et al. (2015) when the population was only 28.12 million. Figure 1. shows the projected population median age in 2010. The median age was 26.3 years and will rise to 38.3 years in 2040, representing a 12-year increase over 30 years. According to Rosli et al., as the population grows, so does the number of disabled people, with the number of disabled people in Malaysia (2015) estimated at 2.8 million, representing 10% of the population (Rosli et al., 2015). However, only 365,677 disabled people have registered with the Department of Social Welfare (DOSW) (DOSW, 2015).

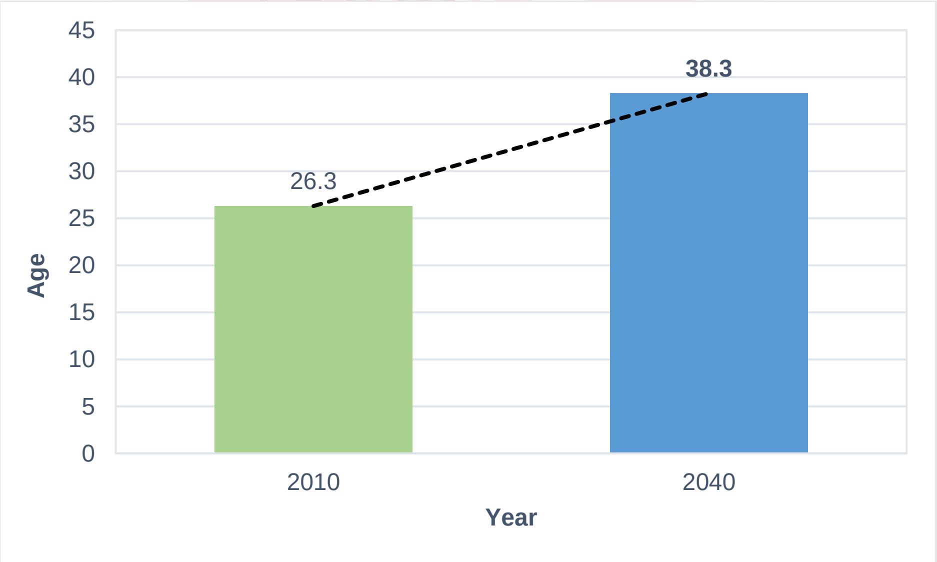

Figure 1.1: Malaysian Median Age Projection
(Source: DOSM, 2017)

Several factors are contributing to the increase of disabled people. According to Newell and Gregor (2002), the elderly is part of disabled people. The significant increase in the number of disabled people among the elderly is due to improved medical qualities (Newell & Gregor, 2002). Reduced birth rates and increased life expectancy have resulted in the projected numbers of older adults 65 years or above in today's society (Elton, 2012). However, the overall dysfunctionality of older people differs from that of young disabled people as older people have some additional minor impairments in sight, hearing, dexterity, and memory that appeared to be a major disabilities compared to the young disabled. With an increased number of aging groups indicates that the Malaysian population is starting to age, and this aging population process is known as a demographic transition (Ibrahim & Zainab, 2014).

The population of disabled people is growing (DOSW, 2016), and as a result, the population of disabled drivers is growing as well. Even though the government assists disabled people, it is hard to find a device that can facilitate their mobility. Driving is an important activity for disabled people to continue their activities and keep their independence optimized in tasks such as shopping, visiting doctors, and maintaining social reintegration (Patrick et al., 2012). Therefore, driving independence is critical in a disabled person's daily life.

The automotive industry is a symbol of humankind's technological marvel. Being one of the world's fastest-growing sectors, its dynamic growth phases are explained by criterions such as the nature of competition, product lifecycle, and consumer demand. Though, Nag et al. (2007) credence that today's global automotive industry is more concerned with consumer demands for styling, safety, and comfort, as well as a few other elements to achieve an effective outcome (Nag et al., 2007). Additionally, there are studies such as those by Mutoh (1988) and Sadler (2016) that show a continuing fascination with the automotive industry and its significant impact on the socio-economic life of mankind and that impact continues till now (Mutoh, 1988; Sadler, 2016).

Automotive requires a long lead time for design, development, and production planning. Hence, a redesigned product is a derivative work, with changes made to suit any new application (Shen & Smith, 2009) and as an alternative to improve production besides having a new design or a factory-customized vehicle. However, product optimization and efficiency are other areas that should be analyzed during the redesign process (Hill et al., 2007).

Presently, the quality of human life is constantly improving, and market demands are vastly different from those of the past. Everyday products that aid in maintaining independence at home, in public places, while traveling, and during leisure activities play an important role (Bieber, 2003). In line with the growing demands is constant development in vehicle design and its performance. Aided by technologies, vehicles are now equipped with many features such as a reverse camera, navigation aid, and intelligent parking assistance that assist and simplify the user's tasks while driving. Therefore, to be competitive in the modern industry, automobile companies must quickly release vehicles that meet rapidly changing market demands. Products often need to be equipped with more functions to satisfy customers' needs.

Notwithstanding, the automotive industry faces new challenges and economic limitations (Bhise, 2012), one such challenge is determining the needs of the inclusive group to produce an inclusive design. Therefore, using inclusive to identify needs or requirements will improve driving quality for both groups of people who have functional limitations and those who do not (Karali, 2015). Moreover, inclusive design is an important approach to ensure that the needs of users with various physical, cognitive, and sensory ability limitations are met (Persad et al., 2006).

Erroneous choice over a product such as a mismatch between user demands and user capabilities results in product exclusion (Simeon Keates & Clarkson, 2003). The blend of elements in everyday items, as stated by Persad et al. (2007), illustrates the link between capabilities against demand. Individual capabilities must therefore be greater than product demand for a product to be fully accessible unless the products are acknowledged to be inaccessible for specific functions. Accessibility refers to the user's ability to observe, understand and interact physically with the product (Keates & Clarkson, 2003). Table 1.1 indicates six typical demands of human capabilities: vision, hearing, cognition, locomotion, reach and stretch, and dexterity (Waller et al., 2007d).

By no means, all decisions that lead to the output solely based on product interaction capabilities can sufficiently cater to the exclusion group. Ergonomics is another applicable health and disease prevention tool (Zare et al., 2016). In some ways, it will maximize safety, efficiency, and comfort by designing for the operator's abilities (Woodcock, 2012).

Conclusively, not all of today's vehicles on the market can truly meet the requirement of all types of users, even if they claim their product will provide a positive experience. Therefore, whenever a new product is created, users of different groups and impairments should be considered to resolve issues such as legibility, usability, cognitive load, and ergonomics (Zitkus et al., 2012).

Table 1.1: Product Interaction Capabilities

Capability (Type)	Description
Vision (Sensory)	The ability to sense color and brightness of light to detect objects, discriminate between different surfaces, or the detail on a surface (Waller et al., 2007a).
Hearing (Sensory)	The ability to interpret sound vibrations. People can identify simple sounds such as beeps and tones and complex sounds such as speech and music against differing background noise (Waller et al., 2007b).
Cognition (Cognitive)	This refers to how a person understands and acts i.e. ability to process information, hold attention, store and retrieve memories, select appropriate responses and actions – language and social skills (Waller et al., 2007c).
Locomotion (Physical)	The ability to move around, bend down, climb steps, and shift the body between standing, sitting and kneeling (Waller et al., 2007e).
Reach & Stretch (Physical)	The ability to put one or both arms out in front of the body, above the head, or behind the back (Waller et al., 2007f).
Dexterity (Physical)	A physical/motor capability which refers to the ability to use one's hands, or the ability to manipulate objects with the hands (Waller et al., 2007f).

1.2 Problem Statement

Physical disability is a condition caused by illness or an injury that limits a person's ability to engage in physical activities. Therefore, this group of people tends to face violations and discrimination in their daily lives, besides major hindrances in accessing certain products and services (Kaklanis et al., 2013). Obstacles in areas such as mobility, transportation, and space lead to poor health besides physical and psychological stresses (Hwang et al., 2020). Numerous research has found that one of the factors causing health distraction is a low ergonomics value practiced (Frye, 2013; Kaklanis et al., 2013; Nicolle & Peters, 1999; Pheasant, 2003; Recovre, 2017; Zare et al., 2016). Kaklanis et al. (2013) also emphasized that ergonomics is one of the significant factors that should be considered by designers despite efforts to improve the product and services for disabled people (Kaklanis et al., 2013). Difficulties in using a product, extra effort as well as pain could be encountered when using a non-ergonomic product.

Sequel to the 2017 and 2018 pieces of research made by Dahuri had provided a better picture of the effects of modification and adaptation on the cars of independent licensed limb disabled drivers (Dahuri et al., 2017; Dahuri & Hussain, 2018). Recent research urges the importance of standard guidelines for adaptive aids, and modification made for disabled drivers has a major advantage on their safety.

The cost and complexity of accommodating disabled people can be substantial (Bayless & Davidson, 2019; Carroll et al., 2021). In general, the cost of retrofitting (or vehicle modification) can range from 4 to 5 digits. Only certain models of automobiles, for example, can have their floor lowered to accommodate wheelchair users. The vehicle must then be installed with equipment for specialist instrumentation or driving controls from a different vendor (Bayless & Davidson, 2019).

It's also difficult to accommodate assistive equipment (Hwang et al., 2020). The interface between mobility aids, such as wheelchairs, and the car, for example, might be difficult. Things can and will go wrong. Certain modifications that improve a vehicle's accessibility may also introduce new complications. The weight of wheelchairs and other assistive technologies, such as deployable ramps, for example, causes strain on the transmission, brakes, and other components of the vehicle (Bayless & Davidson, 2019).

Although factory-installed mobility solutions exist, their scope and functionality are restricted. In the Toyota Sienna, for example, a factory-installed power rotating lift-up Auto Access Seat is available. This seat rotates 90 degrees, then extends from the vehicle and descends to a convenient transfer height, allowing people without assistive devices such as wheelchairs to easily enter and exit (Bayless & Davidson, 2019).

The ability to make more flexible vehicle modifications is beneficial, but it comes at a cost (Berent et al., 2021). It is also expensive to iterate during the alteration procedure. Furthermore, getting the modification procedure right the first time is crucial, especially for individuals who purchase a new vehicle; they may be trapped with that vehicle for a long time, and repeating the process is expensive (Manary et al., 2016).

The Vehicle for Disabled Market is expected to grow at a compound annual growth rate of around 10-11.7% between 2020 and 2026 (MI, 2020; MSR, 2022). The increase in the population of disabled and elderly people, road accidents that cause disabilities, and government programs to empower these individuals with jobs and financial aid are the primary drivers that will drive market growth during the forecast period (MI, 2020). The demanding market shows the need for vehicles for disabled people has increased over the years. However, these factory-set cars are expensive, and the buy-sell process is time-consuming. These cars are also not a universal design or inclusion design type of car, which means when it is designed for the disabled, it can benefit everyone.

To produce a car with a universal design that can comply with the basics, including equitable the use of outcomes that must be useful and marketable to any group of disabled people to avoid segregation or stigmatization, and flexible use of outcomes that must accommodate a wide range of individual preferences and abilities (Ibrahim et al., 2019).

A relevant and easily adaptable technique is required to transform a personal in-market car to mean that it focused on existing solutions to make the proposed concept a reality to be used by the mobility-impaired group to ensure their traveling experience will be more user-friendly and ergonomics. With the motivation to include limbs disabled drivers, a study is expected to determine the preferred interior of the car that can improve features needed to meet the mobility of impaired individuals in most scenarios to benefit them in reducing cost, time, and long process. Figure 1.1 illustrates the previous research summary related to disabled-accessible vehicles. Therefore, it is significant to acknowledge that the ergonomic aspect is not an adequate consideration in overall product design that can serve the disabled.

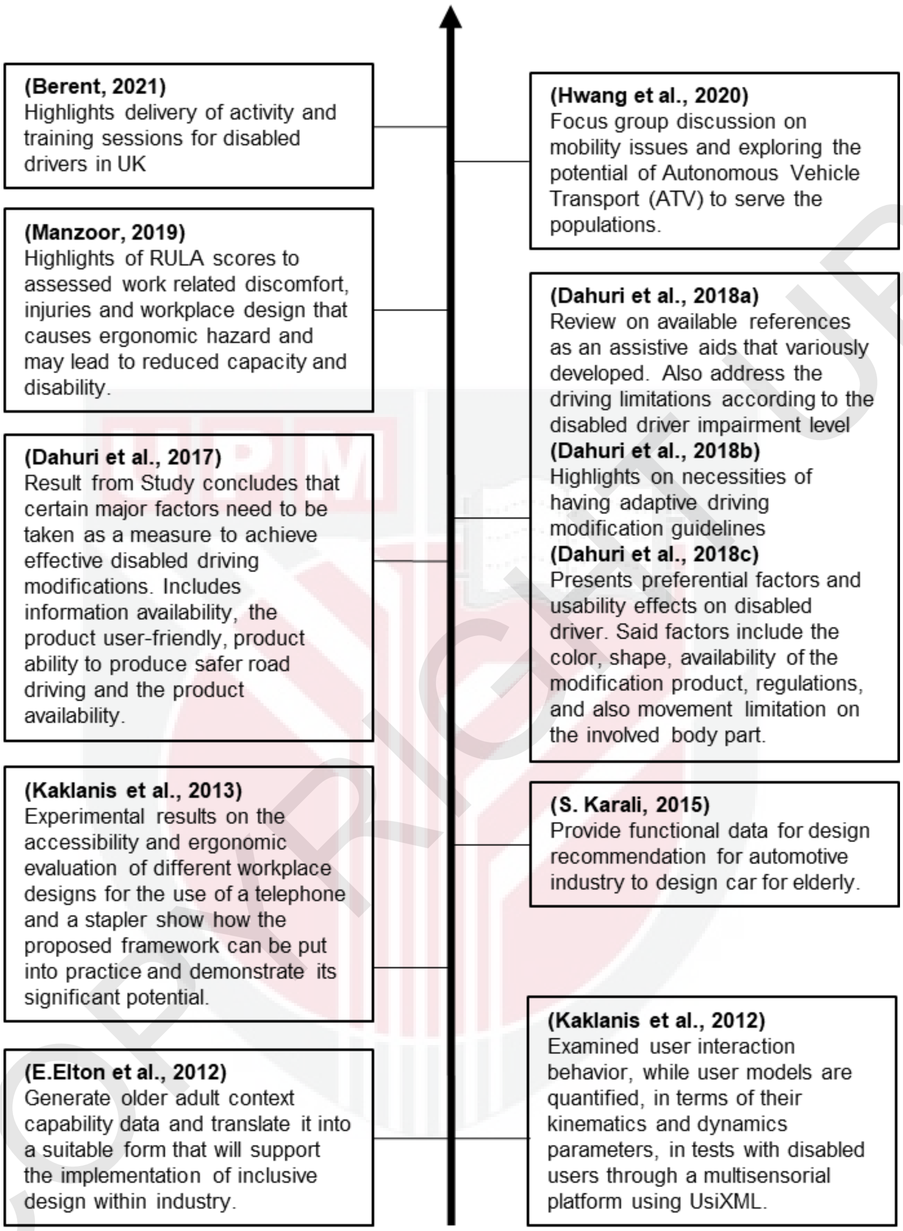

Figure 1.1: Related Research's Result Timeline

1.3 Research Questions

Referring to the previous problem statement, inquiries or questions were raised, which can be cross-referenced with further detailed parameters analysis. These questions form the fundamental core of the research. The research questions imposed on postures condition variety assessment are as follows.

i. What are the needs of a mobility-impaired person (limb disabled person)?
ii. How can we cater to those mentioned needs of mobility-impaired people?
iii. What is the best parameter to identify the ergonomic impact of ergonomics design in comparison to the current design?

1.4 Research Objectives

From the research questions above, the aims are focused on identifying the needs of limb disabled people, solving the problem, designing, performing simulation, and followed by verification and validation. This thesis has four research objectives, which are listed below:

i. To identify the needs of mobility-impaired groups related to the car interior.
ii. To model solution for car interior for mobility impaired using TRIZ.
iii. To develop an ergonomically featured model of car for the mobility impaired.
iv. To verify ergonomic car interior design for mobility impaired.

1.5 Research Scopes and Limitations

This thesis focused on the physically disabled people with lower limbs or upper limbs or combined limbs who regularly drive and are licensed. Also, this thesis is limited to the driver's area. The questionnaires covered users from the Klang Valley region only and were distributed to customers of Faresh Motor Sdn. Bhd. located in Kuala Lumpur, and the Industrial Training and Rehabilitation Centre (Pusat Latihan Perindustrian dan Pemulihan, PLPP) in Bangi. The simulation, testing, and verification were conducted on Perodua MyVi (AT) 2019.

Also, there are a few limitations bound to this research. Firstly, the questionnaire merely caters to upper, lower, and combined limbs disabled drivers. Secondly, TRIZ only suggests methods for solving problems. The best solution is only drawn from a hybrid conceptual design framework. Lastly, redesigned interior merely caters to upper, lower, and combined limb disabled drivers.

1.6 Significance of the Study

Car modification is one of the most important practices for limb disabled drivers before licensing. Therefore, the role of previous research on modifications and guidelines by the expert is vital. This thesis helps to identify the problem and needs of the mobility impaired. The findings of the literature review were used to create a comparative design of available adaptation and modification of car interiors for disabled drivers' references. Also, the outcomes of this thesis result in a model of redesigned car that is tailored to the needs of disabled people.

1.7 Thesis Layout

These thesis chapters are divided into five chapters, beginning with an introduction of the study and concluding with a recommendation for future work. Chapter 1 elaborates on the research origin, intentions, and the scopes considered for the questions derived from the problem statements found. The literature and studies cited in Chapter 2 discuss the literature survey, reviews, and comparative tables with various concepts, understanding, ideas, and different development related to studying the enrolment from the past to the present and which serves as the research method in developing the research methodology or design. In Chapter 3, the flow charts serve as an overview to present the layout of the thesis, providing a clear picture of the methodology. There are also descriptions of the study's subjects, the instruments used, the procedure of data collection, and the statistical treatment of the data. Chapter 4 defines the TRIZ method and its application as a proposed solution, as well as the conceptual design of respective parts. Along with simulations of the currently designed and rebuilt car, a newly redesigned car is verified. and an ergonomics comparison is also elaborated. The discussions were organized to address the research questions that were initially extracted. The thesis is then concluded with Chapter 5, which discusses the achievements of research objectives, results, and recommendations for future research interests.

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