Overview of the Sampling Design and Statistical Methods Used in the National Immunization Survey

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Abstract: The National Immunization Survey (NIS) is a large federally funded survey designed to estimate vaccination coverage rates for children residing in the United States aged 19 to 35 months. In 1999, over 8 million telephone call attempts were made to obtain provider-reported vaccination histories on 22,521 children in the age range of interest.

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The National Immunization Program and the National Center for Health Statistics, Centers for Disease Control and Prevention (CDC), and its contractor, Abt Associates Inc., have implemented the National Immunization Survey (NIS) as one element of the Childhood Immunization Initiative (CII).[1] The CII was set up to (1) improve the delivery of vaccines to children; (2) reduce the cost of vaccines for parents; (3) enhance awareness, partnerships, and community participation; (4) monitor vaccination coverage and occurrences of disease; and (5) improve vaccinations and their use.

One of the *Healthy People 2000*[2] and *Healthy People 2010*[3] objectives is to have at least 90% of children aged 2 years fully vaccinated with the recommended schedule of vaccines. Timely estimates of vaccination coverage levels for children aged 19 to 35 months are needed to monitor changes in vaccination coverage levels. The NIS is conducted to obtain data on vaccination coverage so as to fulfill the monitoring goals of the CII. Using the same data collection methodology and survey instruments in each IAP area, the NIS has the advantage of producing vaccination coverage levels that are comparable among IAP areas and over time.

Beginning with the second quarter of 1994, the NIS has conducted quarterly surveys in 78 Immunization Action Plan (IAP) areas, consisting of the 50 states, the District of Columbia, and 27 other large urban areas (Table 1). This design has made it possible to provide annualized estimates of vaccination coverage levels for ten antigens (diphtheria and tetanus toxoids and pertussis vaccine [DTP], poliovirus vaccine [polio], measles mumps and rubella vaccine [MMR], *Haemophilus influenzae* type b vaccine [Hib], hepatitis B vaccine [HepB], and varicella) within each of the 78 IAP areas with an acceptable degree of precision.

In addition to providing vaccination data from which coverage rates may be monitored, the objectives of the NIS are to assist CDC in allocating resources to states for the purposes of increasing coverage rates, to identify subpopulations and/or geographic areas in which rates are low, and to provide a database for epidemiologic research.

Summary of the NIS Sample Design

The NIS uses two phases of sampling to obtain vaccination information for a large national probability sample of young children: a random-digit-dialing (RDD) survey designed to identify households with eligible children aged 19 to 35 months, followed by the NIS Provider Record Check (PRC) Survey, which obtains provider-reported vaccination histories for eligible children.

The NIS RDD Sample

The NIS RDD design uses independent samples of telephone numbers in each of the 78 IAP areas. With an average sample size of 442 completed RDD interviews in each IAP area, the total number of completed RDD interviews in 1999 was 34,442.

The main goals of the first phase of the sample design are to: (1) select a probability sample of tele-

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Table 1. NIS IAP areas by state with population size of children aged 19 to 35 months, 1999 National Immunization Survey

State/IAP area	Population size
Alabama	89,139
Rest of state	75,709
Jefferson County	13,431
Alaska	14,039
Arizona	107,149
Rest of state	40,716
Maricopa County	66,433
Arkansas	52,193
California	772,850
Rest of state	429,620
Los Angeles	240,219
Santa Clara	38,994
San Diego County	64,016
Colorado	78,583
Connecticut	63,406
Delaware	13,877
Dist. of Columbia	10,397
Florida	293,555
Rest of state	226,711
Duval County	18,299
Dade County	48,545
Georgia	171,297
Rest of state	138,680
Fulton/DeKalb	32,617
Hawaii	25,750
Idaho	26,799
Illinois	262,382
Rest of state	187,819
Chicago	74,563
Indiana	120,546
Rest of state	100,490
Marion County	20,057
Iowa	52,547
Kansas	54,751
Kentucky	75,796
Louisiana	90,447
Rest of state	79,890
Orleans Parish	10,558
Maine	20,915
Maryland	110,369
Rest of state	94,293
Baltimore City	16,076
Massachusetts	113,982
Rest of state	102,185
City of Boston	11,797
Michigan	192,594
Rest of state	168,278
Detroit	24,316
Minnesota	95,357
Mississippi	58,957
Missouri	104,721
Montana	15,327
Nebraska	32,563
Nevada	41,865
New Hampshire	21,112
New Jersey	168,305
Rest of state	160,479
Newark	7,826
New Mexico	39,335
New York	367,384
Rest of state	195,473
NYC—5 counties	171,910
North Carolina	155,717
North Dakota	10,635
Ohio	216,841
Rest of state	165,993
Cuyahoga County	27,866
Franklin County	22,982
Oklahoma	69,117
Oregon	64,665
Pennsylvania	207,421
Rest of state	175,497
Philadelphia	31,924
Rhode Island	17,826
South Carolina	77,372
South Dakota	14,954
Tennessee	103,722
Rest of state	71,533
Shelby County	20,620
Davidson County	11,569
Texas	476,353
Rest of state	307,802
Dallas County	55,220
El Paso County	20,679
City of Houston	59,990
Bexar County	32,663
Utah	57,051
Vermont	9,832
Virginia	138,373
Washington	116,619
Rest of state	84,266
King County	32,353
West Virginia	28,640
Wisconsin	97,727
Rest of state	75,875
Milwaukee County	21,852
Wyoming	8,952

(continued in next column)

Table 1. *(continued)*

IAP, Immunization Action Plan; NIS, National Immunization Survey.

phone numbers for each IAP area, (2) ensure that the target number of interviews is achieved in each IAP area, (3) minimize in a cost-effective manner the number of age-eligible children excluded from the sampling frame, and (4) maintain an up-to-date sampling frame of telephone numbers.

To accomplish these goals, the NIS uses the list-assisted method of random-digit dialing.[4] This method is used to select a random sample of telephone numbers from banks of 100 consecutive telephone numbers (e.g., 617-495-0000 to 617-495-0099) in an IAP area that contain one or more directory-listed residential telephone numbers. The sampling frame of telephone numbers is updated each quarter in order to include new telephone exchanges and area codes. Cellular telephone exchanges are currently excluded from the NIS RDD sampling frame.

The target sample size of completed telephone interviews in each IAP area is designed to achieve an

approximately equal number of children with provider-reported vaccination histories across all 78 IAP areas. The selection of a quarterly probability sample of telephone numbers to meet the target number of completed interviews with age-eligible children in an IAP area poses some challenges, because the 78 IAP areas differ with respect to: (1) the percentage of telephone numbers that are working residential numbers, (2) the likelihood of contacting a person among those numbers that are residential, (3) the percentage of contacted households willing to complete the screener interview, (4) the percentage of households with an age-eligible child, (5) the willingness of parents/guardians to complete the telephone interview, and (6) the percentage of completed telephone interviews with vaccination histories from vaccination providers. These factors lead to considerable variation in the total sample size of telephone numbers needed to achieve the target sample size of completed interviews per IAP area. We have dealt with these challenges by implementing four design tools. First, we use an automated procedure to eliminate a portion of the nonworking and business telephone numbers in the sample before they are dialed by the interviewers.[5] Second, we have developed a statistical model to predict the number of sample telephone numbers needed in each IAP area for a given quarter of interviewing.[6] Third, after drawing the required sample size of telephone numbers for an IAP area, we divide the sample into random subsamples called "replicates." By administering the sample release on a replicate-by-replicate basis, we are able to control the total number of interviews obtained and to spread the interviews for each IAP area evenly across the entire calendar quarter.

The NIS Provider Record Check Survey

At the end of the NIS RDD interview, permission to contact vaccination providers is requested from the parent/guardians of each sample child. When verbal consent is obtained, the child's vaccination providers are mailed an immunization history questionnaire (IHQ). This mail survey portion of the NIS is called the PRC Survey. Vaccination providers who are mailed the NIS IHQ in the PRC Survey are asked to record the sampled child's vaccination history on the IHQ and return it. Providers have the option of responding via mail or facsimile (fax). Postcard reminders and telephone follow-up are used to encourage providers to participate in the study. The information collected from a child's vaccination providers is used to determine whether a child is up-to-date on their vaccinations. Data obtained from the IHQ are used, along with information about the NIS sample design, to estimate vaccination coverage rates for IAP areas, states, and the nation.

Table 2. Content of 1999 NIS household interview

Section S	Screening questions to determine eligibility, roster of eligible children, availability of immunization records
Section MR	Most–knowledgeable-respondent callback/ questions
Section SR	Immunization record callback questions
Section A	Vaccination history, asked if immunization/ records are available
Section B	Vaccination history, asked if immunization records are not available
Section C	Demographic and socioeconomic questions
Section D	Provider information and request for consent to contact the eligible child's/vaccination providers

NIS, National Immunization Survey.

Content of the NIS RDD Household Questionnaire and the IHQ

This section describes the questionnaires used in the NIS RDD telephone survey of households and in the NIS PRC Survey.

Content of the NIS RDD Household Questionnaire

The Computer-Assisted Telephone Interview (CATI) questionnaire used in the RDD portion of the 1999 NIS data collection includes a screening section to identify households with children aged 19 to 35 months and a vaccination interview based on the National Health Interview Survey Immunization Supplement. The questionnaire has been translated into Spanish, and procedures have also been developed for handling households in which neither English nor Spanish is spoken. The content of each section of the 1999 NIS telephone interview is summarized in Table 2.

In Section S, the reason for the telephone call and the purpose of the survey are explained to the RDD respondent, and the household is screened to determine whether any children in the household are aged 19 and 35 months. In Section MR, if there is an eligible child in the household, the respondent is asked whether he/she is the most-knowledgeable person about the child's vaccination. If the respondent indicates that another person in the household is the most knowledgeable and that person is unavailable to be interviewed, a "callback" is scheduled to interview the most-knowledgeable person at a later date.

In Section SR, the person being interviewed is asked whether he/she has a written record (immunization card) of the child's vaccination history. If the child does not have an immunization card, or if the child does and the person being interviewed can easily make its information available for the interview, the RDD interview proceeds. However, if it is determined that the child does have an immunization card, but it is inconvenient

for the person being interviewed to find and use it during the interview, an attempt is made to reschedule the call at a later date when information from the immunization card can be made available during the interview.

When immunization card information is available during the interview, the respondent is asked to provide information from it directly in Section A of the interview. However, when immunization card information is not available, the respondent is asked to recall from memory information about the child's vaccination history in Section B of the interview.

Section C obtains information that includes the relationship of the respondent to the child, the race of the child, the race of the mother, information about household income and educational attainment of the mother of the child, and other information on the socioeconomic characteristics of the household and its eligible children.

At the conclusion of the NIS RDD household questionnaire, consent is requested to contact the child's vaccination providers. If verbal consent is obtained, identifying information (name, address, and telephone number) on the vaccination provider(s) is requested that enables NIS personnel to proceed to contact them. When verbal consent and sufficient identifying information are obtained, the IHQ is mailed to the child's vaccination provider.

Content of the Immunization History Questionnaire

The IHQ is designed to be simple and brief, to minimize burden on the providers, and to encourage participation in the survey. It consists of two pages. Page 1 includes space for a child identification label that contains identifying information about the child (child's name and birth date and the full name of the parent) to assist staff in the provider's office in locating the child's medical record. Page 1 also includes a grid for recording dates of vaccinations. The antigens listed in the NIS questionnaire form columns of the grid, and an additional column is available for recording other vaccines. Page 2 of the questionnaire contains a series of questions that enable the facility and vaccination provider to be characterized (e.g., whether the facility is public or private and the specialty of the provider).

The IHQ is sent by mail to providers along with instructions to mail or fax the questionnaire back after completing. If a response is not obtained after 2 weeks, reminder postcards are sent to the provider. Then, if necessary, another questionnaire packet is mailed 2 weeks later, and finally a telephone call is made to the provider to remind and encourage him/her to complete the form and either mail or fax the information back. In some instances, we accept the reports over the phone. The goal in the data collection process is to give gentle reminders to providers and to make reporting as easy as possible by offering multiple reporting mechanisms and allowing sufficient time.

Key Data Collection Statistics for 1999

Several indicators of survey progress and data quality are routinely produced for the NIS at the IAP area and national levels. Statistics such as survey response rates are also used as measures of data quality. Table 3 presents key national monitoring indicators for the 1999 NIS data collection.

The monumental size of the NIS is evident in the numbers listed in Table 3. A total of 2,049,712 telephone numbers were called in 1999 to identify 1,009,539 households, as shown in rows 3 and 6 of Table 3. Among the identified households, 979,601 (97.0%) were successfully screened for age-eligible children. Of these, 943,267 did not contain age-eligible children, and 36,334 (3.7%) contained one or more age-eligible children. Among the households containing one or more age-eligible children, 33,640 (92.6%) completed the NIS household RDD interview.

The response rates in the NIS are among the highest achieved in large-scale RDD surveys. A standard approach for measuring response rates for RDD surveys, known as the CASRO household response rate, has been defined by the Council of American Survey Research Organizations.[7] In 1999, the CASRO household response rate (row 11) was 79.6%. The CASRO response rate is the product of the resolution rate (88.6%, row 5), the screening completion rate (97.0%, row 7), and the interview completion rate among eligible households (92.6%, row 10). The resolution rate is the percentage of the total phone numbers called that were classifiable as being nonworking, nonresidential, or residential. The screening completion rate is the percentage of known households that are successfully screened for the presence of age-eligible children. In addition, the interview completion rate is the percentage of households with one or more age-eligible children that complete the NIS RDD interview. Alternative response rates that take into account both nonresponse and noncoverage are also used to monitor the NIS.[8,9]

Row 12 of Table 3 shows that there were 34,442 age-eligible children with completed RDD interviews in the 1999 NIS. Rows 13 through 16 of Table 3 list monitoring indicators for the PRC phase of the NIS. Specifically, row 13 gives the rate of obtaining verbal consent from household respondents to contact their children's vaccination providers—84.0% in 1999. The number of IHQs that were mailed to vaccination providers was 37,373. This number exceeds the number of completed child interviews in row 12 because some children have more than one vaccination provider.

Among vaccination providers who were mailed an

Table 3. Key monitoring indicators for 1999 NIS

Row	Key indicator	Number	Percent
Monitoring indicators for RDD phase of NIS			
1	Total selected sample in released replicates	2,533,610	—
2	Phone numbers resolved before CATI	483,898	19.1% (Row 2/Row 1)
3	Total phone numbers called	2,049,712	—
4	Advance letters mailed	822,187	40.1% (Row 4/Row 3)
5	Resolved phone numbers—*resolution rate*	2,243,895	88.6% (Row 5/Row 1)
6	Households identified	1,009,539	45.0% (Row 6/Row 5)
7	Households successfully screened for presence of age-eligible children—*screening completion rate*	979,601	97.0% (Row 7/Row 6)
8	Households with no NIS age-eligible children	943,267	96.3% (Row 8/Row 7)
9	Households with NIS age-eligible children—*eligibility rate*	36,334	3.7% (Row 9/Row 7)
10	Households with NIS age-eligible children with completed RDD interviews—*interview completion rate*	33,640	92.6% (Row 10/Row 9)
11	CASRO response rate	NA	79.6% (Row 5 × Row 7 × Row 10)
12	Age-eligible children with completed RDD interviews	34,442	—
Monitoring indicators for PRC phase of NIS			
13	Children with consent obtained to contact vaccination providers	28,936	84.0% (Row 13/Row 12)
14	Immunization history questionnaires mailed to providers	37,373	—
15	Immunization history questionnaires returned from providers	35,345	94.6% (Row 15/Row 14)
16	Children with adequate provider data	22,521	65.4% (Row 16/Row 12)

CASRO, Council of American Survey Research Organizations; CATI, Computer-Assisted Telephone Interview; NIS, National Immunization Survey; PRC, Provider Record Check survey; RDD, random-digit-dial survey.

IHQ, 94.6% returned the questionnaire or other information pertaining to the child's vaccination history. Among the children with completed NIS household RDD interviews, 22,521 (65.4%) had adequate vaccination histories returned by their vaccination provider(s).

Statistical Methods for Obtaining Estimated Vaccination Coverage Rates in the NIS

For children sampled in the RDD phase of the NIS, sampling weights have been developed that account for the selection of a random sample of telephone numbers within each IAP area, nonresponse arising from sample telephone numbers with an undetermined residential status, post-stratification to published totals, nonresponse arising from sample households that do not complete the screener to determine age eligibility, nonresponse attributable to age-eligible sample households that do not complete the interview, and more than one telephone line in some age-eligible households.

The introduction of bias into an RDD survey can result from lack of telephone coverage within the population of interest. Although the average telephone coverage for NIS age-eligible households is estimated to be 90%,[19] coverage within IAP areas ranges from 76% to 97%. In order to mitigate the potential impact of such bias, weighting adjustments[11] are made to the NIS using data from the National Health Interview Survey, which collects national vaccination data from both telephone and nontelephone households, and the Current Population Survey, which provides geographic data on telephone coverage.

The RDD-phase weights are further adjusted for provider nonresponse resulting from the second phase of sampling. Among children for whom a completed RDD interview was obtained in 1999, the percentage with adequate provider-reported vaccination histories required to determine vaccination status was 65%. Failure to obtain provider data for the remaining 35% was attributable to the parent not giving consent to contact the child's provider in the RDD survey, the failure of the provider to respond to the NIS-provider mail survey, or the failure of the provider to give adequate information about a child's vaccination history from which vaccination status could be determined. To account for potential differences in vaccination rates between children with adequate provider

data and children who do not have adequate provider data, the RDD sampling weights were adjusted in two steps. In the first step and within each IAP area, sampled children were grouped into adjustment cells according to the similarity of their estimated propensities to have adequate provider data. In the statistical literature these propensities are called "response propensities."[12–14] A group of children who have similar response propensities will also be similar with respect to variables that are strongly associated with the probability of having adequate provider data. In this important respect, children within each adjustment cell are comparable. Because of this, all sampled children in the cell may be represented by the sampled children within the cell who have adequate provider data.

In the second step, the RDD-phase sampling weights of children with adequate provider data were divided by the cell's weighted response rate. These adjusted sampling weights enable children with adequate provider data to represent all children belonging to the cell. By doing this, the bias in estimated vaccination coverage rates attributable to differences between sampled children who have and do not have provider-reported vaccination histories is reduced. Within each adjustment cell, children without adequate provider data are represented by children who are similar to them with respect to their response propensities and other associated variables. A more-detailed description of this method is given by Smith et al.[15] Zell et al.[16] describe the estimation methodology used in the NIS prior to 1998.

Vaccination coverage rates correspond to ratio estimates, as described by the statistical literature on methods for complex sample surveys.[17] Because of the adjustment to the RDD-phase sampling weight described above, statistical analyses require only data from children with adequate provider data, along with their adjusted RDD-phase sampling weight. To summarize the statistical methodology by which vaccination coverage rates and their standard errors are obtained from these data, let Y_{hij} be an indicator, for the jth child in the ith sampled household in the hth stratum of the NIS sampling design, which is equal to 1 if the child is up-to-date and 0 otherwise. Also, let W_{hij} denote the adjusted RDD-phase sampling weight of this sampled child. Then, letting

$$\hat{Y}_h = \sum_{i=1}^{n_h} \sum_{j=1}^{m_{hi}} W_{hij} Y_{hij}$$

and

$$\hat{T}_h = \sum_{i=1}^{n_h} \sum_{j=1}^{m_{hi}} W_{hij}$$

the national estimator of the vaccination coverage may be expressed as:

$$\hat{\theta} = \frac{\sum_{h=1}^{L} \hat{Y}_h}{\sum_{h=1}^{L} \hat{T}_h}$$

where L denotes the number of strata (IAP areas) in the NIS.
Letting

$$Z_{hij} = \frac{W_{hij}(Y_{hij} - \hat{\theta})}{\hat{T}_h}, \quad Z_{hi} = \sum_{j=1}^{m_{hi}} Z_{hij},$$

and

$$\bar{Z}_h = \frac{\sum_{i=1}^{n_h} Z_{hi}}{n_h},$$

an estimator of the variance coverage rate, $\hat{\theta}$, is

$$\hat{V}(\hat{\theta}) = \sum_{h=1}^{L} \frac{n_h}{n_h - 1} \sum_{i=1}^{n_h} (Z_{hi} - \bar{Z}_h)^2.$$

In these equations, n_h denotes the number of sampled households containing children with adequate provider data in the hth IAP area, and m_{hi} denotes the number of age-eligible children in the ith household in the hth IAP area.

Quality Assurance in the NIS

The NIS uses state-of-the-art data collection and data processing systems, with numerous built-in, quality-control functions, to collect and process vaccination histories from the eligible households and identified vaccination providers.

The NIS Household RDD Survey

A major contributor to the quality, consistency, and timeliness of the NIS data is its state-of-the-art sample management system, which has been developed to monitor data collection results. An array of highly automated, intelligent systems manages 312 RDD samples annually (78 IAP areas × 4 quarters). Over 20 unique performance measures are tracked for each of these samples. The sample management system, like the survey's quality assurance procedures, follows the guidelines for statistical process control and total quality management techniques.[18,19]

For the RDD component, a cornerstone of the survey's quality assurance program is the online interviewer monitoring system. A random sample of 5% of the interviewers' work is selected for monitoring by quality-control staff and supervisors. The calls and interviews are monitored using audio and video capabilities. Supervisors have access to statistical reports

showing an interviewer's performance over time and in comparison to the group's aggregate statistics. These reports are continuously available and can be reviewed with interviewers at any time. The monitoring system employed for the NIS is one of the most rigorously controlled and comprehensive systems available.

Other important aspects of the quality assurance program for the RDD household survey include matching of the sample telephone numbers to a database of business telephone numbers to remove business numbers from the sample, a PC-based autodialing system to eliminate nonworking numbers, and the matching of telephone numbers with a database of directory-listed residential telephone numbers in order to obtain addresses for as many sample households as possible in order to mail advance letters as a method of maximizing survey response rates. To reduce data entry errors and improve processing of the information, several online, look-up, topic-oriented databases are integrated with the CATI system. For example, when consent to contact the child's vaccination provider is obtained, the name and address of the provider are requested. As this information is provided verbally in the RDD interview, the CATI system finds it automatically in its online look-up list of names, addresses, and telephone numbers of vaccination providers. In addition, several automated built-in range edits and consistency checks are included in the CATI. These additional quality assurance procedures contribute to a reduction in the total cost of the data collection by minimizing interviewer labor and overall burden to respondents.

The PRC Survey

The design and procedures of the provider component follow a proven mail survey methodology documented by Dillman.[20] The major challenge to ensuring data quality for the provider component of the NIS stems from the fact that it is a self-administered mail survey, and such surveys often have low response rates. The most-critical quality-assurance activities occur during postprocessing of the returned questionnaires or vaccination records. All returned immunization history questionnaires are examined to identify and correct any obvious errors prior to data entry, such as data entered in the wrong location on the questionnaire or information submitted for the wrong child. The questionnaires are then data entered with 100% verification. The National Immunization Program also conducts a manual quality-assurance review of 10% of all forms returned by respondents every quarter. Resulting error rates for the edit process are estimated to be <1%.

Summary

The NIS is an important surveillance system that accurately monitors the overall levels of vaccination coverage among young children in the United States. The design of the NIS facilitates inferences about the coverage levels for the total population of children aged 19 to 35 months, as well as for many subgroups and geographic areas of the country. The NIS can provide coverage estimates for a wide range of subgroups of the population defined, for example, by income, race and ethnicity, age of child, marital status of mother, education of mother, household size, mobility status, census region and division, and metropolitan statistical areas. The NIS also has a more-limited capability of producing within-IAP area estimates for subgroups or geographic domains. Although the NIS can effectively monitor vaccination levels for a variety of subgroups at the national level, it is not designed to identify small "pockets of need" within IAP areas without resorting to more-complex statistical methods for obtaining estimates in small areas.

However, a most-important advantage of the NIS is that the same data collection and estimation methodology are used in each IAP area. This, coupled with a centrally operated data collection system continuously monitored using state-of-the-art quality-assurance techniques, ensures the validity of comparisons of estimated coverage rates among states as well as over time.

The inclusion of the PRC in the NIS allows for the production of more-accurate estimates than with data from only a household survey. In addition, important statistical adjustments are made for households without telephones[11] and for provider nonresponse. Current and future expansion of the NIS to collect more–broad-based health data will greatly enhance the utility of the NIS surveillance tool to meet the ever growing need for data at the state and local levels for purposes of public health policy and planning. Finally, estimates from the NIS allow policymakers to evaluate the effectiveness of vaccination delivery programs, to target programs for geographic areas and populations with coverage levels below the targets, and to monitor the introduction of new vaccines.

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