Review of low birth weight prediction models in Indonesia

by Dewi Anggraini

REVIEW OF LOW BIRTH WEIGHT PREDICTION MODELS IN INDONESIA

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Abstract— Low birth weight is one of the most significant contributors to the neonatal mortality rate. It has been an important public health issue in many developing countries. Several prediction models have been developed to forecast newborn delivery weight using a wide range of regression analysis and maternal and neonatal data from Indonesia. However, there has not been any comparison study to investigate the most efficient models or availability of data required by these models. This paper reviews the last five years research carried out on the prediction of delivery weight, particularly prediction for low birth weight. We also investigate whether the significant characteristics are accessible to be measured in rural settings. The results indicate that majority of the prediction models were developed based on maternal characteristics rather than fetal characteristics or the combinations of both. These prediction models were also designed based on data accessible at delivery time rather than before birth due to the lack of maternal and fetal data during the process of antenatal care. Improvement on health information systems, particularly on the quality of complete and accurate statistics on maternal and fetal data throughout pregnancy is urgently required. This can be done by regular update of these estimates to continuously improve the rate of low birth weight delivery.

Index Terms—Coefficient Of Determination, Correlation Coefficient, Mean Prediction Error, Regression Analysis.

I. INTRODUCTION

Neonatal Mortality Rate (NMR) in Indonesia is higher than the World Health Organization (WHO) recommended level. According to Indonesian Demographic and Health Survey (IDHS) 2007, the trend shows a slow decline, accounted for 34 per 1000 live births in 2007 which has no significant difference from what it was in 2002. The national target for the Millennium Development Goals (MDGs) 2015 is 23 per 1000 live births [25]. The IDHS survey has also mentioned that 78.5% of neonatal deaths occur between 0 to 6 days old [8].

Low birth weight (LBW) is well-documented to be one of the most contributing factors to the neonatal mortality. This incidence increases the chance of neonatal deaths among newborns and creates high risk of health problems in later life [14]. It has also been documented that the risk factors of neonatal mortality are 70% preventable by using evidence-based interventions [26].

Consequently, determinations of significant factors influencing the neonatal deaths have clinically and scientifically become an interest focus. Several investigations on the sources of variation in the mortality rate have been carried out using maternal and neonatal data from Indonesia. A wide range of qualitative and quantitative regression models [1]-[5], [9]-[12], [21], [23]-[24], [26]-[28] have been developed. However, this study will focus merely on the statistical models developed in the last five years to predict delivery weight, particularly for LBW infants.

II. PREDICTION MODELS

This study is carried out by a literature study on the original research articles published in the period of 2010 - 2015 on delivery weight prediction models, particularly prediction for the LBW in Indonesia. The information have been retrieved from reputable databases, such as Scopus, PubMed, Web of Science, Science Direct, ProQuest, IEEE Xplore, and Google Scholar. The search was guided by the use of relevant keywords, such as "birth weight", "low birth weight", "prediction models", "Indonesia", and "systematic review" and their combinations. From the chosen literatures, significant characteristics for each model are identified. The efficacy of the existing prediction models is then assessed and compared based on their coefficient of determination (R^2), coefficient of correlation (r), and mean prediction error. Finally, we investigated the availability of the measurements on these characteristics in the rural settings of Indonesia.

Delivery weight is one of the most important measurements that may impact on infants' life survival and well-being. A birth weight less than 2500 grams referred to as LBW is a well-recognized leading factor contributing to the neonatal mortality, particularly during the neonatal period [6]. According to WHO (2005), it is estimated that 4 million newborns die before reaching 4 weeks old, of which more than 95% of these deaths occur in developing countries [18], [26]. As a result, at least one third reduction in the proportion of LBW babies becomes one of the priorities of "A World Fit for Children" platforms proposed by the United Nation [6].

The prevalence of LBW can possibly be detected during the antenatal care process. This can be achieved by proper clinical diagnosis that allows immediate care interventions to reduce the mortality risk both in developing and developed countries [10], [31], [22]. The early diagnosis and treatment are vital and can be facilitated by a reliable prediction model [29]. Having a prediction model to predict the delivery weight accurately, could be extremely beneficial for medical practitioners [22] in preventing the risks of having adverse delivery outcomes. It will also be an effective tool to assistance them in their evidence-based decision strategy on what clinical interventions is appropriate and when should be implemented.

Therefore, a precise and applicable method of predicting delivery weight should be further developed. “Simple and accurate method of estimating newborn weight that can be easily applied to all pregnancies is an important means of reducing mortality rate” [2, p. 309]. Several studies in both developing and developed countries have been attempted to estimate the delivery weight using mathematical and statistical models. Hence, examining the efficiency of existing models and the availability of data required to construct these models in rural Indonesia would be a significant step towards the development of a more reliable weight prediction model.

The systematic search found 7 relevant articles that consist of 10 statistical models for delivery birth weight prediction. Five of the models focused on predicting normal delivery weight, whereas the rest were addressing prediction weight for the low birth weight infants.

III. PREDICTION MODELS BASED ON BOTH MOTHER’S AND FETAL’S CHARACTERISTICS

The five models listed in Table 1 are developed based on available data on mother and fetal.

Model 1 has been suggested by Abdollahian, et al. (2012) to estimate birth weight (for the LBW babies) (BW_i) using 1000 simulated data based on the observed mean and standard deviation of 10 LBW deliveries recorded in a health clinic in Indonesia. This proposed model measured four maternal characteristics, such as age (M_{age})(years old), weight (M_{weight})(kg), hemoglobin level measured before (Hb_{before}), and after (Hb_{after}) vitamin C and iron tablets consumptions (mmHg), and one baby’s characteristic: gestation age at delivery time ($GA_{delivery}$) (weeks). The model was developed using multivariate linear regression (Table 1).

In 2013, Abdollahian, et al. recommended two more prediction models for delivery weight (for the LBW babies) (BW_i) (grams) based on two maternal characteristics: height (M_{height})(cm), and body mass index (M_{BMI}) (kg/cm^2), and three neonatal characteristics measured at delivery time: gestation age ($GA_{delivery}$) (weeks), head circumference (HC)(cm), and chest circumference (CC)(cm). The initial multivariate linear regression model, labeled as Model 2, was developed based on the 10 recorded LBW data out 199 deliveries (Table 1).

The second model of the study, as so-called the proposed model, was developed using 955 multi-normal simulated data based on the mean and standard deviation of the observed LBW data in Model 2. This model is labeled as Model 3 (Table 3).

Abdollahian and Gunaratne (2013) developed two prediction weight models for newborn weight ($BW_{ith\ delivery}$) (grams). First model was formed based on four maternal characteristics: height (M_{height}) (cm), hemoglobin level measured before ($M_{HBbefore}$), and after ($M_{HBafter}$) vitamin C and iron tablets consumptions (mmHg), and body mass index (M_{BMI})(kg/cm^2), and four neonatal characteristics measured at delivery time: gestation age ($GA_{delivery}$) (weeks), length(B_{length}) (cm), head circumference (HC) (cm), and chest circumference (CC) (cm). The initial Multivariate linear regression model (the full model) was developed based on the 189 recorded normal delivery weight data and is labeled as Model 4 in Table 1.

Model 7 is a further development of prediction models on delivery weight for the LBW babies (BW_i) (kg) proposed by Abdollahian (2013). This model was developed based on 482 multi-normal simulated data based on the mean vector and the covariance matrix of the observed data in Model 6 (Table 2). This model considered additional three maternal characteristics, such as age (M_{age}), hemoglobin level measured before (Hb_{before}), and after (Hb_{after}) the consumption of vitamin C and iron tablet consumptions (mmHg).

Table 1 Existing prediction models based on both mother’s and fetal’s characteristics

Model 1	:	$BW_i = 1.46 - 0.00126\ M_{age} + 0.00299\ M_{weight} + 0.00483\ GA_{delivery} + 0.263\ Hb_{before} - 0.200\ Hb_{after}$
Characteristics used to construct the model		
Mother	:	age, weight, hemoglobin level measured before and after iron tablets consumptions
Fetal	:	gestation age at delivery
Model 2	:	$BW_i/100 = 2.6 + 0.141\ GA_{delivery} + 0.018\ M_{height} + 0.551\ HC + 0.375\ CC - 0.494\ M_{BMI}$
Characteristics used to construct the model		
Mother	:	height, and body mass index (BMI)
Fetal	:	gestation age at delivery, head circumference (HC), chest circumference (CC)
Model 3	:	$BW_i/100 = 5.14 + 0.183\ GA_{delivery} - 0.0268\ M_{height} + 0.345\ HC + 0.424\ CC - 0.401\ M_{BMI}$
Characteristics used to construct the model		
Mother	:	height, and body mass index (BMI)
Fetal	:	gestation age at delivery, head circumference (HC), chest circumference (CC)
Model 4	:	$BW_{ith\ delivery} = -6406 + 43.5\ GA_{delivery} + 40\ B_{length} + 88.9\ HC + 20.8\ CC + 10.6\ M_{height} + 43.1\ Hb_{before} + 0.57\ Hb_{after} + 5.1\ B_{BMI}$
Characteristics used to construct the model		
Mother	:	height, hemoglobin level measured before and after iron tablets consumptions, and body mass index (BMI)
Fetal	:	gestation age at delivery, length, head circumference (HC), chest circumference (CC)
Model 7	:	$BW_i\ (kg) * 10 = 28.3 - 0.240\ M_{BMI} + 0.0133\ M_{age} - 0.0307\ GA_{delivery} + 1.05\ Hb_{before} - 0.839\ Hb_{after}$.
Characteristics used to construct the model		
Mother	:	Pre-pregnancy BMI, age, hemoglobin level measured before, and after the consumption of vitamin C and iron tablets consumptions
Fetal	:	gestational age (GA)

IV. PREDICTION MODELS BASE ON MOTHER'S CHARACTERISTICS ONLY

Through the literatures study, we also located four models listed in Table 2 that was constructed based only on mother's characteristics.

Model 6 was developed by Abdollahian (2013) as a prediction model of birth weight for the LBW babies (BW_i) (kg) based on 11 actual LBW observed data and considered only one maternal characteristic: pre-pregnancy body mass index (M_{BMI}) (kg/cm^2). A simple linear regression model was performed as seen in Table 2.

Similarly, a study conducted by Titisari and Siswosudarmo (2013) suggested a simple linear regression model to predict infant birth weight (REFW) (grams). Instead of using pre-pregnancy BMI, this study used fundal height (FH) measurement (cm) in full-term pregnancy as a maternal characteristic model 8 (Table 2).

On the other hand, Sari and Sudiarti (2013) proposed a prediction model for baby's birth weight based on pregnancy weight gain during pregnancy. This study investigated the correlation between pre-pregnancy weight, first trimester weight gain, second trimester weight gain, third trimester weight gain, and birth weight. The aim was to predict delivery weight and investigate the most contributed factors to birth weight. By using correlation analysis and multiple linear regressions, the strength and the relationship direction between the independent variables and birth weight have been determined and the model is labeled as Model 9 (Table 2).

Budiman, Pramono, & Dewantiningrum (2013) also developed a prediction model for baby's delivery weight based on maternal age and weight. The aim was to examine the correlation between maternal age (M_{age}), weight (M_{weight}) (kg) and birth weight (grams) in Indonesia. By using cross-sectional with analytical approach, correlation, and multiple linear regressions, data were analyzed and modeled as Model 10 (Table 2).

Table 2 Existing prediction models based on mother's characteristics only

Model 6	:	BW_i (kg) * 10 = 32.7 – 0.377 M_{BMI}
Characteristics used to construct the model		
Mother	:	pre-pregnancy BMI
Fetal	:	-
Model 8	:	REFW = 126.7 X – 931.5
Characteristics used to construct the model		
Mother	:	fundal height (FH)
Fetal	:	-
Model 9	:	Birth weight = 1,764.133 + 0.023 (pre-pregnancy weight) + 0.131 (first semester weight gain) + 0.037 (second semester weight gain) + 0.037 (third semester weight gain)
Characteristics used to construct the model		
Mother	:	Pre-pregnancy weight, first semester weight gain, second semester weight gain, third semester weight gain
Fetal	:	-
Model 10	:	Birth weight = 1735.42 + 14.07 M_{weight} + 13.95 M_{age}
Characteristics used to construct the model		
Mother	:	Weight and age
Fetal	:	-

V. PREDICTION MODELS BASED ON FETAL'S CHARACTERISTICS ONLY

This systematic study found only one prediction model that formulated based on fetal's characteristics (Table 3).

Model 5 is the improvement of Model 4 where five characteristics, such as maternal height, hemoglobin before and after taking vitamin C and 60 iron tablets, BMI, and baby's chest circumference (CC) were not statistically significant at $\alpha = 1\%$ and 5% in making contribution to the regression model. Therefore, Model 5, suggested by Abdollahian and Gunaratne (2013), is known as a reduced regression of Model 4, involves only three neonatal characteristics at delivery time: gestational age (GA), length and head circumference (HC). By using the same amount of data and analysis method in Model 4, Model 5 is presented in Table 3 below.

Table 3 Existing prediction models based on fetal characteristics only

Model 5	:	$BW_{ith\ delivery}$ = -4140 + 41.8 $GA_{delivery}$ + 43.5 B_{length} + 107 HC
Characteristics used to construct the model		
Mother	:	-
Fetal	:	gestation age at delivery, length, and head circumference (HC)

VI. COMPARISON OF EXISTING PREDICTION MODELS

Having identified the significant characteristics for each model, the efficacy of the existing prediction models was assessed and compared using coefficient of determination (R^2), correlation coefficient (r), and mean prediction error. The results are listed in Table 4.

Table 4 Comparison of the efficacy of the existing prediction models

Proposed Models	Independent Variables	Delivery Weight	Coefficient of Determination (R^2) or Coefficient Correlation (r)	Mean Prediction Error
[1]	4 maternal and 1 fetal characteristics	Low birth weight	R^2 = 64% r = 0.8	3.2 grams
[2]	2 maternal and 3 fetal characteristics	Low birth weight	R^2 = 72.9%	-
[3]	2 maternal and 3 fetal characteristics	Low birth weight	R^2 = 65.9% r = 0.81	1 gram
[4]	4 maternal and 4 fetal characteristics	Normal and low birth weight	R^2 = 62.4% r = 0.79	93.9 grams
[5]	3 fetal characteristics	Normal and Low birth weight	R^2 = 59.4% r = 0.77	159.8 grams
[6]	1 maternal characteristics	birth weight (for the LBW babies)	R^2 = 29.3%	-
[7]	4 maternal and 1 fetal characteristics	Low birth weight	R^2 = 64% r = 0.8	0.09 grams
[8]	1 maternal characteristics	Normal birth weight	-	35 grams*
[9]	Four (4) maternal characteristics:	Normal birth weight	R^2 = 59.4% r = 0.77	159.8 grams
[10]	2 maternal characteristics	birth weight (for normal birth weight)	R^2 = 26.3%	

*The difference between estimated and actual delivery birth weight

Model 1 significantly conveyed that baby's birth weight (for the LBW babies) can be predicted by both mother's and baby's characteristics. Since the correlation coefficient was 0.8 and the mean prediction error was 2.2 grams (Table 4), therefore, it is concluded that the proposed multivariate linear regression model was capable of accurately predicting the weight for the low birth weight babies based on the characteristics of the mother and the fetal.

Model 2 shows that 72.9% of the variation in the weight of LBW babies can be explained by the combination of mother's characteristics (height, gestation week, and BMI) and neonate's characteristics (HC and CC) (Table 4). On the other hand, Model 3 indicated that 65.9% of the variation in the weight of LBW babies can be explained by these characteristics with the correlation coefficient r = 0.8 and the mean prediction error = 1 gram (Table 4). Therefore, it is concluded that three mother's characteristics and two baby's characteristics are enough to provide a reliable prediction of the delivery weight (for the LBW babies).

Model 4 confirms that 62.9% of the delivery weight variation for the newborn weight can be explained by the eight predictors (Tables 1 & 4). The correlation coefficient, r = 0.79, indicating that the model can be used to provide a reliable prediction of new born delivery weight. However, five of these characteristics, the four mother's characteristics and baby's chest circumference (CC), were not statistically significant at α = 1% and 5%. Therefore, they further proposed a reduced regression or Model 5 (Table 3). Based on the information presented in Table 4, the reduced model based on the top three most significant characteristics of the baby explains 59.4% of the delivery weight variation. The correlation coefficient of r= o.77 confirms that the reduced model is capable of providing a reliable weight prediction for the normal delivery weight.

Since both Models 4 and 5 were reliable to provide a prediction of normal delivery weight, the models were employed to estimate the delivery weight for the LBW babies recorded by the clinic. The results show that mean error for the full model was only 93.9 grams, while the reduced model based on 5 less predictors had a mean error of 159.8 grams (Table 4). Therefore, the proposed reduced model based on only 3 predictors can provide a reliable forecast of the delivery weight for LBW babies which is almost as good as the complicated full model with 8 predictors.

Model 6 based on only pre-pregnancy BMI is the best fitted simple linear regression model for the LBW babies. The coefficient of determination (R^2) in Table 4 confirms that 29.3% of the variation in the weight of LBW babies can be explained by the mother's pre-pregnancy BMI.

Model 7 was developed to improve the value of R^2 in Model 6. The correlation coefficient, r, of this model is 0.8 which indicates the model is a reliable model to predict the weight for LBW babies. The efficacy of the proposed model has been assessed through the mean prediction error of 0.09 grams which shows the model is providing a very accurate prediction of the delivery weight for the LBW babies.

Model 8, known as Risanto's formula was developed by Siswosudarmo in 1995 to estimate the infant birth weight based on mother's fundal height measurement. He used a cross sectional study conducted at Dr. Sardjito Hospital and 16 affiliated hospitals in the Province of Yogyakarta, Central Java and measured 560 maternal fundal height measurements of pregnant women. The result shows that the difference between estimated and actual fetal weight using his formula was smaller (35 grams) (Table 4) than the Johnson's formula (115 grams). Therefore, the Risanto's formula for estimating birth weight based on maternal fundal height was more accurate than Johnson's formula.

Model 9 shows that the delivery weight can be estimated based on mother's weight gain from the start of pregnancy or pre-pregnancy to the third semester of pregnancy. The coefficient of determination, R^2 presented in Table 4 suggests that 21.9% of the weight variation can be explained based on these three characteristics that can be easily measured in any rural clinics.

Model 10 confirms that the delivery weight can be estimated from mother's weight and age. The coefficient of determination, R^2 suggests that 26.3% of the variation in birth weight can be explained based on these characteristics. This results are consistent with studies conducted by Abdollahian, et al. (2012) (Model 1) and Abdollahian (2013) (Model 7).

VII. DISCUSSION

Delivery weight is one of the most significant indicators in improving newborns life expectancy and well-being. Together with the knowledge of gestational duration, birth weight can be used to predict the quality of health and the survival chances of newborns [24]. Abnormal fetal size may cause serious problems and illnesses that prevent newborns to grow optimally [28].

Low birth weight (LBW), one of adverse delivery outcomes, becomes an increasingly important awareness in obstetrics and gynecology. This prevalence contributes to approximately 60-80% of neonatal deaths worldwide [16]. According to the Indonesian Research and Health Development (2010), the prevalence of LBW in Indonesia accounts for approximately 9-11% and the reduction trend is not promising.

Birth weight estimate is vital to statistically control and detect the risks of having adverse delivery weight as early as possible. An accurate estimate of delivery weight can assist medical practitioners in making appropriate clinical decision prior to delivery [28], [9] in order to reduce the risks of serious illnesses, such as heart and stroke disease [23] and related problems to the neonates during their adult life.

Sufficient and accessible reliable information on characteristics that influence birth weight are required to develop better prediction models. According to WHO (2011), having complete and accurate health vital statistics are the preferred data source to estimate neonatal mortality rate. This would assist health community in their policy making and resource allocation [24] designed to reduce the mortality rate. However, "reliable estimates for prematurity [involving LBW, small gestation age (SGA), and preterm birth] in Indonesia are not available"[24, p. 938].

In the estimation process of birth weight, identification of the most contributed characteristics of mother and its accessibility are also fundamentally important. The World Health Organization (WHO) (1997) suggested maternal anthropometric measurements, defined as measurement of physical attributes [13], to be accounted for low birth weight prediction in developing countries. Despite the fact that a recent study conducted by Goto (2015a) did not recommend this predictability, except for maternal abdominal circumference, anthropometric measurements are the most applicable, accessible, and affordable method to assess maternal health status during their stages of pregnancy [15].

In this study, it is found that all existing models, except Model 5, have used maternal anthropometric measurements such as weight (Models 1 and 10), haemoglobin level (Models 1, 4, and 7), height (Models 2, 3, and 4), pre-pregnancy BMI (Models 2, 3, 4, 6, and 7), fundal height (Model 8), pre-pregnancy weight (Model 9), and weight gain every trimester of pregnancy (Model 9) in developing their prediction models. These factors are significantly associated with normal and low birth weight. The results are consistent with the statement that "anthropometric measurements can potentially indicate the risks of fetal and maternal outcomes, such as low birth weight and pre-eclampsia" [15].

The anthropometric measurements of fetal are also important and should be measured from the start of pregnancy to delivery time. The clinical context of the neonate is one of significant indicator to be considered when making the prediction [29]. The INTERGROWTH 21st Project has produced international fetal biometric standards based on ultrasound to assess the wellbeing of fetal during the intergrowth process [20] such as, head circumference and abdominal circumference. However, the utilization of ultrasound is apparently difficult in developing countries, particularly in rural areas, due to the lack of health equipment and skilled-personnel [9].

In our study, some fetal characteristics are measured at delivery time, such as gestational age (Models 1, 2, 3, 4, 5, and 7), head circumference (Models 2, 3, 4, and 5), chest circumference (Models 2, 3, and 4), and baby's length (Models 4 and 5). These characteristics significantly contributed to the prediction of delivery weight. Currently in the developing countries, chest circumference (CC) is the best anthropometric indicator of LBW among newborns [9].

It is found that 5 out of 10 existing models in this study have considered both maternal and neonatal characteristics in predicting delivery weight, while the rest only focus on maternal or fetal factors. Even though all mother's characteristics in the existing models can be measured during trimester of pregnancy, the prediction are mostly applicable at or after delivery time due to the lack of information on some predictors during antenatal care, such as birth weight, small-gestation-age (SGA) and Apgar score [22]. It is also found that none of the fetal characteristics, such as birth weight, gestation age (GA), head circumference (HC), chest circumference (CC) and baby's length, are accessible before delivery time.

The lack of knowledge on antenatal measurements and prediction models [22] for birth weight, particularly low birth weight, have been globally hinder clinicians to accurately identify and measure significant factors that contribute to LBW. This leads to the delay in delivering immediate and proper care to pregnant women and fetal. The measurements of the characteristics involved in the prediction models should be recorded and be accessible during the process of antenatal care (ANC) in rural areas in Indonesia. These tasks are part of the standard operational procedure of ANC proposed by the Ministry of Health of the Republic of Indonesia [19].

CONCLUSION AND RECOMMENDATION

This study has used several data base to review the last five years prediction models of delivery weight, particularly for the low birth weight (LBW) in Indonesia. These prediction models currently are applicable at delivery time due to the lack of complete and reliable data related to mother and fetal during pregnancy, particularly for the fetal characteristics. The use of advanced technology, such as ultrasound, will provide the intergrowth measurement of fetal, but it is difficult to be deployed in the rural Indonesia where health resources are limited. Alternatively, models based on the anthropometric measurements of mother and fetal can be the most applicable, accessible, and affordable methods to estimate fetal birth weight in the country. Some of these measurements have been applied in the existing prediction models. However, further investigation is necessary to accurately identify and measure the significant factors that contribute to the delivery weight of LBW infants. This will assist medical practitioners to detect abnormalities at the earlier stage of pregnancy and reduce the delay in providing the required interventions prior to delivery. Consequently improve the quality of care given to pregnant women and fetal through ANC centres.

AUTHORS CONTRIBUTIONS

D.A., M.A., and K.M. contributed to the study concept, design, analysis and interpretation. D.A. collected and summarized information on relevant research articles and policies in Indonesia. D.A. drafted this article, based on critical reading and comments from co-authors. M.A. and K.M. revised this article. All of the authors read and approved this final manuscript. D.A. is the guarantor of this article.

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