

**Description of the Impact Model Used to Estimate the Effect
of Risk Factors on Adverse Maternal and Child Outcomes**

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Introduction

The study of the association between risk factors and adverse outcomes is essential in maternal and child health research. Objective methods of data analyses are needed to assess the impact of modifying the distribution of risk factors on the rates of adverse outcomes in vulnerable populations. For instance, the study of the impact on birth defect rates of moving 25% of the women in the “less than high school education” category to the “more than high school education” category will require data analysis methods that assess the association between maternal education and birth defects. In many studies conducted by the Maternal and Child Health and Education Research and Data Center (the Research Center) at the University of Florida, the association between risk factors and adverse outcomes is analyzed using a log-linear model that associates the expected rate of adverse outcomes to linear combinations of the effects of selected risk factors. In this technical report, we provide a brief explanation of how the impact models used in the Research Center are constructed, followed by some examples of their use in maternal and child health policy research.

Basic Concepts

The Research Center impact model is a conceptual model that can be used for assessing the impact of a set of risk factors on the occurrence rate of an adverse outcome in a given population. The model conceptualizes the adverse event occurrence rate—the number of adverse outcomes in a given number of events or in a given period of time—as the product of the effects—called main effects and interaction effects—of a number of relevant risk factors.

As an example, suppose we are interested in the impact of mother’s race (BL=black, OT=other) and education (<HS = less than high school, HS = high school, >HS = more than high school) on the likelihood of birth defect in her child. Let $P(A, B)$ denote the occurrence rate of birth defects (e.g. number of birth defects per 1,000 births) in a risk category, A, of mother’s race ($A=BL$ or $A=OT$) and B of mother’s education ($B=<HS$, or $B=HS$ or $B=>HS$). In other words, let $P(BL, <HS)$ be the birth defect rate for black mothers with less than high school education ($A=BL$ and $B=<HS$),

$P(OT, HS)$ be the rate for non-black mothers with high school education, and so on. The impact model expresses $P(A, B)$ as a product of four terms:

$$P(A, B) = \kappa \times \varepsilon(A) \times \varepsilon(B) \times \varepsilon(A \& B), \quad (1)$$

where

- κ is the **overall** (baseline) birth defect rate in the population.
- $\varepsilon(A)$ and $\varepsilon(B)$ are the **main effects** of A and B , respectively. Each main effect measures the impact of a particular risk factor, when acting alone, on the overall birth defect rate. The main effect, $\varepsilon(A)$, is the factor by which the overall birth defect rate, κ , would change as the result of the impact of pregnant mother's race acting alone.
- $\varepsilon(A \& B)$ is the **effect of interaction** between mother's race and mother's education. The interaction effect measures how the two risk factors combine to modify the baseline birth defect rate.

As an example of the model in equation (1), consider a **hypothetical population** in which the overall birth defect rate is $\kappa = 20$ birth defects per 1,000 births and the main effects and interaction effects of mother's race and mother's education are as listed in Table 1A. Of course, in practice, these effects are unknown and have to be estimated on the basis of observed data on race, education and birth defect in the population of interest.

The numbers in Table 1 can be used with the model in equation (1) to determine the birth defect rates in each of the six Race—Education risk categories: black mothers with less than high school education ($A=BL, B=<HS$), black mothers with high school education ($A=BL, B=HS$), black mothers with more than high school education ($A=BL, B=>HS$), non-black mothers with less than high school education ($A=OT, B=<HS$), non-black mothers with high school education ($A=OT, B=HS$), and non-black mothers with more than high school education ($A=OT, B=>HS$).

Table 1A Effects of Mother’s Race and Education on the Rate of Birth Defects in Child When There is Interaction Between Race and Education

	Interaction Effects of Race and Education			Main Effect of Race (A)
	<HS	HS	>HS	
BL	2.0	1.0	0.5	2.0
Race (A)				
OT	0.5	1.0	2.0	0.5
Main Effect of Education (B)				
	5.0	2.0	0.1	

The birth defect rate in a given risk category is determined by multiplying the overall rate, κ , by the appropriate effects of mother’s race and mother’s education. For instance, to determine the birth defect rate in the population of all black mothers with less than high school education—that is, in the $A=BL, B=<HS$ risk group—we need to multiply the overall rate $\kappa = 20$ by the three effects: $\varepsilon(BL)$, the main effect of Black mother, $\varepsilon(<HS)$, the main effect of less than high school education, and $\varepsilon(BL \& <HS)$, the interaction effect of black mother and less than high school education. From Table 1A, $\varepsilon(BL) = 2.0$, $\varepsilon(<HS) = 5.0$ and $\varepsilon(BL \& <HS) = 2.0$. Thus the required birth defect rate is

$$P(BL, <HS) = \kappa \times \varepsilon(BL) \times \varepsilon(<HS) \times \varepsilon(BL \& <HS) = 20 \times 2.0 \times 5.0 \times 2.0 = 400,$$

per 1,000 births. Similarly, in the population of all non-black mothers with more than high school education, the rate per 1,000 births is

$$P(OT, >HS) = \kappa \times \varepsilon(OT) \times \varepsilon(>HS) \times \varepsilon(OT \& >HS) = 20 \times 0.5 \times 0.1 \times 2.0 = 2.$$

Table 2A shows the birth defect rates in the six risk categories, calculated using the hypothetical effects in Table 1A.

**Table 2A Birth Defects per 1,000 Births Calculated
 Using the Main and Interaction Effects in Table 1A**

		Education (B)		
		<HS	HS	>HS
Race (A)	BL	400	80	20
	OT	25	20	2

Interpreting the Impact Model

Interaction and main effects. Each main effect and each interaction effect listed in Table 1A equals the amount by which the occurrence rate should be multiplied to reflect the impact of the corresponding effect. For example, since $\varepsilon(OT \& <HS) = 0.5$ in Table 1A, the impact of interaction between mother’s race and mother’s education is to reduce the birth defect rate among the children of non-black mothers with less than high school education by a factor of 0.5. Similarly, $\varepsilon(BL \& HS) = 1$ implies that no change in the birth defect rate occurs as the result of interaction between black race and high school education. In other words, there is no interaction between race category “black” and education category “high school”.

Absence of interaction between two factors is characterized by the property: $\varepsilon(A \& B) = 1$ for all categories of A and B. In that case the two factors are said to be independent.

The occurrence rate in the presence of no interaction depends only on the main effects and can be expressed as a product of three terms: the overall occurrence rate (κ), the main effect of A ($= \varepsilon(A)$) and the main effect of B ($= \varepsilon(B)$). The model reduces to

$$P(A, B) = \kappa \times \varepsilon(A) \times \varepsilon(B).$$

Table 1B lists the race and education effects in a hypothetical population in which the main effects are the same as in Table 1A, but the six interaction effects are all equal

to 1. Thus Table 1B represents a population in which there is no race—education interaction effect.

Table 1B Effects of Mother’s Race and Education on the Rate of Birth Defects in Child When There is no Interaction Between Race and Education

	Interaction Effect of Race and Education			Main Effect of Race (A)
	<HS	HS	>HS	
BL	1.0	1.0	1.0	2.0
Race (A)				
OT	1.0	1.0	1.0	0.5
Main Effect of Education (B)	5.0	2.0	0.1	

The rates in Table 2B are the birth defect rates for the population described in Table 1B.

Table 2B Birth Defects per 1,000 Births Calculated For the Population in Table 1B

	Education (B)		
	<HS >HS	HS	
BL	200	80	4
Race (A)			
OT	50	20	1

Comparing the birth defect rates in Table 2A with the corresponding rates in Table 2B, we can see how interaction between factors can affect the expected number of adverse outcomes. For example, the expected rate of birth defects is 25 per 1,000 when interaction is present between non-black races and less than high school education. This number is doubled (50 per 1,000) when there is no interaction.

When using model (1) for assessing the association between a set of risk factors and a particular adverse outcome, the first step is to look at the interaction effects. Interaction effects are measures of how the risk factors combine to impact the occurrence rates of the outcome of interest. Relative risks provide a convenient method for summarizing the effect of interaction between two factors.

Relative Risk. Relative risk (RR) is a unit-free quantity useful for comparing the risk of adverse event occurrence in two risk groups. Relative risks provide a convenient means of summarizing how adverse event occurrence rates vary across risk groups. *The risk of an adverse event in Group 1 compared to that in Group 2 is*

$$RR(1 \text{ vs. } 2) = \frac{\text{Occurrence rate in Group 1}}{\text{Occurrence rate in Group 2}}$$

Thus a RR value of 1.0 implies that the adverse event rates are the same in the two groups. On the other hand, a RR value less than 1 means that Group 1 has a lower risk of adverse events than Group 2. The value RR=1.5 means that the occurrence rate of adverse event is 50% more in Group 1 than in Group 2.

Table 3A shows the relative risks of birth defect for infants of black mothers relative to that for infants of non-black mothers in the three education groups calculated under two different scenarios.

**Table 3A Risk of Birth Defect for Blacks Relative to Non-Blacks
 in the Three Education Categories**

	RR for Black Mothers		
	<HS	HS	>HS
Interaction-Yes	16	4	10
Interaction-No	4	4	4

The numbers in the top row are calculated for the effects in Table 1A (interaction present) while those in the second row are for the effects in Table 1B (interaction absent). The RR value of 16 in the top row of Table 3A is the result of dividing the birth defect occurrence rate of 400 per 1,000 in Table 2A for black mothers with less than high school education by the rate of 25 per 1,000 for non-black mothers with less than

high school education ($400/25=16$). This is the relative risk of an infant with birth defect for a black mother with less than high school education. We may conclude that, in the less than high school education group, the birth defect occurrence rate for black mothers is 16 times that for non-black mothers. The corresponding rate is 4 ($=80/20$) times that for non-black mothers in the high school education group and is 10 ($=20/2$) times that in the more than high school education group. Thus when there is interaction between race and education, the relative risk of birth defect for black mothers (relative to non-black mothers) changes from 16 to 4 to 10 as the mother's education level changes from <HS to HS to >HS.

In other words, when race and education interact, the rate of occurrence of birth defects in infants born to mothers of black race relative to that in infants born to mothers of non-black race changes with the mother's education level. By contrast, absence of race—education interaction implies that the relative risk for black mothers remains constant ($=4$) across the three education levels.

Relative risks can be used to compare risks in more than two categories. First a baseline category is selected and the RRs are used to compare the risk in the baseline group to the risk in each of the other groups. Table 3B shows the RRs for comparing the risks of a child with birth defect in the three education categories under the two interaction scenarios presented in Table 3A. The RRs are calculated with >HS education as the baseline category. The entries in Table 3B are constructed using the birth defect rates in Tables 2A and 2B. For example, the RR value of 20 for mothers with less than high school education is the result of comparing the birth defect rate of 400 per 1,000 births for black mothers with less than high school education in Table 2A with the corresponding rate of 20 per 1,000 births for black mothers with more than high school education ($400/20=20$).

Table 3B Risk of Birth Defect Infants for Mothers in <HS and HS Education Groups Relative to Mothers in >HS Group in the Two Race Categories

	RR for <HS Mothers		RR for HS Mothers	
	BL	OT	BL	OT
Interaction-Yes	20	12.5	4	10
Interaction-No	50	50	20	20

Again notice that, in the absence of interaction, the RR for each education category remains the same across the two race categories.

Adjusting Relative Risks. In the presence of interaction between mother’s race and education level, it can be seen from Table 3A that there is no single number that summarizes the risk of an infant with birth defect for a black mother compared to that for a non-black mother. Similarly, Table 3B shows that, when education level and race interact, no single number exists for comparing risks in either of the two education groups with that in the >HS education group.

Meaningful and comprehensible comparison of risks in the presence of interaction between risk factors could be problematic when several factors, each with many categories, are involved. Adjusted relative risks are frequently used to overcome this difficulty.

The adjusted relative risk for comparing Group 1 with Group 2 is

$$\text{Adjusted } RR(1 \text{ vs. } 2) = \frac{\text{Adjusted occurrence rate in Group 1}}{\text{Adjusted occurrence rate in Group 2}}$$

The adjusted occurrence rate in a group is calculated by averaging the occurrence rates for that group across all risk categories. The adjusted rate can be interpreted as the rate in a population comprised of individuals distributed evenly across all risk categories.

For example, when there is interaction between race and education, the adjusted occurrence rate for black mothers is the average of the rates for black mothers in the three education level groups in Table 2A. Thus

$$\text{Adjusted rate for black mothers} = \frac{1}{3}(400 + 80 + 20) = \frac{500}{3} = 166.67 .$$

For an interpretation of the value of 166.67 for the adjusted birth defect rate, observe that in a population of 3000 black mothers, comprised of mothers distributed evenly across the three education groups (that is, 1000 mothers in each group), the expected number of children with birth defect is $400+80+20=500$. Thus the birth defect rate in this population is 500 per 3000 or $\frac{500}{3}=166.67$ per 1000.

The corresponding rate for non-black mothers is the average of the three rates for non-black mothers:

$$\text{Adjusted rate for non-black mothers} = \frac{1}{3}(25 + 20 + 2) = \frac{47}{3} = 15.67,$$

Thus, the adjusted RR for black mothers in the presence of interaction is

$$\text{Adjusted RR} = \frac{166.67}{15.67} = 10.64.$$

The corresponding adjusted RR when there is no interaction may be calculated using the rates in Table 2B:

$$\text{Adjusted RR} = \frac{\frac{1}{3}(200 + 80 + 4)}{\frac{1}{3}(50 + 20 + 1)} = 4.$$

Similarly, the adjusted RR for comparing mothers with less than high school education with mothers with more than high school education, if interaction is present, is

$$\text{Adjusted RR} = \frac{\frac{1}{2}(400 + 25)}{\frac{1}{2}(20 + 2)} = 19.32,$$

and, if no interaction is present, then the adjusted RR for comparing mothers with less than high school education with mothers with more than high school education equals

$$\text{Adjusted RR} = \frac{\frac{1}{2}(200 + 50)}{\frac{1}{2}(4 + 1)} = 50.$$

In the presence of interaction, an adjusted RR must be interpreted with caution because it may not reflect a true comparison of the risks within any of the risk levels

used in its calculation. To see this, notice from the first row in Table 3A that the relative risk of birth defect for black mothers is 16, 4 and 10 in the <HS, HS and >HS education groups, respectively. Since none of these RRs equal 19.32, the claim that the risk of a child with birth defect for black mothers is 19.32 times that for non-black mothers is not valid for comparing the two groups within any one of the three education levels.

An adjusted RR may be interpreted as the relative risk in a population comprised of individuals distributed evenly across the risk categories.

This interpretation is consistent with the interpretation of the adjusted rates discussed earlier. For example, the adjusted RR value of 10.64 for black mothers relative to non-black mothers may be interpreted as—In a population in which mothers are evenly distributed across the three education groups, a black mother’s risk of a child with birth defect is 10.64 times that of the risk for a non-black mother.

No such difficulty exists when the two factors do not interact because the adjusted RR is the same as the RR in any of the risk categories. Consequently, the adjusted RR is the appropriate RR for comparing the two groups within every risk level used in the construction of this number.

The general approach to risk analysis with two risk factors may be summarized as follows:

1. Use appropriate statistical tests to see if interaction between the factors, if any, is statistically significant.
2. If significant interaction exists, use unadjusted relative risks for comparing risk groups within levels of the risk factors. Adjusted relative risks, when used to compare groups across levels of interacting risk factors, should be interpreted with caution.
3. If interactions are not significant, use adjusted relative risks for comparing the groups.

Using the Impact Model to Assess Policy Implications

The occurrence rates calculated from the Impact model can be used to develop policies to reduce the adverse event occurrence rates by modifying the sizes of the risk

groups. As an example, consider the hypothetical population for which the birth defect rates in Table 2A are appropriate. In this population, the birth defect rate for black mothers with less than high school education is 400 per 1,000 (= 40.0%) whereas the corresponding rate for black mothers with high school education is 80 per 1,000 (= 8%). Thus, one way to reduce birth defect rate in the population is to move black mothers in <HS group to HS group. The effect on birth defect rate of moving 1000 less than high school educated black mothers to the high school educated group may be determined as follows.

Among 1000 black mothers, we can expect 400 birth defects if they have less than high school education and 80 birth defects if they have high school education. Consequently, moving 1000 black mothers from less than high school education category to high school education category will result in a reduction of $400-80=320$ birth defects in the population.

Thus a cost-benefit analysis of the policy to provide high school education to 1000 black mothers can be performed by comparing the cost of implementing the policy with the benefit of reducing the birth defects by 320.

Of course, the problem is not as simple as it may appear at first sight. Before deciding to implement the policy to improve education level, one needs to examine the nature of the interaction of education level with other risk factors such as income and marital status. Answers to questions pertaining to these problems require a detailed analysis of the data to determine the “best model” that describes the associations of the risk factors with the adverse outcomes of interest.

Using Impact Model to Estimate Occurrence Rates

The Research Center impact model is a theoretical model for describing the association between an adverse outcome and a set of risk factors. The model conceptualizes the expected rate of adverse outcomes as the product of main effects and interaction effects of a number of suspected risk factors.

Unlike the two-factor model described in equation (1), a typical impact model used in the Research Center studies may involve as many as 15 risk factors. See

Appendices I and II for detailed descriptions of adverse outcomes and risk factors investigated in the Research Center studies.

Impact models for three or more factors, though direct extensions of the two-factor model, tend to be much more complicated. For example, with three factors—A=Race (BL, OT), B=Education (<HS, HS, >HS) and C=Marital status (YES, NO)—the impact model takes the form

$$P(A, B, C) = \kappa \times \varepsilon(A) \times \varepsilon(B) \times \varepsilon(C) \times \varepsilon(A \& B) \times \varepsilon(A \& C) \times \varepsilon(B \& C) \times \varepsilon(A \& B \& C), \quad (2)$$

where $\varepsilon(A)$, $\varepsilon(B)$ and $\varepsilon(C)$ are the main effects, $\varepsilon(A \& B)$, $\varepsilon(A \& C)$ and $\varepsilon(B \& C)$ are the two-factor interactions and $\varepsilon(A \& B \& C)$ is the three-factor interaction. Thus, compared to the 4 terms in the two-factor model, the three-factor model contains 8 terms. The number of terms increases rapidly with the number of factors (a four-factor model contains 16 terms) in the model.

Indiscriminate use of models with large number of risk factors has three major drawbacks. First, such models require large amounts of data and large computing resources for checking to ensure that they adequately represent the patterns of association (between risk factors and adverse outcomes) that are being studied. Second, by including too many risk factors in the model, one faces the danger of ending up with a model that describes the data well but contains too many redundant risk factors. Third, major interpretation problems will arise when mutually correlated multiple risk factors are included in the same model.

As an example of the difficulties associated with mutually correlated risk factors, consider the problem of assessing the effect on a child's DDD, the developmental delay or disability (yes, no) of two risk factors—PHS, the mother's health status at pregnancy (severe, moderate, mild) and NHS, the child's newborn health status (severe, moderate, mild). Interpretation of effects of PHS and NHS on the occurrence rate of DDD needs to account for the possibility that there might be a causal effect of PHS on NHS. In other words, improving PHS may cause an improvement in NHS. The total effect of PHS on DDD may be conceptualized as being composed of two components; (1) the direct

effect—the effect of PHS on DDD when there is no change in NHS, and (2) the indirect effect—the effect of PHS on DDD because of the change it causes on NHS. Since NHS cannot have a causal effect on PHS, the problem of decomposing NHS effect into direct and indirect effects does not arise.

The appropriate impact model for assessing the effects of PHS and NHS will depend upon the research question that one wants to answer. To answer the question, “What is the effect of PHS on DDD?” all that is needed is an impact model in which only PHS is included as the risk factor. Similarly, the question, “What is the effect of NHS on DDD?” can be answered with a model containing only NHS as the risk factor. To address the more complex question, “What are the direct and indirect effects of PHS and NHS on DDD?” more than one model needs to be fitted to the data. One model, in which PHS is regarded as the risk factor for NHS is needed to assess the effect of PHS on NHS. A second model in which both PHS and NHS are the risk factors for DDD is needed to assess the direct effects of PHS and NHS. Finally, by imbedding the PHS vs. NHS model in the DDD vs. (PHS, NHS) model, details of which are too mathematical for discussion in this report, the indirect effect of PHS on DDD can be estimated. Table 4 summarizes the model structures appropriate for estimating the effects of PHS and NHS.

Table 4 Models for Assessing Direct and Indirect Effects of PHS and NHS

No	Objective	Outcome	Risk factors
1	Total effect of PHS on DDD	DDD	PHS
2	Total effect of NHS on DDD	DDD	NHS
3	Direct effect of PHS on NHS	NHS	PHS,
4	Direct effects of PHS and NHS on DDD	DDD	PHS, NHS
5	Indirect effect of PHS on DDD	DDD	Imbed (3) in (4)

In the studies conducted in the Research Center, the impact models are selected with the view of ensuring ease of interpretation and computational feasibility. As a consequence, all models are constructed under the assumption that interactions

between more than two factors have negligible effects on the occurrence rates. For instance, when fitting a model with three factors (see equation (2)) the three factor interaction, $\varepsilon(A \& B \& C)$, is set equal to 1. The assumption of negligible higher order interactions is justified by past experience with Research Center data. This assumption has the beneficial effect of reducing the computational and interpretational complexity of the fitted models.

The Research Center impact models are fitted using the GENMOD procedure of SAS with the number of adverse outcomes as the response variable and log link function, assuming Poisson error distribution. This approach models the log of the mean rate of each adverse outcome as a linear function of the main effects and two-factor interactions of the risk factors included in the model. The best fitting model is selected using the stepwise model building with backward selection procedure, starting with a model that includes all main effects and all two-factor interactions. For each outcome analyzed, the adjusted relative risk (RR), the risk of an adverse outcome for a subject in each category of each risk factor relative to the risk in a selected reference category for that factor is calculated.

Policy Scenarios to be Explored Using the Impact Model

Policy scenarios, based on the impact model, will be prepared in the 2004-05 companion studies. In the child maltreatment study, for example, it will be possible to show how moving a certain percentage of women (say 20%) with less than a high school education to having a high school education would result in a certain percentage reduction (say 3%) of verified maltreatment. In the event the model finds an interaction between risk factors, for example, between maternal education and maternal race, it will still be possible to demonstrate that changing the percentage of, say, black women with less than a high school education yields a greater reduction in maltreatment rates than among white women with less than a high school education.

Using the model to explore the effects of modifying risk factors gives policy makers a set of options for commitment of resources. Model results, however, do not take into account the costs associated with interventions that reduce the percentage of

women who have a modifiable risk factor. If intervention costs associated with moving women (or infants) from a high risk category to a low risk category are ascertained, it will become possible to gauge which risk reduction programs yield the greatest return on investment.

In fiscal year 2004-05, The Chiles Center and The Research Center will develop impact scenarios as part of the following studies:

1. The impact of maternal and infant risk factors on pregnancy, birth, and infancy outcomes
2. Perinatal and sociodemographic risk factors associated with child maltreatment: Extending the scope of the analysis
3. Early educational outcomes of children whose mothers were Medicaid beneficiaries
4. The impact of perinatal Medicaid coverage on health care and education costs in the first six years of life.