IDENTIFICATION OF HAZARDOUS ROAD LOCATION BASED ON DESIGN CONSISTENCY AND ACCIDENT PREDICTION MODEL FEDERAL ROAD IN JOHOR

ZAFFAN FARHANA BINTI ZAINAL

A thesis submitted in
fulfilment of the requirement for the award of the
Degree of Master of Civil Engineering

Faculty of Civil and Environmental Engineering
Universiti Tun Hussein Onn Malaysia

JULY 2018

This thesis is dedicated with a great love to my dear parents Mr. Zainal bin Ibrahim and Mrs. Zainon binti Zakaria, who always supported me. I also dedicate it to the light of my life; my family who always supported me till I finish Master‟s Degree by Research. Finally, I will not forget my great friends for always being there for me especially Wan Zahidah binti Musa, Wan Mohamad Ikhwan Shafiq bin Wan Othman, Nurul Nadia binti Che Zakaria and Nur Muna binti Sallahudin. Their support is my strength until I finish my Master‟s Degree by Research.

ACKNOWLEDGEMENT

In the name of Allah, Alhamdulillah, and I am thankful to the almighty for granting me a good health, strength and peace throughout the research period in between difficult and delightful time to completing a master's degree thesis.

It is with a great pleasure that I hereby express my appreciation to everyone who has contributed, in one way or another and without your assistance; this work would have proved impossible.

I am highly thankful to my supervisors, Dr Joewono Prasetijo for his guidance during the whole research. I am also deeply grateful for all the assistance that was rendered to me by the Faculty of civil and environmental engineering, Universiti Tun Hussein Onn Malaysia.

Last but not least, I would like to thank my wonderful parents, Mr. Zainal bin Ibrahim and Mrs. Zainon binti Zakaria for their unconditional love and continue support throughout my journey. I would like to dedicate thanks to my dearest friends, Wan Zahidah binti Musa, for the enormous support, patient and faith for this research journey.

ABSTRACT

Every year road accident in Malaysia is kept rising, especially road accidents occur in between a collision with passenger cars, other motorcycles and single-motorcycle accidents. In early 2016, Johor has been mentioned as the highest ranking hazardous road accident especially federal roads. However, the problem road accident on hazardous road still unsolved even though others research has been done. This study using a new method design consistency and the accident prediction model to decreasing road accidents from occurring at hazardous road locations. The purpose of this study was to determine the relationship of accidents between motorcycles and cars on select segments Federal route 050 (Jalan Kluang – Ayer Itam – Batu Pahat) and Federal route 023 (Jalan Muar – Tangkak). These studies were related a geometry elements of access point, median, shoulder width, lane width and continuous speed of motorcycle and cars to determine value design consistency model (*IC*) and threshold. The data collections were GPS DG-200 to collect continuous speed data, the geometry data collection during the site visit and police data. The models were developed based on the new method of speed profiles, analysis to determine the value of the index integrated design consistency model (*IC*) between motorcycles and cars. The result showed similarities the value of design consistency model with hazardous locations. Hence, the developed accident prediction model was related road design consistency models and accident rates to evaluate the impact of design consistency with road safety. Therefore, based on results and analysis, some discussions of geometric elements based on design consistency result and relationship with road accident occurs between motorcycles and cars at hazardous road locations and some of recommended are provided such as improve widen shoulder for inadequate shoulder, increase enforcement for illegal parking and others.

ABSTRAK

Setiap tahun kemalangan jalan raya di Malaysia terus meningkat terutama kemalangan jalan raya berlaku di antara perlanggaran dengan kereta penumpang, motosikal lain dan kemalangan motosikal tunggal. Pada awal 2016, Johor telah disebut sebagai kemalangan jalan raya berbahaya tertinggi terutama jalan raya persekutuan. Bagaimanapun, kemalangan jalan raya di jalan berbahaya masih belum dapat diselesaikan walaupun penyelidikan lain telah dilakukan. Kajian ini menggunakan model konsistensi reka bentuk dan model ramalan kemalangan baru untuk mengurangkan kemalangan jalan raya daripada berlaku di lokasi jalan berbahaya. Tujuan kajian ini adalah untuk menentukan hubungan kemalangan antara motosikal dan kereta di segmen terpilih laluan Persekutuan 050 (Jalan Kluang - Ayer Itam - Batu Pahat) dan laluan Persekutuan 023 (Jalan Muar - Tangkak). Kajian ini berkaitan dengan elemen geometri jalur akses, median, lebar bahu, lorong lebar dan kelajuan motosikal dan kereta berterusan untuk menentukan model konsistensi reka bentuk nilai (*IC*) dan ambang. Pengumpulan data yang diperlukan adalah GPS DG-200 untuk mengumpulkan data laju berterusan, pengumpulan data geometri semasa lawatan tapak dan data polis. Model-model ini dibangunkan berdasarkan analisis profil laju baru untuk menentukan nilai indeks model konsistensi reka bentuk indeks (*IC*) antara motosikal dan kereta. Hasilnya menunjukkan kesamaan nilai model konsistensi reka bentuk dengan lokasi berbahaya. Oleh itu, model ramalan kemalangan yang dibangunkan adalah berkaitan dengan model konsisten reka bentuk jalan raya dan kadar kemalangan untuk menilai kesan ketekalan reka bentuk dengan keselamatan jalan raya. Oleh itu berdasarkan hasil dan analisis, beberapa perbincangan mengenai unsur-unsur geometri berdasarkan hasil konsistensi reka bentuk dan hubungan dengan kemalangan jalan berlaku antara motosikal dan kereta di lokasi jalan berbahaya dan beberapa cadangan disediakan seperti meningkatkan bahu lebar untuk bahu yang tidak mencukupi, meningkatkan penguatkuasaan untuk tempat letak kereta haram dan lain-lain.

TABLE OF CONTENTS

TITLE		**i**
DECLARATION		**ii**
DEDICATION		**iii**
ACKNOWLEDGEMENT		**iv**
ABSTRACT		**v**
ABSTRAK		**vi**
TABLE OF CONTENTS		**vii**
LIST OF TABLES		**x**
LIST OF FIGURES		**xiv**
LIST OF SYMBOLS		**xvi**
LIST OF ABBREVIATIONS		**xviii**
LIST OF APPENDICES		**xix**
CHAPTER 1 INTRODUCTION		**1**
1.1	Background of research	1
1.2	Problem statement	3
1.3	Aim and objectives	4
1.4	Scope of research	5
1.5	Significance of research	5
1.6	Thesis structure	6
CHAPTER 2 LITERATURE REVIEW		**7**
2.1	Introduction	7
2.2	Hazard identification	7
2.3	Road accident	8
2.3.1	Road accident between motorcycle and cars	11
2.4	Characteristics of road accident	14
2.4.1	Geometric characteristics	14

2.4.2	Speed characteristics	15
2.4.3	Environmental characteristics	16
2.5	Data collection: global positioning system	16
2.6	Operating speed (85th Percentile)	17
2.7	Developed speed profile	21
2.8	Design consistency model	24
2.9	Poisson regression model	27
2.10	Summary	30
CHAPTER 3 METHODOLOGY		**31**
3.1	Introduction	31
3.2	Design of study	31
3.3	Data description	33
3.3.1	Location and characteristics	33
3.3.2	Data collection	34
3.3.3	Primary data	35
3.4	Data analysis	36
3.4.1	Speed characteristics	36
3.4.2	Developed operating speed model	37
3.4.3	Developed design consistency model	38
3.4.4	Developed integrated design consistency model	39
3.4.5	Road accident prediction model	40
3.4.6	Model validation methods	41
3.5	Summary	42
CHAPTER 4 RESULT AND DISCUSSIONS		**43**
4.1	Introduction	43
4.2	Operating speed model	44
4.3	Validation of models	47
4.4	Developed integrated design consistency model	49
4.4.1	Developed integrated design consistency model FT 050 (KM1 – KM5)	49

4.4.2 Developed integrated design consistency model FT 050 (KM6 – KM10) 56
4.4.3 Developed integrated design consistency model FT 050 (KM21 – KM25) 63
4.4.4 Developed integrated design consistency model FT 023 (KM16 – KM20) 70
4.4.5 Developed integrated design consistency model FT 023 (KM26 – KM30) 76
4.5 Road accident prediction model 82
4.6 Discussions 86
4.7 Summary 92

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS 93
5.1 Conclusions 93
5.2 Recommendation 95

REFERENCES 97
PUBLICATIONS 107
APPENDICES 108

LIST OF TABLES

2.1	Road safety and traffic data (OECD, 2015)	9
2.2	Type of road accident (PDRM, 2014)	10
2.3	Location road accidents occur frequently on Johor Federal Roads in 2010 to 2013 (PDRM, 2014)	10
2.4	Road fatalities by road user (OECD, 2015)	12
2.5	Type of vehicle involved in a road traffic accident based on statistics Johor Federal roads in 2010 to 2013 (PDRM, 2014)	12
2.6	Summary previous developed operating speed models for rural highway curves (Abbas *et al.,* 2012)	20
2.7	Design-consistency quality (Mattar-Habib *et al.,* 2008)	26
3.1	Explanatory variables	37
3.2	Thresholds for determination of design-consistency quality	40
4.1	Analysis of variance of motorcycles	44
4.2	Analysis of variance of cars	45
4.3	Regression coefficient of motorcycles	45
4.4	Regression coefficient of cars	46
4.5	Results of F-test for test on speed variance between observed speed and predicted speed for motorcycles	48
4.6	Results of F-test for test on speed variance between observed speed and predicted speed for cars	48
4.7	Geometry parameter and speed of motorcycles FT 050 (KM1 – KM5)	50
4.8	Geometry parameter and speed of cars FT 050 (KM1 – KM5)	50
4.9	Design consistency model of motorcycles FT 050 per km (KM1 – KM5)	53
4.10	Design consistency model of cars FT 050 per km (KM1 – KM5)	53

4.11	Design consistency model FT 050 along segment (KM1 – KM5)	53
4.12	Integrated design consistency model FT 050 per km (KM1 – KM5)	54
4.13	Integrated design consistency model FT 050 along segment (KM1-KM5)	54
4.14	Geometry parameter and speed of motorcycles FT 050 (KM6 – KM10)	56
4.15	Geometry parameter and speed of cars FT 050 (KM6 – KM10)	57
4.16	Design consistency model of motorcycles FT 050 per km (KM6 –KM10)	60
4.17	Design consistency model of cars FT 050 per km (KM6 – KM10)	60
4.18	Design consistency model FT 050 along segment (KM6 – KM10)	60
4.19	Integrated design consistency model FT 050 per km (KM6 – KM10)	61
4.20	Integrated design consistency model FT 050 along segment (KM6 – KM10)	61
4.21	Geometry parameter and speed of motorcycles FT 050 (KM21 – KM25)	63
4.22	Geometry parameter and speed of cars FT 050 (KM21 – KM25)	64
4.23	Design consistency model of motorcycles FT 050 per km (KM21 – KM25)	67
4.24	Design consistency model of cars FT 050 per km (KM21 – KM25)	67
4.25	Design consistency model FT 050 along segment (KM21 – KM25)	67
4.26	Integrated design consistency model FT 050 per km (KM21 – KM25)	68
4.27	Integrated design consistency model FT 050 along segment (KM21 – KM25)	68

4.28	Geometry parameter and speed of motorcycles FT 023 (KM16 – KM20)	71
4.29	Geometry parameter and speed of cars FT 023 (KM16 – KM20)	71
4.30	Design consistency model of motorcycles FT 023 per km (KM16 – KM20)	74
4.31	Design consistency model of cars FT 023 per km (KM16 - KM20)	74
4.32	Design consistency model FT 023 along segment (KM16 - KM20)	74
4.33	Integrated design consistency model FT 023 per km (KM16 – KM20)	75
4.34	Integrated design consistency model FT 023 along segment (KM16 – KM20)	75
4.35	Geometry parameter and speed of motorcycles FT 023 (KM26 – KM30)	77
4.36	Geometry parameter and speed of cars FT 023 (KM26 – KM30)	77
4.37	Design consistency model of motorcycles FT 023 per km (KM26 – KM30)	80
4.38	Design consistency model of cars FT 023 per km (KM26 - KM30)	80
4.39	Design consistency model FT 023 along segment (KM26 - KM30)	80
4.40	Integrated design consistency model FT 023 per km (KM26 – KM30)	81
4.41	Integrated design consistency model FT 023 along segment (KM26 – KM30)	81
4.42	Parameter estimates of Poisson regression model in road accidents at FT 050 (KM1 – KM5, KM6 – KM10, KM21 – KM25) from 2010 to 2014	83
4.43	Goodness of fit test FT 050 (KM1 – KM5, KM6 – KM10, KM21 – KM25) of the Poisson Regression	84
4.44	Parameter estimates of Poisson regression model in road	

accidents at FT 023 (KM16 – KM 20, KM26 – KM30) from 2010 to 2014 85

4.45 Goodness of fit test FT 023 (KM16 – KM 20, KM26 – KM30) of the Poisson Regression 86

LIST OF FIGURES

2.1	Index Road Accident in Malaysia, 2004 – 2014 (JKJR, 2015)	10
2.2	Fatality Distribution by Mode of Transport (Manan & Vàrhelyi, 2012)	13
2.3	Motorcycle Fatalities by Collision with Vehicle Type	13
2.4	Road fatalities by Road User Group in Year 2014 (OECD, 2015)	14
2.5	Speed Profile Analysis (Castro *et al.,* 2008)	22
2.6	Speed Profile (Polus & Mattar-Habib, 2004)	23
2.7	Parameters Considered for Estimating Ra Index (Echaveguren, 2012)	27
2.8	Speed Profile, Average Speed and Areas Bounded	27
3.1	Design of Methodology.	32
3.2	Federal Route 50 (FT 050), Jalan Kluang – Ayer Itam – Batu Pahat (Google Map, 2017)	34
3.3	Federal Route 23 (FT 023), Jalan Muar – Tangkak (Google Map, 2017)	34
3.4	GPS DG – 200.	35
3.5(a)	Conditions Where GPS is placed in the Moving Cars	36
3.5(b)	Conditions Where GPS is placed in the Moving Motorcycle	36
4.1	Observed Speed vs. Predicted Speed of Motorcycles	47
4.2	Observed Speed vs. Predicted Speed of Cars	48
4.3	Continuous Speed Profile of Motorcycles FT 050 (KM1 – KM5)	51
4.4	Continuous Speed Profile of Cars FT 050 (KM1 – KM5)	51
4.5	Continuous Speed Profile between Motorcycles and Cars FT 050 (KM 1 – KM5)	52
4.6	Continuous Speed Profile of Motorcycles FT 050	

	(KM6 – KM10)	58
4.7	Continuous Speed Profile of Cars FT 050 (KM6 – KM10)	58
4.8	Continuous Speed Profile between Motorcycles and Cars FT 050 (KM6 – KM10)	59
4.9	Continuous Speed Profile of Motorcycles FT 050 (KM21 – KM 25)	65
4.10	Continuous Speed Profile of Cars FT 050 (KM21 – KM25)	65
4.11	Continuous Speed Profile between Motorcycles and Cars FT 050 (KM21 – KM25)	66
4.12	Continuous Speed Profile of Motorcycles FT 023 (KM16 – KM20)	72
4.13	Continuous Speed Profile of Cars FT 023 (KM16 – KM20)	72
4.14	Continuous Speed Profile between Motorcycles and Cars FT 023 (KM16 – KM20)	73
4.15	Continuous Speed Profile of Motorcycles FT 023 (KM26 – KM30)	78
4.16	Continuous Speed Profile of Cars FT 023 (KM26 – KM30)	78
4.17	Continuous speed profile between motorcycles and cars FT 023 (KM26 – KM30)	79

LIST OF SYMBOLS

R^2	-	R - squared
R^2 adj	-	R - squared adjusted
V_{85}	-	Operating Speed Model/85^{th} percentile speed
CCR	-	Curvature Change Rate
R	-	Radius of Curve
LW	-	Lane Width
SW	-	Shoulder Width
AADT	-	Average Annual Daily Traffic
L_C	-	Length of Curve
L_T	-	Length of Tangent
V_{85T}	-	Operating Speed Model of Tangent
V_{85MC}	-	Operating Speed Model of Curve
m	-	Metre
km/h	-	Kilometre per Hour
ft	-	Foot
mph	-	Miler per Hour
R_a	-	Relative Area Measure Consistency
V_{avg}	-	Average Weighted (by length) Operating Speed along Highway
A_{CT}	-	Normalized Bounded Area between the Speed Profiles Two Types of Vehicles
IC	-	Integrated Consistency of a Highway Segment
C	-	Design consistency quality
m/sec	-	Meter per Second
km	-	Kilometre
E(Y)	-	Mean
var(Y)	-	Variance
am	-	Morning Time

pm	-	Evening Time
KM	-	Kilometre Post
A_1	-	Speed of Vehicle
L	-	Length Tangent/Curve
AP	-	Access Point
Q	-	Median
t		Tangent
c		Curve
C	-	Basic Consistency of a Highway Segment
L	-	Entire Segment Length
m^2/sec	-	Metre square per Second
V_j	-	Operating Speed along the j^{th} Geometric Element (tangent/curve)
n	-	Number of Geometric Elements along a Segment
V_i	-	Operating Speed
Z	-	Road Accident Prediction
AIC	-	Akaike"s Information Criterion
BIC	-	Bayesian Information Criterion
y	-	The Quality of the Fit between the Observed Values
σ	-	Standard Deviation of Operating Speed
e	-	Exponent
μ	-	The Expected or Mean Number of Counts (Road Accidents) per period
$\sum a_i$	-	Sum of i Areas Bounded Between the Speed Profile and the Average Operating Speed
μ	-	The Predicted Value
x_i	-	The Vector of The Explanatory or Independent Variables
β	-	The Vector of Unknown Regression Parameters
y_{ij}	-	Dependent Random Variables

LIST OF ABBREVIATIONS

ACAD	-	AutoCAD Software
APW	-	Accident Point Weightage
ASEAN	-	Association of Southeast Asian Nations
DG-200	-	Global Positioning System DG-200
FT 050	-	Federal Route 50
FT 023	-	Federal Route 23
GPS	-	Global Positioning System
HPU	-	Highway Planning Unit
IPK	-	Johor Bharu Police Headquarters
JKJR	-	Road Safety Department
JKR/PWD	-	Malaysian Public Works Department
MIROS	-	Malaysian Institute of Road Safety Research
OECD	-	The Organisation for Economic Co-operation and Development
PDRM/RMP	-	Royal Malaysian Police
R	-	R Statistical Software
WHO	-	World Health Organization

LIST OF APPENDICES

APPENDIX	TITTLE	PAGE
A	GPS data of Cars and Motorcycles	108
B	Regression Analysis of Cars and Motorcycle	115
C	R Analysis of FT 050 and FT 023	117
D	Road Accidents FT 050 and FT 023	121
E	Ranking Accident Point Weightage FT 050 and FT 023	123
F	Statistik Kemalangan Jalan Raya Jalan Persekutuan di Negeri Johor Tahun 2010 Hingga 2013	125

CHAPTER 1

INTRODUCTION

1.1 Background of research

In the middle of the ASEAN, Malaysia has the highest road accident risk (per 100,000 populations) and one of the developing countries that facing high road accident in Asia and more than 50% of the road accident fatalities involved motorcyclists. In additional, the West Coast Area of Malaysia is the highest motorcycle accidents due to the high number of registered motorcycles and population. From 1990 to 2008, an entire of motorcycle billion kilometres travelled in Malaysia therefore increased motorcycle also accidents increased as well (Manan *et al.,* 2012). Recently, Malaysia economy is successful, the number of road users increased sharply in the last past years and the amount of traffic accidents that were recorded in Malaysia are rising about 300 00 accidents reported and 1% of fatal accidents for every year and traffic accident has been increasing over the last three decades with an average pace of 9.7% per annum (Mustafa, 2005). Generally, one million people are killed, three millions are disabled for life and thirty millions are severely injured in a road accident as stated by WHO for every year. If this trend continues road traffic accident is will be predicted to be the third important to contribute to the global burden of disease and injury by 2020 and its relevant issues in today‟s society (WHO, 2004).

The large volumes of traffics on the road, accidents can occur by involving collision with passenger cars, collisions with other motorcycles and single-motorcycle accidents. The increase in motorization led to a consequent increase in the number of road traffic accidents (Sohadi, 2005). Based on provisional data by the Royal Malaysian Police, there were 6674 road deaths in 2014, and its decrease about

3.5% compared to 2013. But in 2013, motorcyclist rides represented 62% of all fatalities meanwhile car drivers and passengers represented 20% of fatalities (OECD, 2015) and motorcycles represent more than half the total vehicle population and it contribute more than 47% of the casualties based on deaths, serious and slight injuries in traffic accidents which recorded 48%, 47.4% and 47.7% for the year 2006, 2007 and 2008 (Yuen *et al.,* 2014). Riding a motorcycle is 17 times more dangerous than driving a passenger car and also the motorcyclist will be in front of higher risk of injury or fatality because the level of exposure to injury is higher if compared to other vehicle such as a passenger car in accidents (Sohadi *et al.,* 1995). The potential for exposure in a road accident is highest among the use of a motorcycle because it directly exposed and come in direct contact with the impacting vehicles or obstacle during a collision and resulting in severe injuries and fatal (Rahim *et al.,* 2010). Based on previous studies, accidents occur where any car driver or motorcyclist was not injured, but the either passengers or the other vehicle around 97% of motorcyclist were injured or killed in these accidents compared with 50.5% of car drivers. It also stated that at higher speed motorcycles and car collision than car and car collisions motorcyclist involved were 95.4% likely to be injured while car drivers were 0.9% likely to be injured (Huang & Preston, 2004).

Accidents occur of a combination between 4 elements; the driver, the road, the vehicle and the environment. Faulty vehicles, uneven roads, careless/reckless driving, speeding, drunk driving, inadequate sleep, alcohol and many more are the causes of road accident and also because the road condition itself. The accident can be occurs when lack of design consistency on the road which most drivers make fewer errors in the surrounding area of geometric characteristics especially in hazardous road location. Design consistency is the relationship between the geometric characteristics of a highway and the conditions that the driver expects when drive. When the design is consistent with the driver expects, the highway is also consistent and the worse the consistency, the more likely it is that drivers will be anxious and an accident will happen (Castro *et al.,* 2008). The point design consistency in establishing, operating speed (85^{th} percentile operating speed) is to know the relationship between the operating speed and the factor of geometric design on the two lane highways. The criteria to evaluate design consistency are based on operating speed evaluation of the 85th percentile speed of vehicles, and obtained by using operating speed prediction models (Gibreel *et al.,* 1999). Some researchers

have extended the concept by using continuous speed profiles through the normalized area bounded of speed to determine the speed difference along a road segment and determining a consistency value for the entire road segment (Hassan, 2004; Polus & Mattar-Habib, 2004; Mattar-Habib *et al.,* 2008).

Motorcyclist and car drivers tend to have a higher fatality per distance travelled; therefore this study develops the potential relationship between design consistency which is represented by continuous speed profiles and the occurrence of motorcycles and car accident that results in the identification of the potential locations of accidents along the selected Johor Federal roads. By estimating the 85th operating speed along the road, it produces continuous speed profiles of motorcycles and cars. By using the Poisson model as an accident prediction model to predict accident based on geometry characteristics and integrated design consistency (*IC*). The models are the relationship between design consistencies and expected number of accidents along the road over the years. The findings in the identification of hazardous location for motorcycles and cars are becoming the effective countermeasures to reduce accident frequency and severity of motorcyclist and drivers, in term of road design and traffic behaviour.

1.2 Problem statement

Road traffic becomes more complicated to control due to the continuous increase of traffic on the road, therefore the number of road accidents increases based on this problem. According to the Malaysian Institute of Road Safety Research, in year 2015, there were 26,301,952 registered vehicles and the statistics of road accidents are reported an increase for the time of 2014 (476,196 cases) until 2015 (489,606 cases). On the other hand, the number of injuries in road accident reported showed a decrease from 13,030 (2014) to 11,552 (2015), but the number of death in road accident was reported 6,674 cases in 2014 and 6,706 cases in 2015 (MIROS, 2017).

Alongside road accident increase nowadays, an unresolved issue is about road accident at hazardous location are causing distress to road users. The hazardous road locations are usually based on accident data and as well the increase in the number of vehicles. On the other hand, the accident data information may not explain as the factors that cause an accident occur at that location. Therefore, the actual road environments problems of road location are considered essential as a road safety

indicator in to overcome the accident occur on that road again (Razelan *et al.,* 2014). Road hazard can be physical defects in the highway, such as potholes, intersection, including driveways, curves or bends in the road, the position or movement of other road users, lack of appropriate road markings, improperly graded curves and uneven shoulders, changes in weather and road conditions. Previous study acknowledged, identification of hazardous road location has a higher expected number of accidents compared with other similar location, as a result of local risk factors present at the location or hazardous road location means the process of plotting accident locations on the road maps as a black spot. For example, the accidents that occur based on adverse road design should have a greater influence than impaired driving (Hussien & Eissa, 2016). Poor road design, maintenance, or defects can cause roadway accidents and can be termed of hazards on the road. For example, Federal Route 85 at Simpang Pulai – Kuala Berang highway, Highland roads is exposed to hazard when drivers tend to speed or at night the visibility is reduced. Cameron Highlands from Simpang Pulai in 2010, a bus lost control on the road leading to hit a divider and killing most 26 people. This indicates that there is no clear warning signboard in that area and have a high risk for accidents (Susan, 2014).

To overcome the problem road accident at the hazardous road location in Malaysia, this study using design consistency and accident prediction model to overcome this problem.

1.3 Aim and objectives

The aim of the research was to identify location with high risk by using a new method; design consistency and accident prediction model to decrease problems in identifying the hazardous road locations at Johor Federal roads.

The objective of the research is based on this;

i. To determine speed characteristics of each type of vehicle (motorcycles and cars) based on a road geometric design at FT 050 and FT 023.
ii. To determine the value of the index the integrated road design consistency (IC) of motorcycles and cars at FT 050 and FT 023.
iii. To develop an accident prediction model of potential road accident locations with, relating to accident and road design consistency at FT 050 and FT 023.

1.4 Scope of research

The scopes of this study are included; determined the location by using ranking by accident point system based on weighted adopted by the Highway Planning Unit (HPU) and ranking top highest accident based on police data. Federal Route 50 (FT 050) and Federal Route 23 (FT 023) are being studied and the selected road segments per 5km at Johor Federal roads.

By using Global Positioning System DG-200, speed data are collected through along a selected segment. The vehicle data studied is cars and motorcycles. Other data are collected from authorities; Malaysia Royal Police Department data (PDRM), Public Works Department (JKR) data and Highway Planning Unit and field study for geometry data.

The limitation of information about accident based on the road segments FT 050 and FT 023 are fatal, serious injury and slight injury. The geometric elements used access points, shoulder width, lane width, medians and lengths of road (tangent and curve).

1.5 Significance of research

A road hazard can be terminated any source of danger or near the road that could lead to accidents. For example the vehicles are merging into your lane or slippery road surface after rain. Thus, several past studies in Malaysia have conducted about the trend and factors that cause road accident, especially hazardous road locations of Johor Federal roads by using various accident analysis techniques. Some techniques have been used are black spot identification method, Empirical Bayesian Approach, Artificial Neural Networks and Genetic Algorithm Models and others. In this study, by using a new accident analysis method based on design consistency and accident prediction model in term of improving to reduce the causes of the accident at hazardous road locations. Furthermore, no further research that based on the new techniques on speed profile analysis by developed from 85^{th} percentile speed on a rural highway in Malaysia to estimate design consistency along the road and developed accident prediction models by related the relationship between design consistency and accident probability in term of road safety. Therefore, new methods

are being studied to reduce accident statistics on existing hazardous road locations on the Federal Road.

1.6 Thesis structure

The thesis structure consists of five chapters. Chapter one represents introduction. This chapter explains the backgrounds of study to understand road accident information that occur in Malaysia, especially motorcycles and cars, and the problem, why hazardous road location can cause road accidents frequent, aim and objective, scope of the study, significant of study and the structure of the thesis.

Chapter two describes a common literature review on the meaning of the hazard, road accident, characteristic of road accidents, GPS technology and parameter developed accident prediction model. It provides information about theories, model and techniques used in this research. Chapter three explains the methodology applied for analysis. It explains the methodology to develop the models relating design consistency with safety and includes the detail how the research was conducted, the information of data and processing analysis of data.

Chapter four are details about result, analysis and discussions. This chapter represents the results obtained from the research and shows the validation and modelling results and analysis with a detailed discussion. Chapter 5 described the final conclusion about these findings and gives some recommendation based on research and future. Lastly, the references and appendix using in this study are included at the end of this thesis.

REFERENCES

Abbas, S. K. S., Adnan, M. A., & Endut, I. R. (2011). Exploration of 85th percentile operating speed model on horizontal curve: a case study for two-lane rural highways. *Procedia-Social and behavioral sciences*, *16*, pp. 352-363.

Abbas, S. K. S., Adnan, M. A., Endut, I. R. (2012). An investigation of the 85th percentile operating speed models on horizontal and vertical alignments for two-lane rural highways: A case study. *Journal – The Institution of Engineers Malaysia, 73(1).*

Abdulhafedh, A. (2017). Road crash prediction models: different statistical modeling approaches. *Journal of transportation technologies*, *7*(*2*), pp. 190.

Abojaradeh, M. (2013). Traffic Accidents Prediction Models to Improve Traffic Safety in Greater Amman Area. *Civil and Environmental Research, 3(2).*

Ahmed, I. (2013). Road infrastructure and road safety. *Transport and Communications Bulletin for Asia and the Pacific*, *83*, pp. 19-25.

Alrefaie, M. T. (2014). Road speed profile: from GPS traces to real-time traffic speed. *Proc. of the 15th ACM international symposium on Mobile ad hoc networking and computing*. Philadelphia, Pennsylvania, USA. pp.407-408.

Andersen, C. S., Olesen, A. V., & Bolet, L. (2013). Influence of road characteristics on accident density on secondary rural two-lane roads in Denmark. *Sustainable and safe road design from a human behaviour point of view-Challenges for interdisciplinary work in road safety*.

Andersen, C. S., Reinau, K. H., & Agerholm, N. (2016). The relationship between road characteristics and speed collected from floating car data. *Proc. of the 17th International Conference Road Safety On Five Continents.* Rio de Janeiro, Brazil: Linköping: Statens väg- och transportforskningsinstitut. pp. 10.

Aworemi, J. R., Abdul-Azeez, I. A., & Olabode, S. O. (2010). Analytical study of the causal factors of road traffic crashes in southwestern Nigeria. *Educational research*, *1*(*4*), pp. 118-124.

Baguley, C. J. (1995). Interim Guide on Identifying, Prioritising and Treating Hazardous Locations on Roads in Malaysia. *Public Works Department, Malaysia*.

Baharudin. N., (2016), BH Online. Achieved in December 15, 2016, from http://www.bharian.com.my/node/224137

Barbosa, H. M., Tight, M. R., & May, A. D. (2000). A model of speed profiles for traffic calmed roads. *Transportation Research Part A: Policy and Practice*, *34*(*2*), pp. 103-123.

Boonsiripant, S., Hunter, M., Guensler, R., Rodgers, M., & Wu, S. K. (2007). Speed characteristics and safety on low speed urban midblock sections based on gps-equipped vehicle data. In *Road Safety on Four Continents: 14th International Conference*.

Cafiso, S., & Cerni, G. (2012). New approach to defining continuous speed profile models for two-lane rural roads. *Transportation Research Record: Journal of the Transportation Research Board*, *2309*(*1*), pp. 157-167.

Cafiso, S., Di Graziano, A., & La Cava, G. (2005). Actual driving data analysis for design consistency evaluation. *Transportation Research Record: Journal of the Transportation Research Board*, *1912*, pp. 19-30.

Cardoso, J. L. T., De Macedo, A. L., Kanellaidis, G., Flouda, A., Dimitropoulos, I., Peltola, H., Ranta, S., & Dupre, G. (1998). Improvements of models on the relations between speed and road characteristics. *Task 5.3. SAFESTAR. Laboratories Nacional De Engenharia Civil.*

Cardoso, J. L. T., Kabbach-Junior, F. I., & Suzuki, C. Y. (2010). Analysis of Speed Prediction for Design Consistency of Two-Lane Rural Highways. In *4th International Symposium on Highway Geometric Design*.

Castro, M., Iglesias, L., Rodriguez-Solano, R., & Sanchez, J. A. (2008). Highway safety analysis using geographic information systems. *Proc. of the Institution of Civil Engineers-Transport*. Thomas Telford Ltd. pp. 91-97

Chai, H. (2013). Comparison of field speed data collection methods. *Proc. of the 16th International Conference Road Safety on Four Continents. Beijing, China.* Statens väg-och transportforskningsinstitut.

Coakley, R. (2016). Safety in the Geometric Design of Highways. *Transportation Research Record*, *16*, pp. 3042.

Davis, G. A., Davuluri, S. U. J. A. Y., & Pei, J. (2006). Speed as a risk factor in serious run-off-road crashes: Bayesian Case-Control Analysis with Case Speed Uncertainty. *Journal of Transportation and Statistics*, *9*(*1*), pp. 17.

Dhamaniya, A., & Chandra, S. (2013). Speed prediction models for urban arterials under mixed traffic conditions. *Procedia-Social and Behavioral Sciences*, *104*, pp. 342-351.

Echaveguren, T. (2012). Two-lane rural highways consistency analysis using continuous operating speed measurements obtained with GPS. *Revista Ingeniería de Construcción*, *27*(*2*), pp. 55-70.

Elliott, M. A., McColl, V. A., & Kennedy, J. V. (2003). Road Design Measures to Reduce Drivers' Speed via 'psychological' processes: A Literature Review. *TRL Report 564*.

Faria, D. (2003). *A framework to transform real-time GPS data derived from transit vehicles to determine speed-flow characteristics of arterials.* University of Texas Arlington, US: Ph.D. Thesis.

Fitzpatrick, K., Carlson, P., Brewer, M. (2003). Design speed, operating speed, and posted speed practices. *Transportation Research Board*, pp. 504.

Fitzpatrick, K., Carlson, P., Brewer, M., & Wooldridge, M. (2001). Design factors that affect driver speed on suburban streets. *Transportation Research Record: Journal of the Transportation Research Board*, *1751*, pp. 18-25.

Fitzpatrick, K., Shamburger, C., Krammes, R., & Fambro, D. (1997). Operating speed on suburban arterial curves. *Transportation Research Record: Journal of the Transportation Research Board*, *1579*, pp. 89-96.

Frost, J. (2017). How To Interpret R-squared in Regression Analysis. Retrieved on January 28, 2018, from http://statisticsbyjim.com/regression/interpret-r-squared-regression/

Garber, N. J., & Ehrhart, A. A. (2000). Final Report: The effect of speed, flow, and geometric characteristics on crash rates for different types of Virginia highways. *Virginia Transportation Research Council, Charlottesville. Virginia*, *1*, pp. 10-15.

Gelman, A. (2006). Analysis of variance. *New Palgrave dictionary of economics*.

German Road and Transportation Research Association (1984). *Guidelines for the Design of Roads.* Berlin, German.

Gibreel, G. M., Easa, S. M., Hassan, Y., & El-Dimeery, I. A. (1999). State of the art of highway geometric design consistency. *Journal of transportation engineering*, *125*(*4*), pp. 305-313.

Google Map (2017). *Google Maps Search.* Retrieved on September 15, 2017, from https://www.google.com.my/maps/dir/Ayer+Hitam,+Johor/Bulatan+Simpang+Rantai,+Kampung+Bahagia,+83000+Batu+Pahat,+Johor

Google Map (2017). *Google Maps Search.* Retrieved on September 15, 2017, from https://www.google.com.my/maps/dir/2.2942645,102.5777016/2.1768249,102.5531856/@2.2320784,102.5601418,12z/data=!4m2!4m1!3e0

Hamid, H., Faezi, S. F., & Davoodi, S. R. (2011). Predicting speed model of horizontal curves on exclusive motorcycle lane. *Australian journal of basic and applied sciences*, *5*(*5*), pp. 590-598.

Hamidun, L., (2015). Road accidents totalling 11,867 recorded during Ops Selamat 6/2015. Achieved in August 03, 2017, from http://www.thesundaily.my/news/1335825.

Hanley, K., Gibby, A., & Ferrara, T. (2000). Analysis of accident-reduction factors on California state highways. *Transportation Research Record: Journal of the Transportation Research Board*, *1717*, pp. 37-45.

Harnen, S., Sohadi, R. U. R., Wong, S.V. and Hashim, W. I. W., (2006). Motorcycle accident prediction model for junctions on urban roads in Malaysia. *Advances in Transportation Studies an International Journal*, *8*, pp. 31-40.

Harnen, S., Wong, S. V., Sohadi, R. U. R., & Hashim, W. I. W. (2003). Motorcycle crash prediction model for non-signalized intersections. *IATSS research*, *27*(*2*), pp. 58-65.

Hashim, I. H., Abdel-Wahed, T. A., & Moustafa, Y. (2016). Toward an operating speed profile model for rural two-lane roads in Egypt. *Journal of traffic and transportation engineering (English edition)*, *3*(*1*), pp. 82-88.

Hassan, Y., (2004). Highway Design Consistency: Refining the State of Knowledge and Practice. *Transportation Research Record: Journal of the Transportation Research Board*, *1881*, pp. 63-71.

Hauer, E., 1986. On the Estimation of Expected Number of Crashes. *Accident Analysis and Prevention, 18*, pp. 1-12.

Huang, B., & Preston, J. (2004). *A literature review on motorcycle collisions*. Oxford University: Transport Studies Unit, Final Report. .

Hussien, H. H., & Eissa, F. H. (2016). Identifying Hazardous Road Locations in Saudi Arabia. *Global Advanced Research Journal of Engineering, Technology and Innovation, 5(4),* pp. 045 – 056.

Iyinam, A. F., Iyinam, S., & Ergun, M. (1997). Analysis of relationship between highway safety and road geometric design elements: Turkish case. *Technical University of Istanbul, Faculty of Civil Engineering, Turkey*.

Jacob, A., & Anjaneyulu, M. V. L. R. (2013). Development of crash prediction models for two-lane rural highways using regression analysis. *Highway Research Journal*, *6*(*1*), pp 59-70.

Jiang, Y., & Li, S. (2002). Measuring and analyzing vehicle position and speed data at work zones using global positioning systems. *Institute of Transportation Engineers. ITE Journal*, *72*(*3*), pp. 48.

JKJR (2015), Indeks Kematian Jalan Raya 2004-2014, Achieved in June 24, 2015, from http://www.jkjr.gov.my/ms/maklumat_keselamatan/ststik-kmlgn-jln-rya/1858-indeks-kematian-jalan-raya-2004-2014.html

Kamba, A. N., Rahmat, R. A. O. K., & Ismail, A. (2007). Why do people use their cars: a case study in Malaysia. *Journal of Social Sciences*, *3*(*3*), pp. 117-122.

Karlaftis, M. G., & Golias, I. (2002). Effects of road geometry and traffic volumes on rural roadway accident rates. *Accident Analysis & Prevention*, *34*(*3*), pp. 357-365.

Kibar, F. T., Celik, F., & Aytac, B. P. (2013). An accident prediction model for divided highways: a case study of Trabzon coastal divided highway. *WIT Transactions on The Built Environment*, *130*, pp. 711-719.

Kloeden, C. N., McLean, A. J., Baldock, M. R. J., & Cockington, A. J. T. (1999). Severe and fatal car crashes due to roadside hazards. *NHMRC Road Accident Research Unit The University of Adelaide*.

Kumar, P. S., & Srinivasan, K. (2013). A study on environmental factors influencing road traffic accident victims in district hospital, Karimnagar. *International Journal of Research in Health Sciences, 1(2).*

Lamm, R., & Choueiri, E. M. (1987). Recommendations for evaluating horizontal design consistency based on investigations in the state of New York. *Transportation Research Record*, *1122*, pp. 68-78.

Lamm, R., Psarianos, B., & Cafiso, S. (2002). Safety evaluation process for two-lane rural roads: A 10-year review. *Transportation Research Record: Journal of the Transportation Research Board*, *1796*, pp. 51-59.

Leisch, J. E., & Leisch, J. P. (1977). New concepts in design-speed application. *Transportation Research Record*, *631*, pp. 4-14.

Lobo, A., Rodrigues, C., & Couto, A. (2013). Free-flow speed model based on Portuguese roadway design features for two-lane highways. *Transportation Research Record: Journal of the Transportation Research Board*, *2348*, pp. 12-18.

Lord, D., Geedipally, S. R., & Guikema, S. D. (2010). Extension of the application of conway-maxwell-poisson models: analyzing traffic crash data exhibiting underdispersion. *Risk Analysis*, *30*(*8*), pp. 1268-1276.

Macangus, J., Milligan, C., Montufar, J., & Belluz, L. (2012). Speed characteristics on Manitoba‟s national highway system roads using weigh-in-motion data. *Proc. of the 2012 Conference and exhibition of the transportation association of Canada-transportation: innovations and opportunities*.

Machsus, H. S., Wicaksono, A., & Djakfar, L. (2013). The Prediction Models of Motorcycle Accidents on Surabaya Arterial Roads Using Generalized Linear Models. *Middle-East J. Sci. Res*, *18*(*12*), pp. 1859-1866.

Manan, M. M. A., & Várhelyi, A. (2012). Motorcycle fatalities in Malaysia. *IATSS research*, *36*(*1*), pp. 30-39.

Mattar-Habib, C., Polus, A., & Farah, H. (2008). Further evaluation of the relationship between enhanced consistency model and safety of two-lane rural roads in Israel and Germany. *European J. of Transport and Infrastructure Research*, *4*(*8*).

Mehar, A., Chandra, S., & Velmurugan, S. (2013). Speed and acceleration characteristics of different types of vehicles on multi-lane highways. *European Transport*, *55*, pp. 1825-3997.

Memon, R. A., Khaskheli, G. B., & Qureshi, A. S. (2008). Operating speed models for two-lane rural roads in Pakistan. *Canadian Journal of Civil Engineering*, *35*(*5*), pp. 443-453.

MIROS (2017). General Road Accident Data in Malaysia (1997 – 2016). Retrieved on January 04, 2018, from https://www.miros.gov.my/1/page.php?id=17

Mohammed, H. (2013). The influence of road geometric design elements on highway safety. *International Journal of Civil Engineering & Technology (IJCIET)*, *4*(*4*), pp. 146-162.

Mohanty, M., & Gupta, A. (2015). Factors affecting road crash modelling. *Journal of transport literature*, *9*(*2*), pp. 15-19.

Mouskos, K., Sun, W., & Qu, T. (1999). *Impact of Access Driveways on Accident Rates at Multilane Highways* (No. NJ-99-008-NCTIP5,). National Center for Transportation and Industrial Productivity, New Jersey Institute of Technology.

Müller, R., & Drax, C. (2014). Essential Basics and Limitations of Safety and Risk Management. In *Aviation Risk and Safety Management*. Switzerland: Springer International Publishing. pp. 7-17.

Mustafa, M. N. (2005). Overview of current road safety situation in Malaysia. *Highway planning Unit, Road Safety Section, Ministry of Works*. pp. 5-9.

Nicholson, A. (1998). Superelevation, side friction, and roadway consistency. *Journal of Transportation Engineering*, *124*(5), 411-418.

OECD (2015). Road Safety Annual Report 2015. Paris: OECD Publishing. pp. 307 – 318.

Omari-Sasu, A. Y., Isaac, A. M., & Boadi, R. K. (2016). Statistical models for count data with applications to road accidents in Ghana. *International Journal of Statistics and Applications*, *6*(*3*), pp. 123-137.

Oppong, R. A. (2012). *Statistical analysis of road accidents fatality in Ghana using Poisson regression*. Kwame Nkrumah University of Science and Technology: Ph.D. Thesis.

Oxley, J., Yuen, J., Ravi, M. D., Hoareau, E., Mohammed, M. A. A., Bakar, H., Saraswathy, V., Nair, P. K. (2013). Commuter motorcycle crashes in Malaysia: An understanding of contributing factors. *Annals of advances in automotive medicine*, *57*, pp. 45 - 54.

Papayannoulis, V., Gluck, J. S., Feeney, K., & Levinson, H. S. (1999). Access spacing and traffic safety. *Urban Street Symposium,* pp. 28-30.

PDRM (2014), “Statistik Kemalangan Jalan Raya Jalan Persekutuan di Negeri Johor Tahun 2010 hingga 2013,” Royal Malaysian Police, Ed. Johor Bahru, Malaysia.

Polus, A., & Mattar-Habib, C. (2004). New consistency model for rural highways and its relationship to safety. *Journal of transportation engineering*, *130*(*3*), pp. 286-293.

Polus, A., Livneh, M., & Craus, J. (1984). Effect of traffic and geometric measures on highway average running speed. *Transportation Research Record: Journal of the Transportation Research Board*, *960,* pp. 038-212.

Praticò, F. G., & Giunta, M. (2012). Modeling operating speed of two lane rural roads. *Procedia-Social and Behavioral Sciences*, *53*, pp. 664-671.

Rahim, S. A. S. M., Zulkipli, Z. H., Paiman, N. F., Wong, S. W., Marjan, J. M., Faudzi, S. A. M., Manap, A. R. A. (2010). Recent trend of fatal motorcycle crashes in Malaysia. In *Proc. of the 8th International Forum of Automotive Traffic Safety (INFATS)*.

Razelan, I. S. M., Hamid, H., Hwa, L. T., & Farhan, A. (2014). Identification of Hazardous Road Sections: Crash Data versus Composite Index Method. *International Journal of Engineering and Technology*, *6*(*6*), pp. 481.

Roshandeh, A. M., Agbelie, B. R., & Lee, Y. (2016). Statistical modeling of total crash frequency at highway intersections. *Journal of traffic and transportation engineering, 3*(*2*), pp. 166-171.

Russo, F., Mauro, R., & Dell"Acqua, G. (2012). Rural highway design consistency evaluation model. *Procedia-Social and Behavioral Sciences*, *53*, pp. 952-960.

Schurr, K., McCoy, P. T., Pesti, G., & Huff, R. (2002). Relationship between design, operating and posted speeds on horizontal curves on two-lane rural highways in nebraska. In *TRB 81st Annual Meeting, TRB, Washington, DC*.

Shenker, R., Chowksey, A., Sandhu, H. A. S. (2015). Analysis of relationship between road safety and road design parameters of four lanes National Highway in India. *Journal of Business and Management, 17*(*5*), pp. 60 - 70.

Sohadi, R. U. R. (2005). Updates of road safety status in Malaysia. *IATSS Research*, *29*, pp. 78-80.

Sohadi, R. U. R., Mackay, G. M., & Hills, B. L. (1995). Preliminary analysis of motorcycle accidents: short-term impacts of the running headlights campaign and regulation in Malaysia. *Journal of Traffic Medicine*, *23*(*1*), pp. 17-28.

Srinivasan, S. (1982). Effect of roadway elements and environment on road safety. *Institution of Engineers*, *63*.

Stamatiadis, N., Lord, D., Pigman, J., Sacksteder, J., & Ruff, W. (2010). Safety impacts of design element trade-offs for multilane rural highways. *Journal of Transportation Engineering*, *137*(*5*), pp. 333-340.

Susan, T. (2014). Movement for change of Sarawak Online. Achieved in December 25, 2017, from https://mocsarawak.wordpress.com/2014/02/01/most-dangerous-malaysian-roads-and-highways/

Thakali, L., Kanitpong, K., & Hossain, M. (2009). Development of Accident Prediction Models, their Possibilities and Efficacy for the Developing Countries; a Thai Experience. *Proc.of the Eastern Asia Society for Transportation Studies Vol. 7, The 8th International Conference of Eastern Asia Society for Transportation Studies.* pp. 355-355.

Torregrosa, F. J. C., Zuriaga, A. M. P., & García, A. G. (2013). New geometric design consistency model based on operating speed profiles for road safety evaluation. *Accident Analysis & Prevention, 61,* pp. 33-42.

Vereinigung Schweizerischer Strassenfachleute (1991). *Design Generalities: Speed, Basic Data for Design.* Swiss norm, Zurich, SN 640 080b.

Wang, J. (2006). *Operating Speed Models for Low Speed Urban Environments based on In-Vehicle GPS.* Georgia Institute of Technology: Ph.D. Thesis.

WHO (2004). *World report on road traffic injury prevention.* Switzerland: World Health Organization.

WHO (2009). *Global Status Report on Road Safety: Time for Action*. Switzerland: World Health Organization.

Yuen, C. W., Karim, M. R., & Saifizul, A. (2014). Analysis of motorcyclist riding behaviour on speed table. *The Scientific World Journal*, pp. 9.

Zhao, W., Goodchild, A., & McCormack, E. (2011). Evaluating the accuracy of spot speed data from global positioning systems for estimating truck travel speed. *Transportation Research Record: Journal of the Transportation Research Board*, *2246*, pp. 101-110.

Zhong, C., Sisiopiku, V., Ksaibati, K., & Zhong, T. (2011). Crash prediction on rural roads. *Proc. of the 3rd International Conference on Road Safety and Simulation, Indianapolis, Indiana*.

Zuriaga, A., García, A., Torregrosa, F., & D'Attoma, P. (2010). Modeling operating speed and deceleration on two-lane rural roads with global positioning system

data. *Transportation Research Record: Journal of the Transportation Research Board*, *2171*, pp. 11-20.