UNIVERSITI PUTRA MALAYSIA

MODELING STUDENTS' BACKGROUND AND ACADEMIC PERFORMANCE WITH MISSING VALUES USING CLASSIFICATION TREE

NORSIDA BINTI HASAN

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By

NORSIDA BINTI HASAN

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

December 2014

DEDICATIONS

To my beloved

husband, Abd Wahab Jusoh,
parents, Hasan Omar and Diwi Che Mat,
sisters, Ruzana and Siti Nur.

Thank you for all of your support along the way.

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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Chair: Mohd Bakri Adam, Ph.D.

Faculty: Institute for Mathematical Research

Student's academic performance is a prime concern to high level educational institution since it will reflect the performance of the institution. The differences in academic performance among students are topics that has drawn interest of many academic researchers and our society. One of the biggest challenges in universities decision making and planning today is to predict the performance of their students at the early stage prior to their admission. We address the application of inferring the degree classification of students using their background data in the dataset obtained from one of the high level educational institutions in Malaysia. We present the results of a detailed statistical analysis relating to the final degree classification obtained at the end of their studies and their backgrounds. Classification tree model produce the highest accuracy in predicting student's degree classification using their background data as compared to Bayesion network and naive Bayes. The significance of the prediction depends closely on the quality of the database and on the chosen sample dataset to be used for model training and testing. Missing values either in predictor or in response variables are a very common problem in statistics and data mining. Cases with missing values are often ignored which results in loss of information and possible bias. Surrogate split in standard classification tree is a possible choice in handling missing values for large dataset contains at most ten percent missing values. However, for dataset contains more than 10 percent missing values, there is an adverse impact on the structure of classification tree and also the accuracy. In this thesis, we propose classification tree with imputation model to handle missing values in dataset. We investigate the application of classification tree, Bayesian network and naive Bayes as the imputation techniques to handle missing values in classification tree model. The

investigation includes all three types of missing values machanism; missing completely at random (MCAR), missing at random (MAR) and missing not at random (MNAR). Imputation using classification tree outperform the imputatation using Bayesian network and naive Bayes for all MCAR, MAR and MNAR. We also compare the performance of classification tree with imputation with surrogate splits in classification and regression tree (CART). Fifteen percent of student's background data are eliminated and classification tree with imputation is used to predict student's degree classification. Classification tree with imputation model produces more accurate model as compared to surrogate splits.

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

PERMODELAN LATARBELAKANG DAN PENCAPAIAN AKADEMIK PELAJAR DENGAN NILAI HILANG MENGGUNAKAN POKOK KLASIFIKASI

Oleh

NORSIDA BINTI HASAN

December 2014

Pengerusi: Mohd Bakri Adam, Ph.D.

Fakulti: Institut Penyelidikan Matematik

Pencapaian akademik pelajar menjadi keutamaan di institusi pengajian tinggi kerana ia mencerminkan prestasi institusi tersebut. Perbezaan pencapaian aka-demik di kalangan pelajar sentiasa menjadi topik perbincangan yang menarik minat ramai penyelidik dan masyarakat umum. Di dalam kajian ini, analisis statistik memperlihatkan perkaitan di antara pencapaian akademik pelajar semasa bergraduat dan latarbelakang mereka. Salah satu daripada cabaran besar yang dihadapi oleh pembuat dasar serta perancangan universiti hari ini adalah untuk meramal pencapaian pelajar semasa awal kemasukan mereka ke universiti. Kami menangani aplikasi penafsiran klasifikasi ijazah pelajar menggunakan data latarbelakang dalam set data yang diperolehi daripada salah satu Institusi Pengajian Tinggi Awam (IPTA) di Malaysia. Kami paparkan hasil analisis statistik yang terperinci berkaitan dengan klasifikasi ijazah yang diperolehi semasa tamat pengajian berdasarkan latarbelakang mereka. Model pokok klasifikasi menghasilkan kejituan tertinggi berbanding dengan rangkaian Bayesian dan Bayes naif. Signifikasi ramalan sangat bergantung kepada kualiti pangkalan data serta bergantung juga kepada sampel yang akan digunakan untuk model latihan dan model pengujian. Nilai hilang samada dalam pembolehubah peramal atau pembolehubah tindakbalas merupakan masalah yang biasa dalam bidang statistik dan perlombongan data. Kes-kes nilai hilang yang selalunya diabaikan menyebabkan kehilangan maklumat dan boleh meghasilkan keputusan yang berpihak. Pemisah gantian (*surrogate split*) dalam pokok klasifikasi piawai boleh menjadi pilihan semasa mengendalikan nilai-nilai yang hilang bagi set data besar yang mengandungi paling banyak 10 peratus nilai hilang. Walau bagaimanapun bagi set data yang mengandungi lebih daripada 10 pratus nilai hilang, terdapat impak yang buruk ke atas struktur pokok klasifikasi dan kejituan klasifikasi. Di dalam tesis ini, kami mencadangkan model pokok klasifikasi dengan imputasi untuk menangani nilai hilang dalam set data. Kami mengkaji penggunaan pokok klasifikasi, rangkaian Bayesian dan Bayes naif sebagai teknik imputasi untuk menangani nilai hilang dalam model pokok klasifikasi. Kajian ini meliputi kesemua tiga jenis mekanisma nilai hilang: hilang sepenuhnya secara rawak (MCAR), hilang secara rawak (MAR) dan hilang bukan secara rawak (MNAR). Imputasi menggunakan pokok klasifikasi mempunyai kejituan mengatasi imputasi menggunakan rangkaian Bayesian dan Bayes naif bagi kesemua mekanisma iaitu MCAR, MAR dan MNAR. kami juga membandingkan pencapaian model pokok klasifikasi dengan imputasi dengan kaedah pemisah gantian dalam pokok klasifikasi dan regresi piawai (CART). Lima belas peratus daripada data latarbelakang pelajar dihapuskan dan model pokok klasifikasi dengan imputasi digunakan untuk meramalkan kelas ijazah pelajar. Model pokok klasifikasi dengan imputasi menghasilkan model yang lebih jitu berbanding dengan pemisah gantian.

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I certify that a Thesis Examination Committee has met on (**18 December 2014**) to conduct the final examination of (**Norsida binti Hasan**) on his (or her) thesis entitled "**Student's Background and Academic Performance Modeling with Missing Values using Classification Tree**" 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 (**Degree of Doctor of Philosophy**).

Members of the Thesis Examination Committee were as follows:

Mat Rofa b Ismail, Ph.D.
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairperson)

Noor Akma bt Ibrahim, Ph.D.
Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Md Nasir b Sulaiman, Ph.D.
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Internal Examiner)

Mojtaba Ganjali, Ph.D.
Professor
Faculty of Mathematical Sciences
Shahid Beheshti University
Iran
(External Examiner)

ZULKARNAIN ZAINAL, Ph.D.
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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:

Mohd Bakri Adam, Ph.D.
Associate Professor
Institute for Mathematical Research (INSPEM)
Universiti Putra Malaysia
(Chairperson)

Mohd Rizam Abu Bakar, Ph.D.
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

Norwati Mustapha, Ph.D.
Associate Professor
Faculty of Computer Science and Information Technology
Universiti Putra Malaysia
(Member)

BUJANG KIM HUAT, Ph.D.
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

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DECLARATION

Declaration by graduate student

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Name of Member of Supervisory Committee:	____________________	Name of Member of Supervisory Committee:	____________________

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LIST OF ABBREVIATIONS

CART	Classification and Regression Tree
STPM	Malaysian Higher School Certificate
PKPG	In-service Teacher Education Programme
KDPK	In-service Teachers with Diploma in Special Education Programme
MCAR	Missing Completely At Random
MAR	Missing At Random
MNAR	Missing Not At Random
RRP	Random Recursive Partitioning
ITree	Imputation Tree
UPSI	Universiti Pendidikan Sultan Idris
FB	Faculty of Languages
FPE	Faculty of Business and Economics
FSKPM	Faculty of Cognitive Science and Human Development
FSM	Faculty of Music
FSS	Faculty of Sports Science
FSSK	Faculty of Human Sciences
FST	Faculty of Science and Technology
FTMK	Faculty of Information Technology and Communication
CGPA	Cumulative Gred Point Average
FP	False Positive
FN	False Negative
TP	True Positive
TN	True Negative

CHAPTER 1

INTRODUCTION

1.1 Student's Academic Performance

Student performance is a prime concern to high level educational institution since it will reflect the performance of the institution. Researchers and educators conducted many studies and experiments to determine the factors that affect student's performance. Socio-demographic characteristics such as age, gender, marital status, family status, ethnicity and previous achievement are shown to affect their undergraduate academic performance (Brown and Burkhardt, 1999; Clayton and Cate, 2004; Stevens et al., 2004; Ding et al., 2006; Ismail and Othman, 2006; Lietz, 2006; Gibb et al., 2008).

One of the biggest challenges in university decision making and planning today is to predict the performance of their students at the early stage prior to their admission. This is not an easy task but the findings is important to assist the university in determining future policy on student admissions and to provide the necessary plans to improve student performance. One of the significant facts in universities is the explosive growth of students' information in databases system. As the amount of these data increasing rapidly, the interest has grown in tapping these data to extract the hidden information that is valuable to the management. The discipline concern with this task is known as data mining. Data mining techniques can be used to extract meaningfull information and to develop significant relationships among variables stored in the students' background data.

1.2 Classification Tree

In this thesis, we applied classification tree because it produced the best accuracy as compared to naive Bayes and bayesian network. Classification and Regression tree (CART) is a supervised learning method that constructs a flow-chart-like tree as the classification model from the data and uses the tree model to classify the future data. Classification tree is a flow-chart-like tree structure consists of one root, branches, nodes and leaves. Classification tree analysis is a form of binary recursive partitioning where a node (parent node) in a decision tree, can only be split into two child nodes. The term "recursive" refers to the fact that the binary partitioning process can be applied over and over again (Breiman et al., 1984).

Classification tree is usually obtained in two steps. Initially a large tree is grown using a greedy algorithm, and then this tree is pruned by deleting bottom nodes through a process of statistical estimation. The greedy algorithm typically grows a tree by sequentially choosing splitting rules for nodes on the basis of maximizing some fitting criterion. All possible splits consist of possible splits of each predictor variable. This step generates a sequence of trees, each of which is an extension of previous trees. A single tree is then selected by pruning the largest tree according to a model selection criterion such as cost-complexity pruning, cross-validation, or even multiple tests of whether two adjoining nodes should be collapsed into a single node (Breiman et al., 1984). This pruning process ensures the tree which fits the information in the learning dataset, but does not overfit the information.

The CART begins with the entire sample of student's data. This entire sample is heterogeneous, consisting of all students. It then divides up the sample according to a splitting rule and a goodness of split criterion. Each internal node has an associated splitting rule which uses a predictor variable to assign observations to either its left child node or right child node. The splitting rules for our sample are question of the form, "Is the FACULTY F2, F3 or F6?" or put more generally, is $X \in d$, where X are some variables and d is some elements within that variable. If the criterion is satisfied, we follow the division to the left and if the said criterion is not satisfied, we follow the division to the right. Such questions are used to divide or split the sample. The CART algorithm considers all possible variables and all possible values in order to find the best split. The best split refers to the question that splits the data into two parts with maximum homogeneity (Breiman et al., 1984). Maximum homogeneity of child nodes is defined by impurity function $i(t)$ which is equivalent to the maximization of change of impurity function Δi_t as shown by

$$\Delta i_t = i(t_p) - P_l i(t_l) - P_r i(t_r),$$

where

- t_p is a parent node,
- $i(t_p)$ is the impurity measure for the parent node,
- P_l is the proportion of the samples in node t that go to the left node t_l,
- P_r is the proportion of the samples in node t that go to the right node t_r,
- $i(t_l)$ is the impurity measure for left child node,
- $i(t_r)$ is the impurity measure for right child node.

Since the parent node is constant for any split, then, the maximization problem is equivalent to minimizing the following expression

$$P_l i(t_l) + P_r i(t_r). \tag{1.1}$$

Equation (1.1) implies that CART will compare different splits and determines which of these will produce the most homogeneous subsamples. Common measures are:

1.3 Problem Statements

Student's performance is a prime concern to high level educational institution because it will reflect the performance of the institution. The differences in academic performance among students are a topic that has drawn interest of many academic researchers and our society. However, the student's performance is not encouraging since less than 4 percent of student in public university in Malaysia obtained first class degree classification upon graduation (Graduate Tracer Study Report 2009, Retrieved 14/11/2012).

Even though there is a weak relationship between employees performance with CGPA as reported by Hashim (2012), employers usually use the students academic performance as the selection criteria to shortlist the candidates for the interview. Hashim (2012) also stated that several well-established companies in Malaysia limit their recruitment only to those students who achieve 3.00 CGPA and above. Therefore, the biggest challenges in university decision making and planning today is to understand the student's performance pattern and then to predict the performance of the students at the early stage prior to their admission. To our knowledge, there is no study has yet been made to model student's background data from all faculties in a university to classify and predict the final degree classification. The findings can assist the university in determining future policy on student admissions and to provide the necessary plans to improve student performance.

The significance of the prediction depends closely on the quality of the database and on the chosen sample dataset to be used for model training and testing. Unfortunately, missing values either in predictor or in response variables are a very common problem in statistics and data mining. Cases with missing values are often ignored and standard methods for complete data are run on the remaining data cases. If the rate of missing values is less than 1 percent, missing values are considered trivial, 1 percent to 5 percent missing values are considered manageable, 5 percent to 15 percent missing values require sophisticated methods to handle and more than 15 percent may severely impact any kind of interpretation (Acuna and Rodriguez, 2004; Peng et al., 2005). To our knowledge, there is no study has yet been made of sensitivity of missing data in the classification tree structure and classification accuracy with big sample size.

Case deletion method discards valuable information about features that are observed which results in loss of information and possible bias (Shafer, 2002; Little and Rubin, 2002). One effective way of dealing with missing values is to impute them with some reasonable value before proceed with inference. The key to imputation techniques is to substitute with the most probable values and meanwhile preserve the joint relationships between variables. Imputation by a constant using mean or mode values will ignore the between-attribute relationships and assumes that all missing values represent the same value, probably leading to considerable distortions. Surrogate split in standard classification tree is a possible choice for large dataset contains at most ten percent missing values. However, for dataset contains more than 20 percent missing values, there is an adverse impact on the accuracy of the classification tree (Peng et al., 2005). Peng et al. (2005); Saar-Tsechansky and Provost (2007) showed that imputation methods are able to increase the accuracy in classifcation model. However, these research are limited to missing completely at random (MCAR). Tree-based approach for missing values imputation was proposed by Vateekul and Sarinnapakorn (2009). However, this method is applicable for quantitative data.

In this thesis, we propose classification tree model with imputation to handle missing values in dataset. We investigate the application of classification tree, Bayesian network and naive Bayes as the imputation techniques to handle missing values in classification tree model. The investigation includes all three types of missing values machanism; missing completely at random (MCAR), missing at random (MAR) and missing not at random (MNAR).

1.4 Research Objectives

The main objective of this research is to develop an accurate model to predict student's academic performance using their background data with the present of missing values. To achieve the objective, the following sub-objectives are adopted:

1. To propose classification tree model with imputation to handle dataset with missing data.

2. To propose an imputation method for three types of missing data mechanism: MCAR, MAR and MNAR.

3. To propose the predictor variable for student's academic performance.

1.5 Research Contributions

There are three main contibution of this research:

1. Classification tree model with missing data imputation for predicting the student's academic performance based on their background data.

2. Imputation method for three types of missing data mechanism: MCAR, MAR and MNAR.

3. Predictor variables for student's academic performance.

1.6 Organization of Thesis

This thesis contains seven chapters; Introduction, Literature Review, Research Methodology, Data Pre-processing and Missing Data Injection, Model Development, Experimental Results and Conclusion and Future Work. The details of the chapter are as follow:

Chapter 1 provides an overview of the thesis, such as background studies, problem statement, objectives and reseach contribution.

Chapter 2 presens the literature reviews on the existing work to determine the factors that affect student's performance. This description is particularly focused on socio-demographic characteristics such as age, gender, marital status, family status and ethnicity. We present an overview of the major data mining techniques used in predicting student's academic performance. Classification tree is the common method for mining student's data. However it is sensitive to the presence of missing values. The reviews on sensitivity of missing values and how to handle missing values in data mining are also presented.

Chapter 3 provides the methodology applied in this study. Research framework including data, data pre-processing and missing data injection, model design, model development and model implementation are briefly explained in this chapter.

Chapter 4 presents the data pre-processing and missing data injection. The descriptive data analysis is carried out to investigate the relationship between categorical variables of student's academic performance according to their gender, university academic intake category, age and race. Data mining techniques namely classification tree, Bayesian network and naive Bayes are applied to student's background data to predict student's degree classification. We also simulate the student's background data using the correlation of the actual data, then, we simulate the three types of missing data mechanism (MCAR, MAR and MNAR). The influence of missing values in classification tree, Bayesian network and naive Bayes are then investigated by removing levels of student's background data.

Chapter 5 provides a detailed explaination on the development of classification tree with imputation model. The imputation of missing values using three imputation techniques; classification tree, Bayesian Network and naive Bayes are explained. All three imputation techniques are implemented on datasets having three types of missing values mechanism; MCAR, MAR and MNAR.

Chapter 6 presents the results of experiments applied to real student's background and academic performance dataset to evaluate the performance of proposed algorithms.

Chapter 7 gives concluding remarks and directions of future research.

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