

AKNOWLEDGEMENTS

Praises be unto God for only because of His guidance the author is able to finish this thesis titled "TIME SERIES AND PAIR-COPULA MODELING OF INFLUENZA-LIKE ILLNESS IN THE UNITED STATES" well and on time.

This thesis is written based all the studies and experiments the author has learned from during the months of intensive process, and this thesis is meant to fulfill a part of academic requirements of the Mathematics Program of Faculty of Science and Technology, Universitas Pelita Harapan.

During the process of finishing this thesis, the author have been given help and support from a lot of people to make it possible, and the author would like to express the utmost gratitude to everyone who has helped in the completion of this thesis.

1. Mr. Eric Jobiliong, Ph.D., as Dean of Faculty of Science and Technology.
2. Mrs. Dela Rosa, S.Si., M.M., M.Sc., Apt., as Acting Vice Dean of Faculty of Science and Technology.
3. Mr. Laurence, S.T., M.T., as Administration & Student Affairs Director of Faculty of Science and Technology.
4. Mr. Kie Van Ivanky Saputra, Ph.D., the Head of Mathematics Department of Universitas Pelita Harapan, as well as the thesis advisor, who gave much help and guidance during the writing process and have helped the author develop as a student.
5. Ms. Giovani Gracianti, S.Si., S.Inf., M.Sc., M.Act.Sc., the thesis advisor, who has given a lot of discussion topics and suggestions to the author to better the thesis.
6. Mr. Ukur Arianto Sembiring, S.Si., M.Si., as the author's academic advisor during years of study.
7. Lecturers and staffs in the Mathematics Department who have shared their knowledge and taught much to the author during the years of study.
8. Family, who encouraged the author in all her pursuits, especially to Father and Mother, who had given both emotional and financial support, always ready to lend a sympathetic ear during the process, and wanted only the best for their daughter.
9. Amanda Priscilia Muliawan, Earlitha Olivia Lionel, and Ribka Maya Saputra, who have helped make the harder times bearable, the better times

worth living, and having a long fuse in dealing with the incessant nagging of the author.

10. Close friends and classmates, who gave the author support throughout the study and didn't hesitate to offer help whenever needed.
11. All other people who have helped the author either directly or indirectly during the completion of this thesis.

This thesis will hopefully be of help to anyone who reads it.

Tangerang, February 11th, 2019

(Karen Vanessa Angriawan)

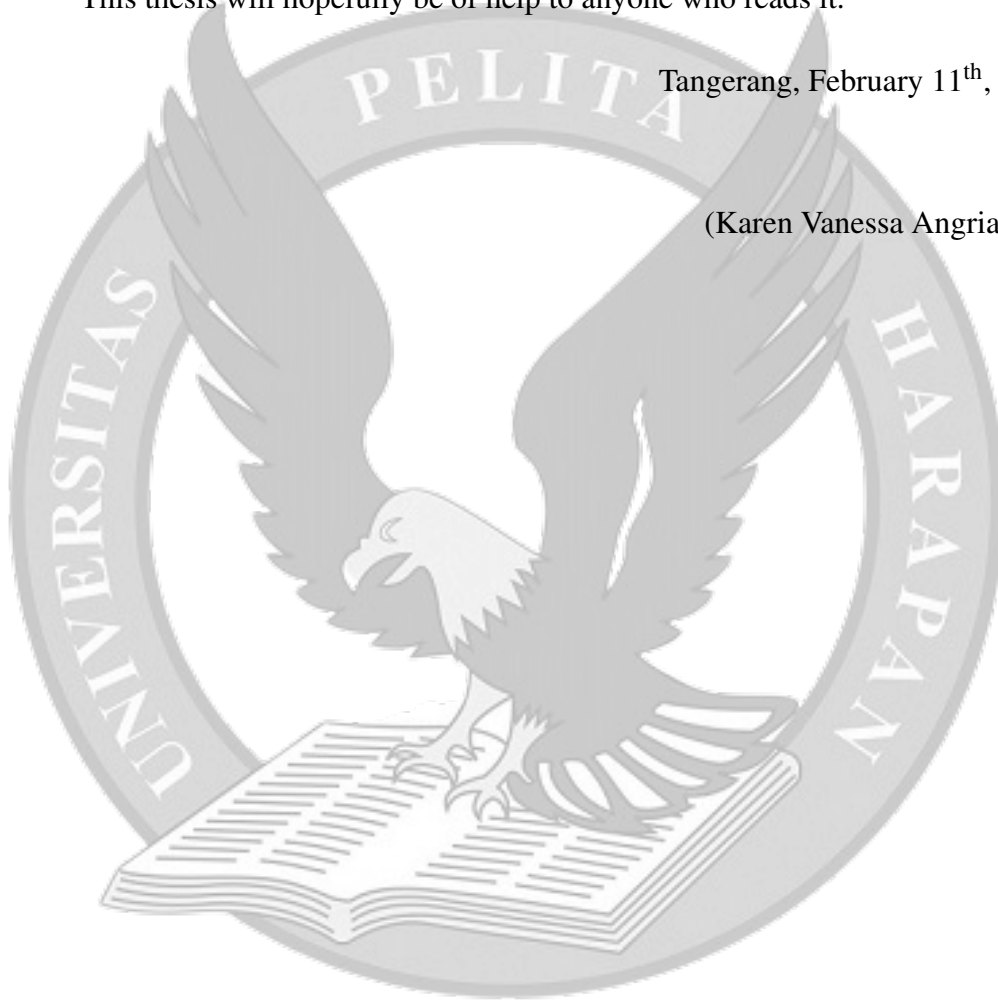
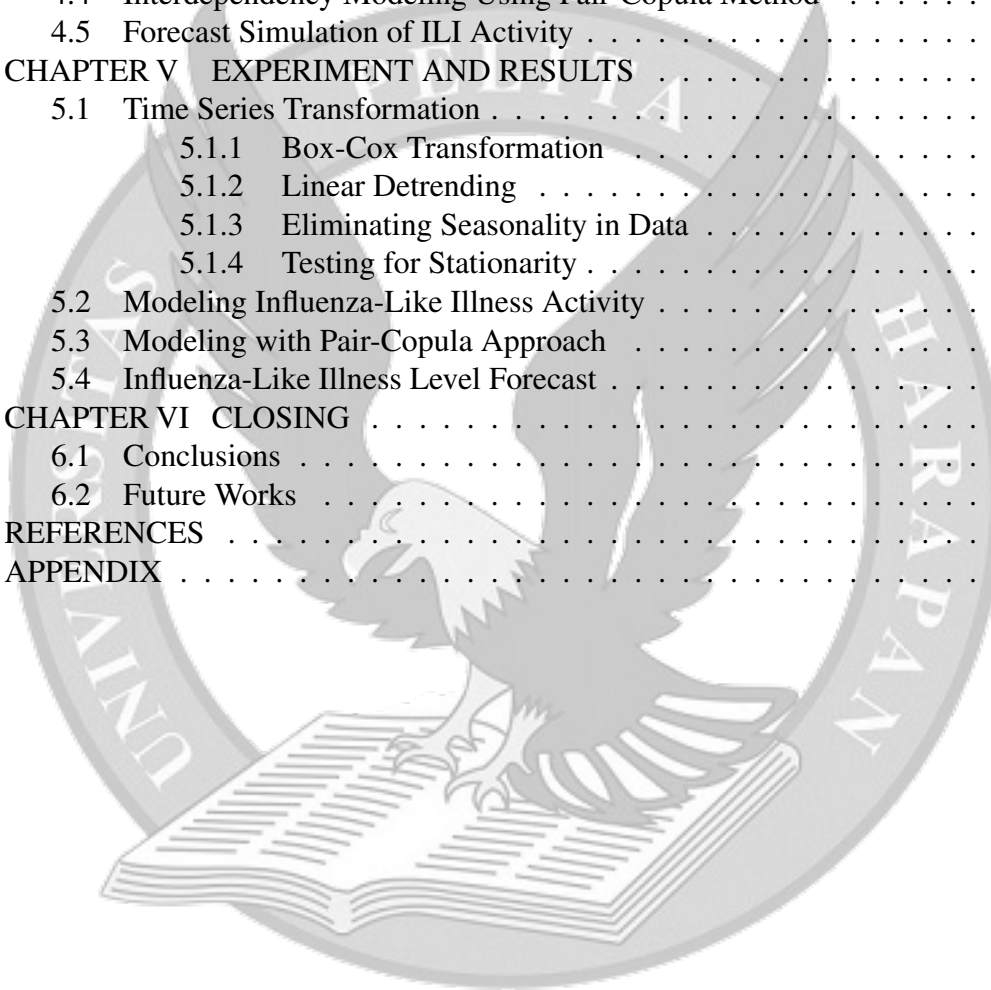


TABLE OF CONTENTS

| | |
|--|------|
| STATEMENT OF THESIS AUTHENTICITY | ii |
| APPROVAL BY THESIS SUPERVISORS | iii |
| APPROVAL BY THESIS EXAMINATION COMMITTEE | iv |
| ABSTRACT | v |
| <i>ABSTRAK</i> | vi |
| ACKNOWLEDGEMENTS | vii |
| TABLE OF CONTENTS | ix |
| LIST OF FIGURES | xii |
| LIST OF TABLES | xiii |
| LIST OF APPENDIX | xiv |
| CHAPTER I INTRODUCTION | 1 |
| 1.1 Background | 1 |
| 1.2 Problem Statement | 2 |
| 1.3 Objectives | 2 |
| 1.4 Restrictions and Assumptions | 3 |
| 1.5 Benefits | 3 |
| 1.5.1 Theoretical Benefits | 3 |
| 1.5.2 Practical Benefits | 4 |
| 1.6 Thesis Structure | 4 |
| CHAPTER II ARMA-GARCH Model | 5 |
| 2.1 Introduction | 5 |
| 2.2 ARMA(p, q) Model | 9 |
| 2.3 Pure GARCH(k, l) Case | 9 |
| 2.4 The ARMA(p, q)-GARCH(k, l) Model | 11 |
| 2.5 Strict Stationarity and Weak Stationarity in Time Series | 11 |
| 2.6 Classical Regression in the Time Series Context | 13 |
| 2.6.1 Linear Trend | 13 |
| 2.6.1.1 Akaike's Information Criterion (AIC) | 17 |
| 2.6.1.2 Bayesian Information Criterion (BIC) | 17 |
| 2.7 Cyclical or Seasonal Trends | 18 |
| 2.8 Identification Tools | 19 |
| 2.8.1 Autocovariance and Autocorrelation Function | 19 |
| 2.8.2 Autocorrelation Function and Partial Autocorrelation Function of ARMA(p, q) | 20 |
| 2.8.2.1 Estimation of Autocorrelation Function | 21 |
| 2.8.2.2 Estimation of Partial Autocorrelation Function | 22 |
| 2.8.3 The Dickey-Fuller Unit-Root Test | 24 |
| CHAPTER III Copula Method | 26 |
| 3.1 Basic Copula | 26 |
| 3.2 Pair Copula Model | 27 |
| 3.2.1 Methodological background | 27 |
| 3.2.2 Bivariate Copula Families | 31 |

| | |
|---|-----|
| 3.3 Literature Review | 33 |
| CHAPTER IV METHODOLOGY | 36 |
| 4.1 Data & Model Description | 36 |
| 4.2 Time Series Transformation | 38 |
| 4.2.1 Box-Cox Transformation | 38 |
| 4.2.2 Eliminate Trend Detected in the Data | 39 |
| 4.2.3 Remove Seasonal Effects Detected in the Data | 39 |
| 4.3 ILI Levels Modeling Using ARMA-GARCH Model | 40 |
| 4.4 Interdependency Modeling Using Pair-Copula Method | 41 |
| 4.5 Forecast Simulation of ILI Activity | 43 |
| CHAPTER V EXPERIMENT AND RESULTS | 46 |
| 5.1 Time Series Transformation | 46 |
| 5.1.1 Box-Cox Transformation | 46 |
| 5.1.2 Linear Detrending | 47 |
| 5.1.3 Eliminating Seasonality in Data | 47 |
| 5.1.4 Testing for Stationarity | 48 |
| 5.2 Modeling Influenza-Like Illness Activity | 49 |
| 5.3 Modeling with Pair-Copula Approach | 54 |
| 5.4 Influenza-Like Illness Level Forecast | 57 |
| CHAPTER VI CLOSING | 61 |
| 6.1 Conclusions | 61 |
| 6.2 Future Works | 61 |
| REFERENCES | 65 |
| APPENDIX | A-1 |



LIST OF FIGURES

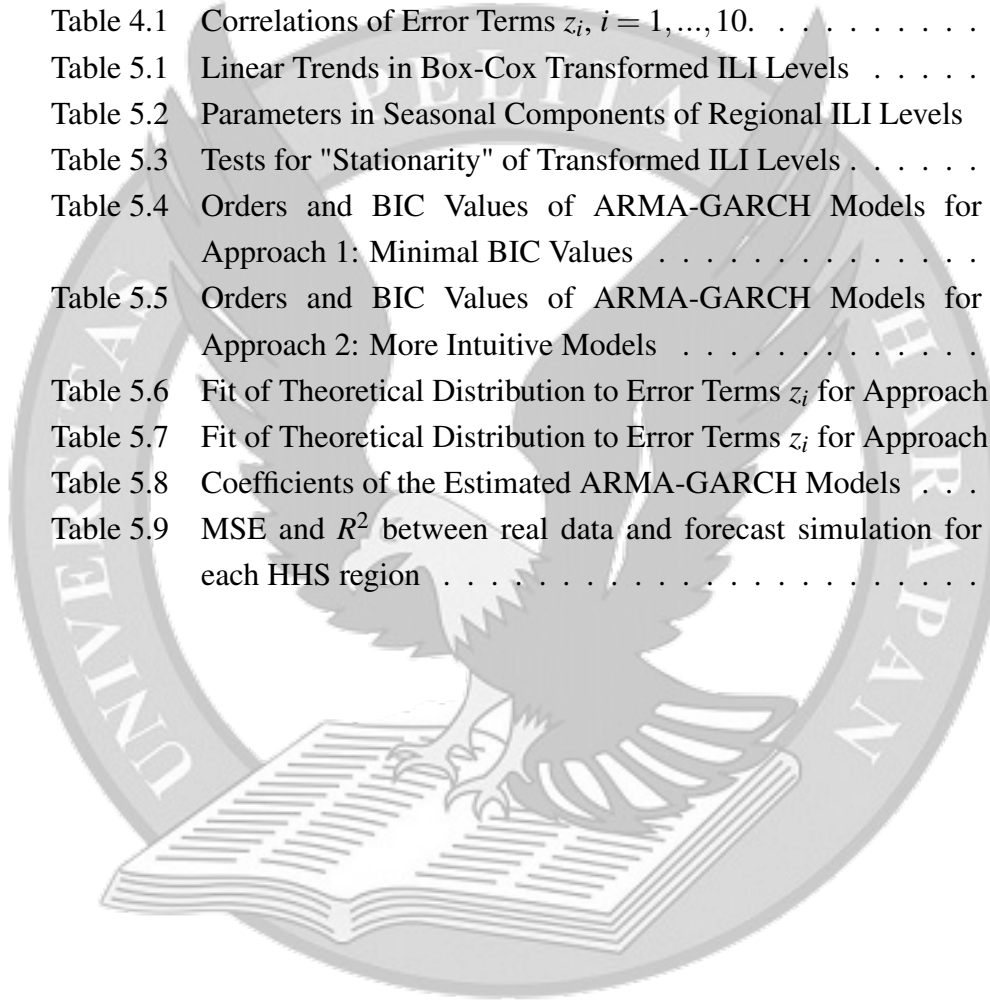
| | | |
|------------|---|----|
| Figure 2.1 | Exhibit: Average Monthly Temperatures, Dubuque, Iowa. Source: [23] | 18 |
| Figure 2.2 | Exhibit: Time Series Plot of a Random Walk. Source: [23] | 25 |
| Figure 3.1 | Example of five-dimensional C-Vine (left) and D-Vine (right) trees with edge indices. Source:[34] | 30 |
| Figure 3.2 | Proposed data analysis and model building workflow and provided functionality in the package CDVine . Source:[34] | 31 |
| Figure 3.3 | Denotation and properties of bivariate elliptical copula families. Source:[34] | 32 |
| Figure 3.4 | Denotation and properties of bivariate Archimedean copula families. $D_1(\theta) = \int_0^\theta \frac{c/\theta}{\exp(x)-1} dx$ is the Debye function. For $\delta = 1$ the upper tail dependence coefficient of the BB8 copula is $2 - 2^{\frac{1}{\theta}}$. Source:[34] | 32 |
| Figure 4.1 | ILI Levels in Region 1-3. | 37 |
| Figure 4.2 | Flow chart of data transformation. | 38 |
| Figure 4.3 | Scatter Plots of Rank-Transformed Error Terms z_i | 42 |
| Figure 5.1 | Data before and after the Box-Cox Transformation for HHS Region 1 | 46 |
| Figure 5.2 | Data before and after the removal of linear trend for HHS Region 1 | 47 |
| Figure 5.3 | Data before and after the removal of seasonal effect for HHS Region 1 | 48 |
| Figure 5.4 | ACF and PACF of Transformed ILI Levels in HHS Region 1 | 51 |
| Figure 5.5 | ACF and PACF of the Error Terms z_1 for HHS Region 1 | 53 |
| Figure 5.6 | Selected Tree Structure T_1 for Error Terms z_1, \dots, z_{10} in 10 HHS Regions. <i>Note:</i> We use the following abbreviations for the pair-copula families: Frank copula (F), Gaussian copula (Ga), Tawn type 1 copula (T), rotated Tawn type 2 copula [90°] (Ta90), Student's- <i>t</i> copula (t), BB8 copula(B), Survival BB8 copula (SB), Rotated BB8 copula [90°] (B90), Rotated BB8 copula [270°] (B270). | 54 |
| Figure 5.7 | Simulated forecast of future ILI levels in HHS region 1 | 57 |
| Figure 5.8 | Simulated forecast of future ILI levels in HHS region 1 with 95% confidence interval against real data | 58 |
| Figure 5.9 | Simulated forecast of future ILI levels in HHS region 5 | 58 |

Figure 5.10 Simulated forecast of future ILI levels in HHS region 5 with
95% confidence interval against real data 59



LIST OF TABLES

| | | |
|-----------|--|----|
| Table 2.1 | Observations of radiation emitted through closed doors of $n = 42$ randomly selected ovens. Source:[18]. | 7 |
| Table 2.2 | Pairs of $(\lambda, l(\lambda))$. Source:[18]. | 8 |
| Table 2.3 | Analysis of Variance for Regression | 16 |
| Table 3.1 | Outline of Literature Review | 35 |
| Table 4.1 | Correlations of Error Terms $z_i, i = 1, \dots, 10$ | 42 |
| Table 5.1 | Linear Trends in Box-Cox Transformed ILI Levels | 47 |
| Table 5.2 | Parameters in Seasonal Components of Regional ILI Levels | 48 |
| Table 5.3 | Tests for "Stationarity" of Transformed ILI Levels | 49 |
| Table 5.4 | Orders and BIC Values of ARMA-GARCH Models for Approach 1: Minimal BIC Values | 50 |
| Table 5.5 | Orders and BIC Values of ARMA-GARCH Models for Approach 2: More Intuitive Models | 51 |
| Table 5.6 | Fit of Theoretical Distribution to Error Terms z_i for Approach 1 | 52 |
| Table 5.7 | Fit of Theoretical Distribution to Error Terms z_i for Approach 2 | 52 |
| Table 5.8 | Coefficients of the Estimated ARMA-GARCH Models | 53 |
| Table 5.9 | MSE and R^2 between real data and forecast simulation for each HHS region | 59 |



APPENDIX

| | | |
|------------|----------------|-----|
| Appendix A | Data | A-1 |
| Appendix B | Code | B-1 |

