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Topic (iv): New and emerging methods, including automation through machine learning, imputation, evaluation of methods

**IMPROVING IMPUTATION: THE PLAN TO EXAMINE COUNT, STATUS, VACANCY, AND  
ITEM IMPUTATION IN THE DECENNIAL CENSUS**

**Supporting Paper**

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**I. BACKGROUND**

1. The Census Bureau began imputing values for missing responses with the 1950 census. The fact that this also was the first census to be processed by an electronic computer was not a coincidence. Since that time, the Census Bureau has worked to create or refine computerized techniques for imputing responses. One procedure developed to take advantage of the processing power of computers was the use of a “hot deck” – first implemented in the 1960 census - to impute values from nearby housing units. A hot deck is a data table (or “matrix”) in which values of reported donor responses, stratified by selected characteristics of the individuals, are stored and updated on a flow basis and used as needed to assign values of the variable(s) in question to donees, that is, people (or housing units) with similar characteristics who did not respond. This means that values imputed generally come from the nearest household (“nearest neighbor”) with similar characteristics. Hot deck imputation (also known as “allocation”) is used in most cases when it is not possible to assign values either from other information provided by the respondent or from information provided by other household members. This method is applied not only to population characteristics (for example, age, race, educational attainment, and income) but also to housing characteristics (such as housing tenure), housing unit status (whether an address actually identifies a unique housing unit), occupancy status, and population count. The hot deck is also known as a “sequential” hot deck because housing units are sorted geographically first, after which the hot deck sequentially stores and allocates values as it passes from one housing unit to the next.

2. As computer capacity grew, so did the effort to make hot-deck imputation more accurate by making the matching criteria more sophisticated. For example, more dimensions (characteristics) were used to match donors and donees. The number of values stored in each hot deck cell increased to accommodate situations where there was a large non-response and the risk of assigning values from the same donor repeatedly was higher. For example, in Census 2000, the hot decks used to assign an Hispanic origin were stratified by age and race, and they also were divided into three separate hot decks by whether the person had a Spanish surname (as determined from a dictionary of names): 1) donors with a Spanish surname, 2)

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donors with a non-Spanish surname, and 3) donors with no surname or with a name that was not clearly either Spanish or not Spanish.

## II. THE PROBLEM

3. The Committee on National Statistics' Panel to Review Census 2000 (2004) noted several concerns about the "sequential hot deck (SHD)" approach. First, the panel noted that the SHD relied on a single donor rather than obtaining more information from the local area, which could result in the hot deck assigning an "odd" value from that single donor. Second, SHD may not fully incorporate the multivariate nature of imputation. Third, this method may have difficulty doing simultaneous imputation of several variables that are correlated. Finally, SHD fails to produce an error estimate that could be used to determine a measure of item non-response variance so that it could be included as a component of the overall variance estimate. (2004, 442-444) An external panel, tasked with reviewing the Census Bureau's Program of General Census and Survey Research and Support and three of its specific programs (Missing Data and Imputation, Small Area Estimation, and Ethnographic Applications), had similar concerns (see Tanur et al., 2003). The panel recommended a "state-of-the-art imputation engine for basic demographic characteristics of households and the individuals within them." They also recommended the use of administrative records to improve the imputation models (2003, 13).

4. In response to these concerns and recommendations, the Census Bureau has launched an extensive and rigorous research effort in preparation for the 2010 census to study the possibility of using alternative imputation methodologies.

## III. TYPES OF IMPUTATION

5. Two main paths of research are being conducted on imputation: 1) count imputation and 2) characteristic imputation.

6. The count imputation path comprises the following types of imputation:

- Household Size Imputation. When Census Bureau records indicated that a housing unit was occupied but the number of residents could not be determined from the information available, a population count for the unit was imputed.
- Occupancy Status Imputation. When Census Bureau records indicated that a housing unit existed but whether it was occupied or vacant could not be determined from the information available, occupancy status (occupied or vacant) was imputed; then, if the unit was imputed to be occupied, a household size was imputed.
- Housing Unit Status Imputation (referring to whether the address actually identified a unique housing unit). When Census Bureau records contained an address, but there was insufficient information about whether the address represented a valid, nonduplicated housing unit, the unit's status as an occupied housing unit, a vacant housing, or a nonexistent housing unit was imputed. If the unit was imputed as occupied, its household size was imputed. Examples of addresses not considered to represent housing units include buildings used only for business purposes.

7 Present research efforts on characteristic imputation will be applied only to the Census 2000 short-form characteristics – household relationship, sex, age, race, Hispanic origin, housing tenure (renter/owner), and occupancy type.

## IV. ALTERNATIVE IMPUTATION METHODOLOGIES

8. The following are the main methodologies being tested:

A. Administrative records data involving direct assignment. For records that can be matched to administrative records, and under circumstances permitted by relevant legal authorities and polices, the information will be assigned to the matched census record. Methodologies using administrative records will adhere strictly to all requirements to protect the confidentiality of respondent's information.

- B. Administrative records data involving modeling. For records that cannot be matched to administrative records, modeling will be implemented only for count imputation topics (status, occupancy, and count).
- C. Spatial modeling. In this technique (see Thibaudeau, 2002), characteristics are obtained from neighboring housing units to generate an imputed value through statistical modeling, systematically capturing the relationship among characteristics of interest. Spatial modeling in this application refers to the relationship between the missing data item and other characteristics from geographically close households. This process allows imputation errors to be assessed.
- D. Canadian Census Edit and Imputation System (CANCEIS). In 1992, Statistics Canada introduced a new method of imputation for demographic variables (Bankier, 1997; Bankier, 2000). The key features are first to identify the nearest neighbor from which to borrow information and then to determine the minimum number of variables to impute for the record requiring imputation. This procedure reverses the traditional imputation procedure of determining what variables to impute first and then finding the information from comparable neighbor households. The advantage of CANCEIS is that, rather than looking at only one or two variables at a time, it maximizes the number of variables viewed simultaneously, resulting in a better preservation of the joint distribution of variables before and after imputation.
- E. Modified traditional hot deck. Improvements such as capping the maximum allowable household size and performing imputation in phases using a pre-defined geographic sort will be evaluated.

## V. STRATEGY FOR TECHNICALLY EVALUATING ALTERNATIVE IMPUTATION METHODOLOGIES

9. The plan for evaluating each type of imputation is composed of the following steps:
- A. Create a “truth deck” for each state. The “truth deck” files are made up of households for which no imputation was needed under the Census 2000 edit and imputation process for anyone in the household. Certain fields are flagged as being “missing” for the purpose of this analysis. The truth deck is intended to reflect as much as possible the results of the Census 2000 operations, so the truth deck identifies about the same percentage of cases requiring imputation based on the missing data patterns observed in Census 2000. About the same percentage of records with reported data is flagged and treated as if the reported data are missing for analysis purposes. The construction of this comparison file is discussed below. Separate sets of truth deck files were created for count imputation and for characteristic imputation.
- B. Run each of the methods, including the traditional hot deck, against the truth deck file for each state.
- C. Compare the resulting distributions against the reported values; calculate statistics that can be used to compare the results for each alternative methodology, including the traditional hot deck; and analyze the operational feasibility of the method in a decennial census environment.

## VI. Creation of Truth Decks

10. Three different truth decks are being created:
- A. The count imputation truth deck file is a housing-unit-level file stratified by selected characteristics at the block-group level. The truth decks for each state use available census information to stratify all records into different groups, based on selected operational, characteristic, and geographic variables. Classification variables may vary from state to state. A uniform probability of missing: 1) status, 2) occupancy, or 3) count information is assigned to all records within each stratum. The probability is the ratio of the number of cases requiring each type of count imputation to the total number of cases within each stratum. Each record is randomly flagged as needing imputation or not based on the probabilities in

each stratum. The flagging process is replicated 100 times to account for variability in the random selection of records being flagged. Afterwards, this truth deck is used as the data file on which to run different count imputation methodologies and conduct analyses allowing comparison of imputed values to actual values. For each method described in Paragraph 8 above, at least one imputation is run for each replication.

B. The housing unit population characteristic imputation truth deck file is a person- level file for imputing race, Hispanic origin, age, sex, relationship, and tenure. Even though tenure is a housing-unit level characteristic, we use the same truth deck. The methodology is similar to that for the count imputation truth deck but with different flagging procedures. For person characteristics, the flagging is set at the person level. Tenure is set at the housing-unit level. The truth deck is being constructed based on the observed missing data patterns in Census 2000. Namely, if a characteristic is usually missing with another characteristic for a certain segment of the population, the pattern is retained when flagging fields or records for imputation. County and household size are the two most important factors for determining the missing pattern. The missing pattern varies from county to county and, within a county, it varies from one-person households to two-person households, from two-person households to three-person households, etc.

C. A separate truth deck consisting of vacant housing units only is being created to evaluate whether the imputed results from spatial modeling or the Census 2000 hot deck are closer to the reported values for the type of vacancy.<sup>2</sup> The methodology to create the vacancy truth deck will be similar to the methodology of the other truth decks.

## **VII. APPLYING THE ALTERNATIVE METHODOLOGIES**

11. The table below summarizes which methodologies will be applied to each imputation type:

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<sup>2</sup> Type of vacancy consists of the following categories: 1) for rent; 2) for sale only; 3) rented or sold, not occupied; 4) for seasonal, recreational, or occasional use; 5) for migrant workers; and 6) other vacant.

Method	Count Imputation			Characteristic Imputation						
	Status	Occupancy	Count	Race	Hispanic origin	Age	Sex	Tenure	Relationship	Type of vacancy
Admin. Records, Direct Assignment	X	X	X	X	X	X	X			
Admin. Records, Modeling	X	X	X							
Spatial Modeling	X	X	X					X		X
CANCEIS						X	X		X	
Traditional Hot Deck	X	X	X	X	X	X	X	X	X	X
Revised Hot Deck*	X		X							

\* The Revised Hot Deck will not affect characteristic imputation and will not be available for inclusion into the first phase of characteristic imputation evaluation. As the table indicates, only the traditional hot deck can currently impute all types of missing information. If a new method is recommended to replace the hot deck for some types of imputation, then clearly a hybrid approach to imputation will be required to impute situations that the new method cannot.

### VIII. FULLY EVALUATING THE RESULTS

12. The research question to be answered is - can we develop an imputation method that is superior to the current hot deck method and meets the following criteria/guidelines:

- Numerical and Distributive Accuracy
- Operational Feasibility and Cost Effectiveness
- Public Acceptance

Evaluation of numerical and distributive accuracy of the results from these methodologies is being conducted on two levels. On one level, we are using descriptive analyses involving the examination of distributions (for example, single year of age, race by Hispanic origin, and age by sex by relationship) to compare the impact of each methodology on characteristics of interest. On another level, we are employing statistical measures that summarize the accuracy of the imputations based on each method.

13. Additional information is being collected and analyzed concerning operational feasibility issues such as:

- The complexity of the method/process
- The impact and interrelationship of external systems and subsystems
- The number of operating systems, run times, file formats and programming languages used
- Security issues (e.g., use of administrative records needing an approved environment for processing)
- The degree of human intervention
- The number of machine-to-machine transfers required

14. Based on the experience of implementing the hot deck methodology, any “new” method (or methods) chosen will need to be fully and clearly explained to ensure that the public and data users understand the method, its usefulness, and any other implications.

## **IX. TIME FRAME FOR ANALYSIS**

15. Alternative methodologies are currently being run on the various “truth deck” files, including the above-mentioned evaluation measures, and these methodologies will be compared and analyzed. One or more methodologies will be selected with the goal of developing the specific individual methodology or a hybrid of methodologies for testing in the 2006 Census Test.

## **X. LIMITATIONS**

16. We have noted the following limitations thus far:

- Because not all methods generate all needed fields (even within the count/status and item areas, see table on page7), it will be a challenge to compare them.
- Because we will generate multiple measures for each method, it will be a challenge to develop an overall “summary” of these measures.
- The truth deck reflects decennial respondents or non-response follow-up interview results; thus, their status as “truth” is an assumption that is not always correct. However, they are taken as the standard for comparison.
- The method for creating truth decks may itself create an unknown bias that may favor one methodology over another.
- Treating housing units as independent evaluation units ignores the fact that properties of addresses and people are geographically clustered.

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