Low Birth Weight Data

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1 Introduction

Low birth weight (LBW) is defined by the World Health Organisation as a birth of an infant weighing less than 2500 grams. Low birth weight is closely associated with fetal and perinatal mortality, inhibited growth and cognitive development, and chronic diseases later in life. Physicians are therefore interested in understanding the effects of different behavioural and environmental variables on the likelihood of having a low birth weight.

The variables identified in Table 1 have been shown to be associated with low birth weight in the obstetrical literature. The goal of this study is to ascertain if these variables were important in the population being served in the medical center where this data was collected. We then build, compare, and discuss different models for predicting the likelihood of a low weight birth given these variables.

Variable	Abbreviation
Low Birth Weight (0 or 1)	LOW
Age of the Mother in Years	AGE
Weight in pounds at the last menstrual period	LWT
Race (1 - White, 2 = Black, 3 = Other)	RACE
Smoking status during pregnancy (Yes = 1, No = 0)	SMOKE
Number of previous premature labours	PTL
History of hypertension	HT
Presence of uterine irritability	UI
Number of visits to physician during first trimester	FTV
Birth weight in grams	BWT

Table 1: Caption below table.

2 Review of the Obstetrical Literature

Reviewing the obstetrical literature allows us to understand how these variables and their interactions should influence the likelihood of a low birth weight. This information can then be compared with the results from an exploratory analysis of the data (see Section 4), allowing us to determine how our data differs from what would be expected and to make informed decisions when building predictive models.

2.1 Effects of variables on low birth weight

A brief description of the effect of each variable on low birth weight is given below.

- **AGE -** Fraser and Brockert [1995] showed that teenage mothers have a significantly higher risk than mothers who were 20 to 24 years of age of delivering an infant who had low birth weight.[8] However, advancing maternal age is associated with a decreased potential for fetal growth and it has been shown that the adjusted risk for low birth weight at term is the lowest in younger mothers and increases with advancing maternal age.[14]
- **SMOKE -** Smoking during pregnancy inhibits full fetal development and is closely associated with low birth weight.[3] However, the degree to which smoking affects low birth weight varies significantly with the average number of cigarettes smoked per day, with birth weight decreasing as the category of cigarette number per day increases.[11] This study uses

a binary SMOKE variable - a more detailed categorisation of smokers would most likely improve the quality of the models.

- **RACE -** There is a higher rate of LBW among black women when compared with white women.[9] Race effectively acts as a proxy variable - encoding information about sociodemographic, health-related, and behavioural differences between different racial groups.[10]
- **LWT -** Progressive increase in pre-pregnancy weight was paralleled by progressive increase in mean birth weight and decrease in the incidence of low weight births.[5]
- **PTL -** The risk of the birth of a subsequent low birthweight infant is 2 to 5 times higher than average for mothers who have had a previous low birthweight delivery and increases with the number of prior low-weight births.[1]
- **HT:** Both chronic and pregnancy induced hypertension are strongly associated with retarded fetal growth and pre-term birth. As a result, maternal hypertension is strongly associated with low infant birthweight. [16][6]
- **FTV -** Increasing the number of physician visits can lead to earlier and more accurate diagnosis of LBW risk factors. Many studies have established a link between date of the first visit, total number of visits and length of pregnancy and LBW, a relation that is stronger if the first visit is delayed or if the number of visits is smaller than normal.[12][4][2]
- **UI -** The incidence of preterm labour in women with uterine irritability is not as frequent as in patients with other high-risk factors. However, preterm labour does occur in patients with uterine irritability at a rate higher than that in the general obstetric population.[13]

2.2 Interactions between variables

An interaction describes a situation in which the effect of one non-dependent variable on 'LOW' is dependant on the state of a second non-dependent variable. This is equivalent to saying the effects of the the non-dependent variables are not additive. Listed below are the interactions which are most relevant according to the obstetrical literature.

- **SMOKE/AGE -** Older mothers, who are already at risk of giving birth to low birthweight infants, might be more susceptible to the effects of maternal smoking. [reference] determined that maternal age has a modifying effect on the association between maternal smoking and birthweight. The association between low birthweight and age increases with maternal age.[17]
- **SMOKE/RACE -** The LBW risk difference associated with smoking is greater among black women. This might be due to the fact that even if black women smoked significantly fewer cigarettes per day, they might have higher cotinine levels compared to white women. [7]
- **AGE/FTV -** For adult first-time mothers, fewer than 10 prenatal care visits was the only significant factor affecting LBW. Therefore, health education programs or prenatal care aimed at preventing LBW should be tailored according to the age of pregnant mothers. The effect of FTV on LBW is stronger for younger mothers.[15]

3 Structure of the Dataset

The dataset in question contains data collected on 189 women, 59 of which had low birth weight babies and 130 of which had normal birth weight babies. In this study, there is a single binary response variable "LOW", where

$$\text{LOW} = \begin{cases} 1, & \text{if Birth weight} < 2500\text{g} \\ 0, & \text{otherwise} \end{cases}$$

The eight covariates provided were treated as either categorical or continuous variables in the conducted analyses. Maternal age (AGE), maternal weight (LTW), number of physician visits during the first trimester (FTV), and history of premature labor (PTL) were analyzed as continuous variables. It should be noted that FTV and PTL are in reality discrete quantitative variables, as they are numeric variables with a countable (i.e. not infinite) number of values. However, because these covariates have numerous levels which have a defined "order" to them, the decision was made to treat them as continuous predictors in the regression model. On the other hand, maternal race (RACE), smoking status (SMOKE), history of hypertension (HT), and presence of uterine irritability (UI) were treated as categorical variables.

4 Exploratory Analysis

An exploratory analysis is performed, first investigating the correlation between the predictor variables and the response variable, and then checking for meaningful interactions between predictor variables. The reasons for these analyses are twofold:

- Investigate whether the associations and correlations in our data are consistent with the obstetrical literature.
- As a guideline for the inclusion of main effects and interactions in candidate models.

Note that when calculating correlation, no inferences are mare about causality. Instead it is used to compare the associations in the data with those in the obstetrical literature to see if the data is consistent. Also a significant correlation with low birthweight gives reason to strongly consider these variables as main effects in the candidate models.

4.1 Correlation with LBW

The Spearman correlation coefficient was calculated between the dependant variable (BWT) and each of the continuous variables - AGE, LTW, FTV, and PTL. The Spearman correlation was chosen due to the non-normal distribution of each of these variables, as determined by a series of Shapiro-Wilks tests. The Spearman correlation coefficients and related p-values are given in Table 2. Both LWT and PTL are significantly correlated with BWT, with p-values of 0.001 and 0.005 respectively. They are therefore strong candidates to consider as parameters in the candidate models.

	AGE	LWT	FTV	PTL
ρ	0.061	0.248	0.07	-0.204
p-value	0.404	0.001	0.338	0.005

Table 2: Spearman correlation results and their respective p-values. The highlighted cells indicate statistically significant results.

Box plots were used to identify how the non-continuous variables in the dataset were associated birth weight and are therefore strong candidates to consider as parameters in the candidate models (See Section 1 and Section 2).

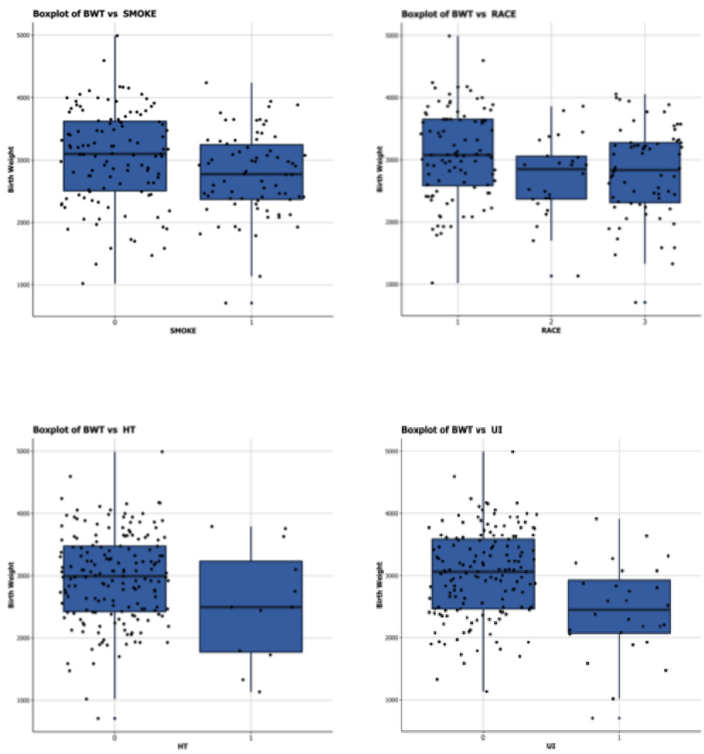

Figure 1: Box plots for each of the non-continuous variables against birthweight.

BWT vs RACE: The mean birth weight for black women and the 'other' group are both slightly lower than for white women (200 g). These results are consistent with the obstetrical literature.

BWT vs SMOKE: Note that the mean birth weight for smokers is 2700g and the mean for non-smokers is 3100g, showing the negative association between smoking and birth weight in the dataset.

BWT vs HT: The mean birth weight for pregnant women with hypertension is lower than the mean birth weight of women with no hypertension history. It is important to note that only a few women in our dataset have a history of hypertension, nonetheless the association is consistent with the literature.

BWT vs UI: Note the 600g difference in mean birth weight between women without UI (3100g) and those with UI (2500g). This is again consistent with the literature and suggests that UI should be strongly considered as a main effect in the candidate models.

4.2 Interactions Between Sets of Variables

Drawing from the interactions found in the obstetrical literature, we investigate whether these interactions are also relevant in our dataset. Speculative investigations of different interactions were also performed and these interactions are visualised in the plots below.

- **AGE/FTV -** There is an evident difference in the mean both within and between FTV groups. This pattern suggests that AGE might have a varying effect the response variable LOW depending on the number of physician visits. It is important to note, however, that there are few in FTV groups 3 and 4, and only one woman is in group 6. We must therefore

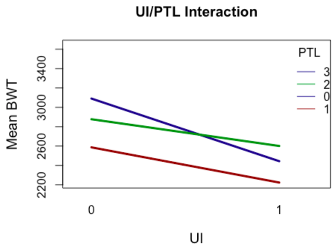

Figure 2

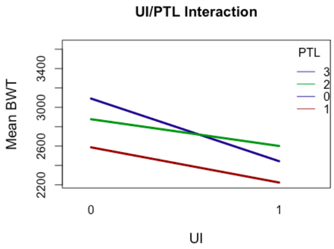

Figure 3

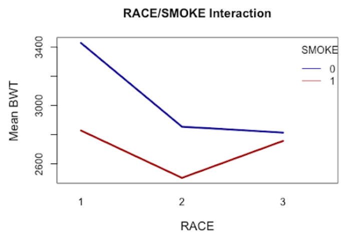

Figure 4

be wary when extrapolation the significance of this interaction term, due to the limited number of data points.

- **LWT/FTV -**
- **RACE/SMOKE -** This plot shows that the effect of smoking on birthweight is dependent on race. This is consistent with the obstetrical literature and gives us reason to include it in our models.
- **UI/PTL -** We tested this interaction speculatively and noticed from the graph that the lines were not parallel. From this plot, it appears the effect of UI on birthweight is reduced for women with more pre-term labours. This gives us reason to include it in our models and see if it is statistically significant.
- **AGE/SMOKE -** The plot shows the data points for smokers vs non-smokers, along with the mean birth weight at each age. As the lines are not parellel, there is evidence of some interation. The significance of this interaction will be tested in Section I.

5 Question 1

The four variables which are considered the most clinically important are AGE, LWT, RACE, and FTV. Using these variables, a model building exercise is carried out using AIC and AIC weights to determine the model that best fits the data.

5.1 Model Building

There is a trade-off between accuracy and interpretability when deciding on the number and order of interaction terms to include in these models. Due to this fact, only a small number of first-order interaction terms are included in the candidate models. The interaction terms included in the candidate model are the significant interactions determined by the literature review and exploratory analysis (see sections 2.2 and 4.2). The principle of constructing hierarchical models also dictates that if an interaction term is included, the constitutive main effect variables should also be included.

First a model is constructed with the main effects only:

$$RACE + FTV + AGE + LWT \tag{1}$$

Secondly, a model with all interaction terms:

$$RACE + FTV + AGE + LWT + LWT/FTV + AGE/FTV \tag{2}$$

Then models with each singular interaction term:

$$RACE + FTV + AGE + LWT + AGE/FTV \tag{3}$$

$$RACE + FTV + AGE + LWT + LWT/FTV \tag{4}$$

The final two candidate models retain AGE/FTV as an interaction term because it is clear from the exploratory analysis that it is significant. These models examine the effect of adding both LWT and RACE individually as main effects.

$$RACE + FTV + AGE + LWT + AGE/FTV \tag{5}$$

$$FTV + AGE + LWT + AGE/FTV \tag{6}$$

5.2 Comparing the Models

The models are evaluated against each other using a modification of the Akaike Information Criterion (AIC). When the sample size is small, there is a substantial probability that AIC will select models that have too many parameters - AIC will overfit. To address overfitting, AICc is used: AICc is AIC with a correction for small sample sizes:

$$\text{AICc} = \text{AIC} + \frac{2k^2 + 2k}{n - k - 1} \tag{7}$$

where n denotes the sample size and k is the number of parameters in the model. Note that as $n \to \infty$, the penalty term tends to 0 and AICc converges to AIC. The results for each of the models are shown below.

Model	AICc Score	Δ AICc	AICc Weight
$AGE + FTV + LWT + AGE/FTV$	225.70	0.00	0.57
$AGE + RACE + FTV + LWT + AGE/FTV$	227.24	1.54	0.26
$AGE{+}RACE{+}FTV{+}LWT{+}AGE/FTV{+}LWT/FTV$	228.79	3.09	0.12
$AGE + RACE + FTV + AGE/FTV$	231.34	5.65	0.03
$AGE + RACE + FTV + LWT$	235.03	9.34	0.01
$AGE + RACE + FTV + LWT + LWT/FTV$	236.64	10.94	0.00

Table 3: Comparison of candidate models using AICc. The best performing model is highlighted.

Based on the AICc weights, we determine that the best model is given by equation 6. The final model with coefficients is given by:

$$\mathbb{E}(LOW) = -0.166 + 0.0658AGE + 2.844FTV - 0.0155LWT - 0.131AGE/FTV \tag{8}$$

A final model was also constructed using the backward elimination procedure. Starting with the full model given by equation 2, the variable with the highest p-value controlling the type 1 error at $\alpha = 0.1$ was iteratively removed. Both FTV/LWT and $RACE$ were removed using this procedure, resulting in the following model:

$$\mathbb{E}(LOW) = -0.166 + 0.0658AGE + 2.844FTV - 0.0155LWT - 0.131AGE/FTV \quad (9)$$

Both the AICc, backward elimination, and stepwise selection procedures give the same final model. The AICc criterion for each of these is given below.

Procedure	Model	AICc
Using AIC	$LOW \sim AGE + FTV + LWT + AGE/LWT$	225.70
Backward Selection	$LOW \sim AGE + FTV + LWT + AGE/LWT$	225.37
Stepwise selection	$LOW \sim AGE + FTV + LWT + AGE/LWT$	225.37

Table 4: Comparison of AICc scores using the different model selection methods.

5.3 Interpreting the Final Model

The final model can be interpreted in terms of the odds ratios. The odds ratios are given by e^{β_i}, where β_i is the coefficient for the i^{th} parameter. The odds ratios are summarised below.

Parameter	Coefficient	Odd Ratio
AGE	0.0658	–
FTV	2.844	–
LWT	-0.0155	–
AGE/FTV	0.131	–

Table 5: Coefficients and odds ratios for parameters in the final model.

NEED TO UNDERSTAND HOW TO INTERPRET ODDS RATIOS!!

6 Question Two

The set of potential predictive variables is expanded to include UI, HT, PTL, and SMOKE. Using the same procedures outlined in 5.1, candidate models are chosen and then compared. The final model is then interpreted in terms of the coefficients and odds ratios.

6.1 Model Building

The candidate models were constructed according to the principles outlined in section 5.1. First constructing a model with main effects only and one full model with all relevant interactions determined by the exploratory analysis and literature review. Then different models were constructed to isolate the effect of different main effect and interaction terms. These models are shown in table 6.

6.2 Comparing the Models

The models are evaluated against each other using the modified Akaike Information Criterion (AICc). The results for the models are shown below. In total, 11 candidate models were compared, only a subset of which are shown here, as they are interesting to compare.

Model	AIC Score	Δ AIC	AIC Weight
$LWT + HT + SMOKE + PTL/UI + AGE/FTV$	211.53	0.00	0.30
$LWT + HT + SMOKE + RACE + AGE/FTV + PTL/UI$	212.24	0.71	0.21
$LWT + HT + PTL/UI + AGE/FTV$	212.30	0.77	0.21
$FTV + LWT + HT + SMOKE + RACE + PTL/UI$	220.71	9.18	0.00
$AGE + FTV + LWT + HT + SMOKE + RACE + PTL/UI$	221.96	10.43	0.00

Table 6: Comparison of a subset of the candidate models using AICc. The best performing model is highlighted.

The best performing model does not include RACE as a main effect, and contains only AGE/FTV and PTL/UI as interaction terms. The importance of these interaction terms is clear as they are present in each of the best performing models. Removing AGE as a main effect or removing AGE/FTV as an interaction term significantly inhibits the performance of the model. It is also interesting to note that model 2 and 3 perform similarly, even though model 3 does not have SMOKE or RACE as main effects. We can interpret this as the information gained from these two variables is offset by the complexity penalty included in the AICc formula.

A summary of the models and AIC scores for backward selection, stepwise selection, and AIC procedures is given below below. Note that they all result in the same final model, although both backward and stepwise selection have better AIC scores.

Procedure	Model	AICc
Using AIC	$LOW \sim AGE/FTV + PTL/UI + LWT + HT + SMOKE$	211.53
Backward Selection	$LOW \sim AGE/FTV + PTL/UI + LWT + HT + SMOKE$	210.3
Stepwise selection	$LOW \sim AGE/FTV + PTL/UI + LWT + HT + SMOKE$	210.3

Table 7: Comparison of AICc scores using the different model selection methods.

The final model is given by:

$$\begin{aligned} LOW \sim\ & 0.0721AGE + 3.4535FTV + 1.1812PTL + 1.5861UI + 0.6389SMOKE \\ & +1.8637HT + -0.0158LWT + -0.1551AGE/FTV + -1.6058PTL/UI \end{aligned} \tag{10}$$

6.3 Interpreting the Final Models

7 Limitations

References

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