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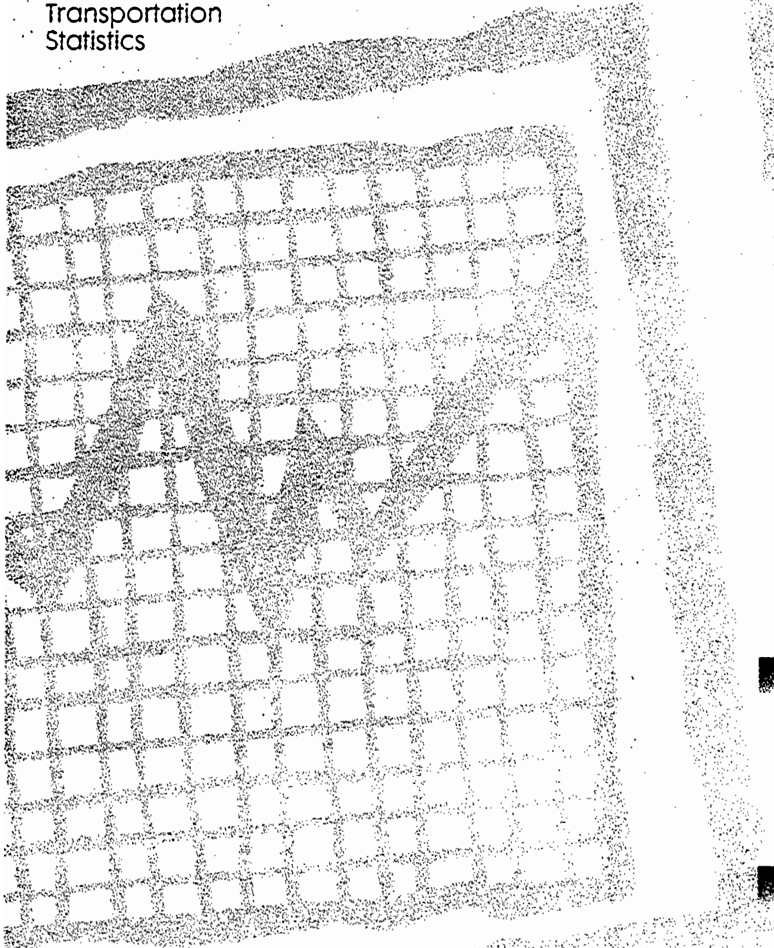

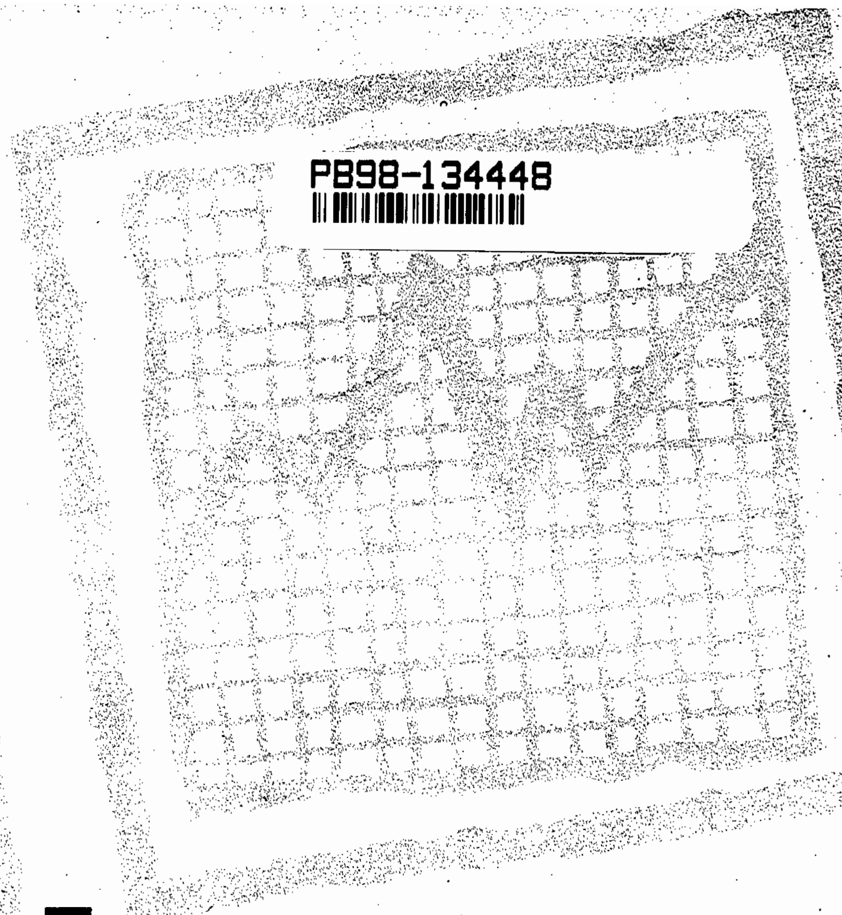

Implications of Continuous Measurement for the Uses of Census Data in Transportation Planning

IMPLICATIONS OF CONTINUOUS MEASUREMENT FOR THE USES OF CENSUS DATA IN TRANSPORTATION PLANNING

BUREAU OF TRANSPORTATION STATISTICS

U.S. DEPARTMENT OF TRANSPORTATION

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Marsha Fenn, Advanced Management Technology, Inc., designed and edited the report. Tomara Arrington, Graphic Services, U.S. Department of Transportation, provided the cover design and report layout.

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PREFACE

The Bureau of the Census received a great deal of congressional criticism concerning the cost and accuracy of the 1990 census. In response to that criticism, the Bureau extensively evaluated alternative methods for conducting the decennial census. Early in the planning process, the Census Bureau selected a new data-collection system for thorough testing and possible implementation as an alternative to the traditional census in 2000. Under this new system, called "Continuous Measurement," the detailed social, economic, and housing information, including journey-to-work data, traditionally collected decennially with the long-form questionnaire on a sample basis, would instead be obtained by an ongoing, "continuous" monthly survey. The census would obtain only population and housing unit counts and a few basic characteristics.

A change from the traditional long-form census questionnaire to Continuous Measurement could significantly impact how state and metropolitan transportation planners use decennial census data. Pursuant to its statutory responsibility for representing the Department of Transportation and the transportation community in matters of federal statistical policy, the Bureau of Transportation Statistics conducted a study to assess the implications of Continuous Measurement data for the uses of census data in transportation planning.

This study of Continuous Measurement began in mid-1994 and concluded in early 1995. The report presents the findings from that study, and reflects the Census Bureau's proposal for Continuous Measurement at that time. Soon after the study's completion, Census officials received the report so as to inform the Bureau's decisionmaking for the 2000 census. Since then, the Bureau has made minor changes to its plans, but the basic proposal for an ongoing monthly survey remains the same.

On February 28, 1996, the Census Bureau formally announced that it planned once again to use a long-form questionnaire in the 2000 census, but as a bridge to a new Continuous Measurement system in the next decade. The Bureau is conducting an operational test of Continuous Measurement in selected metropolitan and rural areas in 1996 in anticipation of initiating the Continuous Measurement survey, now called the American Community Survey, in 1999. The Bureau of Transportation Statistics' study of Continuous Measurement and this report are, therefore, an important first step in informing the transportation community of the new census data system that it must adapt to after the 2000 census.

The American Community Survey will be a large monthly household survey independent of the census. For the years 1999 to 2001, the survey will consist of the same questions asked in the 2000 long form, and will go to 400,000 households per month. After 2001, the content can vary and the sample size will likely drop to 250,000 households per month.

The overlap between the decennial long-form data and data from the American Community Survey will allow transportation planners to compare the two data sets to determine the implications of Continuous Measurement for the uses of decennial census data in transportation planning.

Bureau of Transportation Statistics
April 1996

EXECUTIVE SUMMARY

BACKGROUND

State and metropolitan transportation planning organizations rely on the data from the decennial census for a broad array of applications. Data from the long-form census questionnaire, which includes questions covering place of work, mode of transportation to work, carpooling, travel time and time of departure to work, vehicles available, and mobility limitations are used for planning and modeling travel behavior. The Intermodal Surface Transportation Efficiency Act of 1991, the Clean Air Act Amendments of 1990, and the Americans with Disabilities Act all increase the transportation planning requirements and related data requirements of states and metropolitan planning organizations (MPOs).

Congress has expressed concern about the accuracy and the cost of the 1990 census effort. In response to this concern, the Census Bureau is considering alternatives to the traditional long-form questionnaire for the 2000 census. One of these alternatives, called Continuous Measurement, would replace the long-form questionnaire with an ongoing sample survey conducted each month, and the decennial census would only collect the count of the number of persons and housing units and a few key population and housing characteristics.

Continuous Measurement has been heavily promoted by the Census Bureau as a replacement for the long form. Because of the potential for loss of the critical transportation data collected by the long-form questionnaire, and the prospect for collection of such data in a new Continuous Measurement process, the Bureau of Transportation Statistics contracted with the COMSIS Corporation to study the implications of Continuous Measurement for the uses of census data in transportation planning.

DESIGN AND METHOD OF THE STUDY

COMSIS assembled a panel of seven experts on the uses of data in the field of transportation planning to assess the implications of Continuous Measurement. Prior to the first meeting of the group, extensive background materials were sent to all participants describing uses of census data in transportation planning and the methodology of and proposals for Continuous Measurement. Panel members were asked to identify issues for discussion at the first workshop.

At the first workshop, held in September 1994, representatives of the Census Bureau provided the panel with an overview of Continuous Measurement and presented the Bureau's current thinking on its testing and implementation. The panel also heard a debate on the merits of Continuous Measurement between Dr. Leslie Kish, Professor Emeritus, University of Michigan, and Dr. Stephen Fienberg, Carnegie Mellon University. The panel then identified key Continuous Measurement issues to be developed into position papers for presentation and discussion at the panel's second session.

During the nine weeks between the first and second workshops, each member of the panel prepared a paper analyzing a specific topical area or issue pertaining to the implications of Continuous Measurement for the use of census data in transportation planning. The panel reconvened in November 1994, and presented their papers, discussed and debated issues regarding Continuous Measurement and data needs for transportation planning, determined the findings of the study, and made recommendations.

GENERAL FINDINGS

The transportation planning expert panel assembled for this study found that Continuous Measurement holds promise for providing useful data for transportation planning, but that Continuous Measurement is an untested process, the results of which need to be compared and evaluated against those obtained from a conventional census. The panel questions the advisability of the Census Bureau making a decision in 1996 to eliminate the long-form questionnaire for the 2000 census without sufficient testing, and questions the Bureau's ability to implement new systems to put Continuous Measurement into operation by 1999. The panel believes the Census Bureau should undertake a test for the 2000 census where long-form data are collected nationwide and compared with a parallel collection of Continuous Measurement data for a representative sample of geographic areas. The panel expressed concern about the potential loss of benchmark data at the beginning of a new millennium. The panel also expressed skepticism about congressional funding of Continuous Measurement past the first three years at the sampling rates currently proposed.

DETAILED FINDINGS

Study findings are organized into four major topics of discussion: 1) Data Availability, 2) Data Suitability for Planning Needs, 3) Process/Implementation Issues, and 4) Summary Recommendations.

DATA AVAILABILITY

■ *Timeliness and Currency*

The panel believes that more timely and current data under Continuous Measurement are a major benefit of the proposal. Under Continuous Measurement, the Census Bureau anticipates that data products will be made available within one year of the collection year, and annual updates of data will be available continuously.

■ *Continuity and Cost*

Continued availability of the data collected in the long-form decennial census questionnaire is imperative. Long-form census data provide larger samples at lower costs per person than surveys conducted locally for specific uses. The panel perceives threats to the continued availability of data under Continuous Measurement, such as the potential for congressional reductions in funding, which may reduce Continuous Measurement sample sizes or cancel the Continuous Measurement process altogether sometime in the future.

The panel recommends further evaluation of other options to Continuous Measurement, such as an intercensal long-form collection at mid-decade with appropriate reductions in sample size to keep costs in line with once-a-decade collection. The panel emphasizes the need for a smooth transition between the current method of collection and Continuous Measurement if it is implemented.

■ *Accessibility and Confidentiality*

The trend in transportation planning has been to narrow the focus of analysis in geographic detail, from ZIP Codes to census tracts and even smaller units. Census data from 1990 from Summary Tape Files 1 and 3 and the Census Transportation Planning Package (CTPP) are very important for this level of analysis. Travel and land-use studies make extensive use of cross-sectional data (e.g., travel mode by income and by size of household) available only in the CTPP. The Census Bureau's Public Use Microdata Sample data are also very helpful in this type of analysis, but are geographically limited.

The panel believes that it is important to ensure that data will be readily accessible to users as quickly as possible after collection. As sample sizes decrease under Continuous Measurement, the panel is concerned that the Census Bureau's Microdata Review Panel may increasingly restrict access to microdata to protect confidentiality. The panel respects concerns about confidentiality, but would like a full examination of alternatives to maintain and increase user access to data, such as deputizing researchers and MPO staff or shielding personal data through creative means of disclosure avoidance. The panel recommends that public use microdata from Continuous Measurement be released for geographic areas of 100,000 or more population.

DATA SUITABILITY FOR PLANNING NEEDS

Data that are collected and made accessible must still pass the test of suitability for the desired task. The panel identified concerns with various facets of data accuracy, both in the Continuous Measurement proposal and in current long-form data collection efforts. The panel was also impressed by promised Continuous Measurement flexibility features.

■ *Accuracy*

With Continuous Measurement, the Census Bureau anticipates greater accuracy in coding and interviewing due to permanent staffing, instead of the temporary staffing associated with taking the census every 10 years. The Census Bureau acknowledges that significant sampling error would be present in annual Continuous Measurement data, which will be alleviated by creating multiyear moving averages. However, representatives of the Census Bureau assured the panelists that annual point estimate data from Continuous Measurement would be released with caveats, because of their high sampling error. Some panel members expressed concern that the high sampling error in annual Continuous Measurement, compared with long-form data, would reduce the suitability of data for various applications, while other panelists asserted that the reduced levels of confidence and increased error are acceptable for the types of applications performed with the data.

The panel also expressed concern for the accuracy of Continuous Measurement's projected response rates and of the representative demographic sampling of those responding. The potential exists for reduced response rates if the data are not collected in a decennial census with its national publicity program and media coverage, which would then negatively impact quality or increase the cost of data collection.

■ *Flexibility in Content and Sampling*

The panel was impressed with Continuous Measurement's potential for flexibility in content and sampling, including experimenting with wording of questions such as journey to work, adding questions for particular needs such as response to a new rail opening or a flood, and increasing sampling rates in a state or region for special purposes. The panel cautions users about the conflict between continuity and flexibility.

■ *Content and Geocoding*

The panel was very concerned about the accuracy of place-of-work geocoding in general (whether or not Continuous Measurement is implemented). The proposed Master Address File continuously corrects and updates residence addresses, but not businesses. The panel strongly recommends that the Census Bureau update business addresses for use in place-of-work coding on a level comparable to that made for household addresses.

The panel expressed concern about the wording of certain questions, such as the journey to work. Asking about the "usual day" rather than a specific day underrepresents lesser used transportation options. The panel recommends experimentation with additional questions such as nonwork trips and trip chaining.

PROCESS/IMPLEMENTATION

The panel expressed misgivings about Continuous Measurement as a "moving target." The Continuous Measurement process is evolving, and a final Continuous Measurement proposal may be far different from the proposal evaluated by this panel, and possibly far less appealing.

■ *Costs and Implications of Maintaining and Updating Data*

The panel recognized the increase in data maintenance that will occur under Continuous Measurement. The panel questioned who would incur the costs if the Census Bureau relies on continuous updating of geographic information by states and MPOs. This may be an unacceptable burden if funding is not provided, particularly for small MPOs.

Concern also existed about changing geographic boundaries on a constant or annual basis. Annual data must be coded to a consistent geography from year to year to be valuable, or, if updated, flagged in a reference file associated with the zone. Annexations and other boundary changes could make analysis much more difficult. Implementing the plan without working out such details with the transportation community, states, and MPOs is not advisable.

■ *Intergovernmental Cooperation*

A smooth transition from decennial long form to Continuous Measurement demands the participation of interested parties. The Department of Transportation, groups such as the American Association of State Highway and Transportation Officials, committees of the Transportation Research Board, and others need continued involvement in testing data, content, and methods, and in identifying products. The panel suggested that the U.S. Department of Transportation (DOT) and the Census Bureau establish a mechanism for interested parties to receive continued updates on plans and procedures, such as electronic bulletin boards and newsletters.

SUMMARY RECOMMENDATIONS

Several recommendations were made by the transportation planning expert panel for consideration by the Census Bureau, federal decisionmakers, and the transportation community.

CENSUS BUREAU

1. Set up a process to allow transportation experts access to the results of its Continuous Measurement simulation project.
2. In cooperation with the transportation planning community, implement a design and content effort for journey-to-work and related questions. In addition to research on the wording of the journey-to-work question itself, the expert panel also recommends testing questions on access and egress modes from the "major" commuting mode (e.g., driving or walking to a bus stop or rail station). Distinguishing among the combinations of modes used to get to and from work, which may often differ for many people, is an important concern to transportation planners.
3. Improve transportation data user access to census data, such as deputizing researchers and MPO staff.
4. Emphasize the continual update of business addresses, including geocoding and test methods.

Other issues that the Census Bureau needs to consider include proper representation of rare populations, development of procedures for more cooperative interaction with MPOs, and potential improvements to transportation models. The panel expressed concern about lower or biased response rates. The panel recommends that the Census Bureau conduct research during the testing to determine whether response rates are consistent across a broad spectrum of the population, and what steps could be taken to reduce bias from nonresponse.

FEDERAL AND CONGRESSIONAL DECISIONMAKERS

1. Invest in research and experimentation, including parallel long-form collection in the decennial year along with Continuous Measurement, to ensure availability of needed data at appropriate levels of accuracy.
2. Consider total costs to the user community (i.e., state and local governments, and MPOs) of changing collection methods, not only costs of the Census Bureau. The transportation planning expert panel believes it would be valuable to study what the different approaches would cost various levels of government. One example is the need for various agencies to continually maintain geographic referencing systems and other data, in order to keep the Census Bureau Master Address File current for Continuous Measurement implementation. Federal decisionmakers need as complete an estimate as possible of the full cost differences for the collection methods, and not just the costs to the Census Bureau and to other federal government agencies, in order to choose the best option.

DEPARTMENT OF TRANSPORTATION

DOT needs to intensify the research and training it provides for various users of census data in the transportation community. The transportation planning expert panel recommends, in particular, establishing specialized training oriented to the needs of small and medium-size MPOs. The panel expressed concern that the staffs at such MPOs might try using data from a Continuous Measurement approach in the same way that data developed for one point in time had been used from the previous decennial censuses.

CONCLUSIONS

Continuous Measurement has the potential for increasing the utility and timeliness of census data for transportation planners if:

- it is tested in parallel to the regular decennial long form in the year 2000 to provide users with comparative data;
- users determine that Continuous Measurement data are an acceptable alternative to the conventional census; and
- it is carried out as planned and promised with full continuous surveys, with the promised data products provided in a timely manner, and with flexibility for special requests honored and completed at a reasonable cost.

Chapter 1 Purpose of the Study

State and metropolitan transportation planning organizations rely on the data from the decennial census for a broad array of applications. Data from the long-form questionnaire, which includes questions on place of work, mode of transportation to work, carpooling and vehicle occupancy, travel time to work, time of departure from home to work, the number of vehicles available to each household, and the number of persons with a health condition that limits their mobility outside the home are used for planning and modeling travel behavior.

Transportation data have been collected with the long form in each census since 1960. After the 1970, 1980, and 1990 censuses, the U.S. Department of Transportation (DOT) funded the development of a special tabulation by the Census Bureau of data tailored to the transportation planning data needs of over 300 metropolitan planning organizations (MPOs) and the 50 state departments of transportation.

State and metropolitan transportation agencies are increasingly reliant on census data to meet the requirements of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and the Clean Air Act Amendments of 1990 (CAAA). The procedures involved in the comprehensive transportation planning process required by the ISTEA are very data intensive. Small-area data from the decennial census provide much of the required information for trend analysis, travel modeling, and other analyses related to highway, transit, and multimodal planning and development. The CAAA, for example, requires state and local public agencies to prepare comprehensive vehicular travel and pollutant profiles. These profiles require analysis of detailed household characteristics, mode of travel, trip lengths, and commuter patterns for which data are frequently obtained from the decennial census.

Despite the increasing dependence of states and MPOs on decennial census data, the Census Bureau is considering eliminating the long-form questionnaire for the 2000 census and replacing it with a Continuous Measurement data-collection system. Congress has expressed concern about the increasing undercount and cost of conducting the decennial census, and some critics attribute a large share of these increases to the long-form data collection. Continuous Measurement is one response to that criticism.

Under Continuous Measurement, the 2000 census would collect on a 100-percent basis only basic items including population and housing unit counts and a few key population and housing characteristics. The more detailed characteristics collected in past censuses from a sample of households using the long-form questionnaire would not be collected. Instead, the long form would be replaced by a smaller sample survey that would be conducted monthly on a "continuous" basis.

Discussion of the Census Bureau's plans for the 2000 census took place at a session of the 1994 annual meeting of the Transportation Research Board. Attendees expressed concern over the potential for loss of the time series of transportation data traditionally collected with the long-form questionnaire, and the collection of such data in an untested Continuous Measurement process. The attendees called for an evaluation of such a change as it would affect transportation planning.

In response to the concerns of the transportation profession, DOT's Bureau of Transportation Statistics (BTS) contracted to have an independent assessment made of the implications that a "Continuous Measurement System," compared with the long-form questionnaire, would have on the extensive uses of the data from the decennial census for transportation planning. This report documents the study conducted and provides conclusions and recommendations regarding the possibility of implementing a Continuous Measurement system.

BTS has the mandated responsibility for representing DOT and the transportation community in matters related to federal statistical policy and is the DOT representative to the Federal Agency Policy Committee on the Year 2000 Census. BTS provides the Office of Management and Budget with DOT's requirements for data from the decennial census for use in state and local transportation planning activities required by federal legislation.

CHAPTER 2 IMPORTANCE OF CENSUS DATA FOR TRANSPORTATION PLANNING

HISTORICAL PERSPECTIVE

The Bureau of the Census has included transportation questions in the long-form questionnaire for each decennial census since 1960. The 1960 census included three questions pertaining to transportation: worker's place of work (city, county, and state), worker's mode of travel to work, and the number of automobiles available at home. Journey-to-work questions were first added to the census primarily to collect data on commuting interchanges between large cities and their suburbs. These data were then used to delineate metropolitan statistical areas. Also, during the 1960s, most urban areas simultaneously conducted extensive origin-destination (OD) surveys, and transportation planning efforts relied on census data to check the results of the surveys.

Most urban areas continued to use their basic OD survey data in the 1970s, and utilized 1970 census data to update this information. However, the 1970 census marked a major advancement in the availability of data for urban transportation planning. For the first time, place-of-work and means-of-travel-to-work data were coded to the census block, using Address Coding Guides and the Dual Independent Map Encoding files developed by the Census Bureau. The block-level data could then be aggregated to form user-defined tabulation areas.

After the 1970 census, the U.S. Department of Transportation (DOT) funded the creation by the Census Bureau of the Urban Transportation Planning Package (UTPP). The UTPP was a special tabulation of 1970 census data tailored to meet the data needs of metropolitan transportation planning. The data contained in the package were tabulated by traffic analysis zone (TAZ), developed by the local metropolitan planning organizations (MPOs). Each planning agency wishing data in the UTPP format contracted with the Census Bureau directly for processing the data.

From 1975 to 1977, the Census Bureau included questions pertaining to the journey to work as part of the Annual Housing Survey (AHS). The transportation supplement to the AHS was sponsored by DOT. Surveys were conducted in 60 metropolitan areas over the three-year period, and a national survey was conducted in 1975. During this time period, the Journey-to-Work Statistics Branch was created within the Census Bureau to oversee the collection, processing, tabulation, and analysis of journey-to-work data.

The transportation supplement to the AHS increased the demand for transportation planning data among MPOs, and the escalating cost of conducting OD surveys contributed to the MPOs' increased dependence on decennial journey-to-work data. The 1980 census included several transportation data items not collected in 1970. In addition to questions regarding place of work and mode of travel to work, the following were included on the long-form questionnaire for 1980:

- type of carpooling arrangement,
- number of persons riding in the carpool,
- travel time from home to work,
- number of automobiles available to each household,
- number of trucks or vans available to each household, and
- number of persons with a disability that limited or prevented access to public transportation.

The 1980 place-of-work data were once again coded to census tract and block. As a result of the improvements in the coding reference materials developed under the direction of the Census Bureau's Journey-to-Work Statistics staff, the majority of workers were coded down to small-area geography, a significant improvement over the 1970 census.

Again, after the 1980 census, the Census Bureau produced and DOT sponsored the UTTP special tabulations, which states and MPOs had the option of purchasing. Nonmetropolitan transportation agencies could purchase a modified version of the package.

The 1990 census produced several new advancements in the funding, geocoding, and processing of transportation statistics. The 1990 Census Transportation Planning Package (CTPP), formerly called the UTPP, was sponsored by the 50 state departments of transportation through a pooled-funding arrangement with the American Association of State Highway and Transportation Officials (AASHTO). The funding supported the processing of data in the CTPP format for all states and MPOs for the first time. In contrast to the

1970 and 1980 UTPPs, the 1990 CTPP comprised two separate packages: one for states, the State Element; and the other for MPO planning regions, the Urban Element. The Urban Element is coded at the TAZ level, while the State Element provides demographic and commuter data for political units such as cities and counties throughout the state.

Further technical advancements by the Census Bureau and DOT were achieved in the place-of-work coding for the 1990 census. The first was the development of the Census/MPO Cooperative Assistance Program, which provided MPOs the opportunity to assist Census in geocoding place-of-work data for their region. The second advancement was the development and implementation by the Census Bureau of an automated place-of-work coding system.

USES OF DECENNIAL CENSUS DATA

State and regional transportation planning agencies have grown increasingly dependent on census data over the past 30 years. Federal legislation enacted since the last decennial census, including the Intermodal Surface Transportation Efficiency Act (ISTEA), the Clean Air Act Amendments of 1990 (CAAA), and the Americans with Disabilities Act (ADA), require more detailed analyses of transportation systems and environmental impacts than previously conducted. As a result, these analyses require better quality data for smaller geographical areas. Over the years, the decennial census has become one of the most dependable and consistent sources of journey-to-work, household, income, and employment data available to the transportation planning profession. This also applies to the myriad of governmental agencies at all levels with responsibilities to plan and develop transportation systems. Demographic and journey-to-work data are used in a variety of transportation, land-use, and air quality analyses. A brief discussion of the various uses of census data in transportation planning follows.

SURVEY EXPANSION

Many of the metropolitan planning organizations in large urbanized areas periodically collect a sample survey of demographic and travel data of people and households. Because the data-collection effort is so costly, most small urban area MPOs do not collect travel survey data and rely solely on the demographic and journey-to-work data provided by the decennial census. However, in most large urban areas, locally collected travel survey data are augmented by the census demographic data for sampling, weighting, and expansion, to provide more information on geographic and demographic variability. Typically, the survey samples are very small, in many cases representing one-half to one percent of the population. Many MPOs use census data to:

1. determine sample sizes and the categories used for sampling through a stratified sample design,
2. check for biases in the survey results, and
3. expand and weight the travel survey data to represent the regional population.

TREND ANALYSIS

Transportation planners utilize census data to monitor trends in travel behavior. The decennial census provides consistent comparable data for states and metropolitan areas throughout the country. The decennial census is an excellent source of cross-sectional and time-series demographic data within and among metropolitan areas. Planners and policymakers can consistently observe changes over decades in mode of travel, carpool size, trip length, household size, vehicle ownership, and so forth—all of which affect the development of metropolitan, state, and national transportation policies. Regionally, trend analyses are used to develop strategies that reduce traffic congestion and improve air quality (e.g., transportation control measures and travel demand management programs).

TRANSPORTATION MODELING

Travel demand models try to replicate people's travel behavior by time of day, trip purpose, and mode choice. Models are adjusted or calibrated to match current base-year travel and are then used to simulate and forecast travel in future years. The travel demand forecast process is designed to estimate the demand and use of major highway and transit improvements, an important factor in deciding whether or not to make such investments. Model sets require household and trip data for traffic analysis zones. The variables most commonly used in current transportation models include, income, household size, place of work, and vehicle ownership, all of which are major factors in determining a household's overall trip-making decision.

Once models are developed they must be validated against "observed" data, such as data from the decennial census. That is, the model results (trip volumes and traffic flows) are compared with observed data and the model is adjusted until it replicates what is occurring during a specific point in time—the base year. Aggregate work-trip data by traffic analysis zone of residence, zone of employment site, and by the interchange between the two areas are used to validate modeled work-trip distribution and mode choice models.

LAND-USE MODELS

Land-use models spatially allocate future total regional household and employment data and determine the impacts of these allocations on transportation and land–use policies. Land-use models are applied at census tract, aggregations of census tract, or traffic analysis zone levels of geography and require household data by place of residence and employment data by place of work. As in transportation modeling, land-use models are developed using cross-sectional data sets obtained primarily from census data. The models are validated to a specific point in time (the census year), and then forecast the spatial allocation of households and employment in future years.

TRANSIT ANALYSIS, CIVIL RIGHTS, AND ADA REQUIREMENTS

Transit planners utilize census data to identify existing and potential markets of transit riders. Markets are identified by tracking changes in the region's population and employment base. Census data are also used to compare the proximity of transit service to populations with special needs and to establish the ridership potential of extending transit and adding transit service into new areas.

Federal requirements call on transit operators and planners to conduct analyses on the equitable provision of service to minority populations and to provide comparable accessible transit service to elderly and handicapped persons. The Federal Transit Administration requirements of Title VI of the Civil Rights Act of 1964 require that transit operators equitably provide transit service to minority populations within the transit operator's service area. The analysis requires transit operators to compare service provided to minority and nonminority tracts. This analysis relies heavily on short- and long-form decennial demographic data at the census tract level.

The ADA requires state and local transit operators to provide comparable transit service to elderly and handicapped persons within one-quarter mile of a bus route in the transit system's service area. Census long-form data identifying persons with mobility impairments are used to develop and improve transit services for these groups.

FEDERAL TRANSPORTATION AND ENVIRONMENTAL REGULATIONS

The 1991 ISTEA, together with the 1990 CAAA, call on transportation planners to manage congestion, analyze the environmental impacts of transportation projects and programs, and assist those areas that are not in attainment of National Ambient Air Quality Standards to achieve attainment. To achieve these goals, transportation planners rely heavily on census results for demographic (primarily short-form) and journey-to-work (long-form) data to carry out several functions:

- quantify the air quality benefits of projects,
- select projects that maximize the effectiveness of discretionary funds, and
- select projects that will enable states and MPOs to conform to the goals established in their State Implementation Plans (SIPs) for air quality.

All of the transportation planning activities described above (e.g., travel demand forecasting, trend analysis, and land-use model allocation) are necessary activities within each of these functions. For example, land-use and transportation models are used together to forecast traffic volumes, speeds, and trips. These data are used to estimate emissions associated with different transportation projects and programs. The emissions results are then used in the conformity analysis to revise the SIPs for air quality, and to subsequently carry out conformity analysis of transportation plans and programs with those SIPs.

THE FUTURE OF TRANSPORTATION PLANNING MODELING

In the 1993 report *Transportation Infrastructure: Better Tools Needed for Making Decisions on Using ISTEA Funds Flexibly*, the General Accounting Office (GAO) determined that to fully respond to the requirements of the CAAA and the intent of the ISTEA, the transportation profession needed to improve transportation travel forecast models. GAO recommended that travel models be improved to provide better information for analyzing the impacts of transportation projects on air quality. This report gave rise to the Travel Model Improvement Program (TMIP) by DOT. "TMIP is designed to implement enhancements to the current travel demand models and to develop new modeling procedures that accurately and reliably forecast travel for a broad range of modes, policy actions, and operational conditions."[1]

Preliminary findings of TMIP indicate a shift from aggregate levels of analysis to more detailed analysis. Modeling is moving toward being done in a more disaggregate fashion. In addition, modeling has to become more sensitive to analyses of projects and policies beyond those related to traditional large capacity increases such as changing travel demand to match supply of services available. More detailed analysis requires the continued support of the short-form decennial census, preservation or enhancement of long-form data whether collected decennially or continually, and further improvements in the geocoding of place-of-work and place-of-residence data at small levels of geography.

CENSUS PRODUCTS

The Bureau of the Census produces four data products from the decennial census that are used in transportation planning. The following section provides a brief description of each of these products.

CENSUS TRANSPORTATION PLANNING PACKAGE

The CTPP, formerly the UTPP, has been produced for the past three decennial censuses and has evolved to be one of the largest Census Bureau special tabulations. The 1990 CTPP required an estimated budget of $2.6 million. AASHTO organized the funding to obtain data for all metropolitan areas and states, representing the first national accumulation of this information. Full funding for the project came from urban and state planning monies provided to metropolitan areas and states by DOT. The CTPP includes special tabulations of journey-to-work data for states and MPOs. The data are issued on magnetic tape by the Census Bureau and on CD-ROM by the Bureau of Transportation Statistics.

SUMMARY TAPE FILES (STFS)

STFs contain demographic, social, economic, and housing data weighted to represent the total population. The data are coded to residence geography and are issued on magnetic tape and CD-ROM. The STFs provide data for states and their subareas, for example, county, census tract, and block group.

TIGER FILES

Topologically Integrated Geographic Encoding and Referencing System (TIGER) files include a coordinate-based digital map of the entire United States and an automated geographic database. TIGER files are used for mapping, geocoding addresses to census geography, aggregating census data to transportation analysis zones and districts, analyzing network attributes, and for routing/accessibility studies and travel demand modeling/simulation. TIGER files are available from the Census Bureau on CD-ROM. The Bureau of Transportation Statistics provided funds to develop the CD-ROMs.

PUBLIC USE MICRODATA SAMPLE (PUMS) FILES

PUMS files contain a sample of individual responses (housing units and persons) to the census long form. PUMS files are not tabulated like the CTPP and STF files. To protect the confidentiality of individual responses, PUMS files are only released for large geographic areas with a population exceeding 100,000 persons. The files also contain weights for persons and households that expand the sample data to the total population. The Census Bureau makes PUMS files available on magnetic tape and CD-ROM.

[1] *Travel Model Improvement Program Newsletter,* August 1994.

CHAPTER 3 CENSUS PLANS FOR CONTINUOUS MEASUREMENT

As Continuous Measurement is currently in the developmental stages, no definitive "Continuous Measurement Proposal" is available in a single source document. The Census Bureau staff provided the transportation planning expert panel with several working papers written on Continuous Measurement.[1] (See chapter 4 for a description of the expert panel and its role in this study.)

In addition to the background papers, the transportation planning expert panel was given the opportunity to question the Continuous Measurement staff. In some cases, Census Bureau representatives amended or clarified the positions established in the background papers, particularly in terms of levels of geography and frequency of delivery of certain products. Therefore, the Continuous Measurement proposal as evaluated by the panel is based on these Census Bureau papers, with modifications as stated by Continuous Measurement staff during the panel meetings.

CONTINUOUS MEASUREMENT SYSTEM

Under a Continuous Measurement system, the decennial census conducted in 2000 would collect on a 100-percent basis only the population and housing unit counts and minimal demographic information such as age, race and Hispanic origin, sex, and household relationship. The transportation characteristics traditionally obtained from a sample of households using the long-form questionnaire, as well as the whole range of social, economic, and housing data collected on the long form, would not be collected. Instead, the long form would be replaced with a monthly Intercensal Long-Form Survey

Data from these continuous monthly surveys would be cumulated to produce averages over various periods of time. Annual estimates for large cities, metropolitan areas, and states could be derived by cumulating 12 months of interviews, but a five-year cumulative average would be required to produce estimates for small areas, such as traffic analysis zones, that are based on a sample of comparable size to that obtained in the traditional decennial census.

SAMPLING RATES

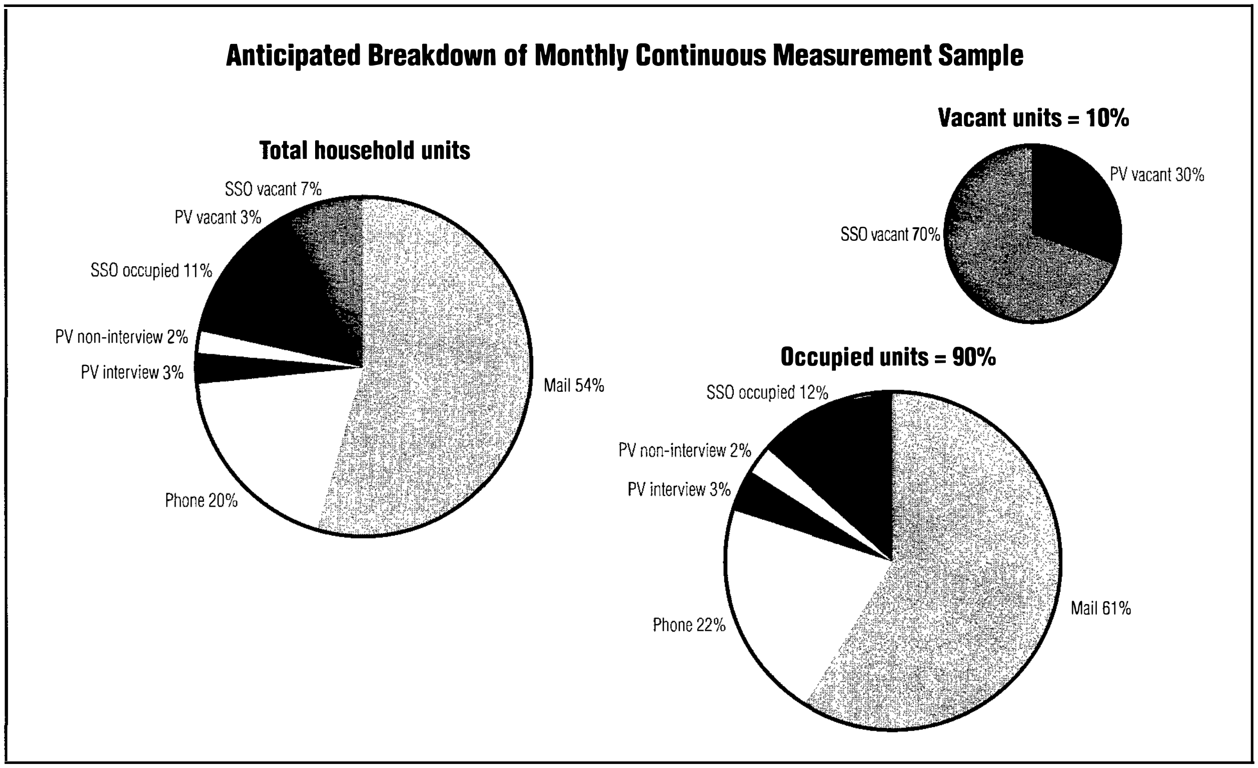
The sampling frame for the Intercensal Long-Form Survey would be a Master Address File of all housing units in the United States, which the Census Bureau will construct and update on a continuous basis. The Census Bureau plans to mail Intercensal Long-Form Survey questionnaires to about 400,000 households each month during the first three years (1999 through 2001) of the Continuous Measurement program, dropping to a steady state of about 250,000 households each month thereafter. The steady state sampling fraction is about 0.25 percent per month, for a total sample of about 15 percent over a five-year period. The Census Bureau expects that about 10 percent of units in the mailouts will be vacant. Of the occupied units, 60 percent are expected to respond through the mail, an additional 22.4 percent through phone contact.

The Census Bureau plans personal visits for a 30-percent sample of the remaining households. In other words, 30 percent of those who are not successfully surveyed by mail or phone (30 percent of the remaining 17.6 percent) will be designated for a personal visit, while 70 percent will be subsampled out (with no further attempt at contact). Of those designated for a personal visit, it is anticipated that 57 percent will be successfully interviewed. Overall, 85.5 percent of surveys mailed to occupied households are expected to be successfully completed (see figure).

TESTING PROGRAM

The first stage of the Census Bureau's multiphased testing program consists of testing and data collection under the Cumulative Estimates Simulation Project. In this project, 1990 data from the Oakland region are ran-

1 All papers are listed in the Bibliography, appendix C. Two of the key papers by Charles Alexander of the Census Bureau are included in appendix E: "Small Area Estimation with Continuous Measurement: What We Have and What We Want," document CM-14 in the Continuous Measurement Series, March 1994; and "A Prototype Continuous Measurement System for the U.S. Census of Population and Housing," document CM-17 in the Continuous Measurement Research Series, May 1994, hereinafter referred to as CM-17.



domly "split" to represent three separate "dummy" years and collection points of data. The "new" data sets are being tested to identify variances, changes in weights, averaging of data, and potential data products. Several additional tests and data collection activities will take place over the next four years, including alternative versions of the questionnaire, and collection and processing issues (see table 3-1).

SCHEDULE FOR IMPLEMENTATION

The Census Bureau anticipates testing the Continuous Measurement system through 1998, and beginning actual Continuous Measurement data collection in 1999. The decision on whether to go ahead with Continuous Measurement or stay with the decennial long form (or some combination thereof) must be made in calendar year 1996.

REPORTING OF DATA

The Census Bureau plans to release both summary tape files and microdata files from Continuous Measurement, similar to products that are issued for the decennial census.

SUMMARY TABULATIONS FOR LARGE GEOGRAPHIC AREAS

Census will release statistically reliable annual estimates for large geographic areas of 250,000 population or more. Census Bureau staff advised the transportation planning expert panel that annual summary data might be made available for areas of 100,000 population or more if the Bureau's Micro Data Review Panel approves release of these data. The Census Bureau states that annual summary data will be available within one year of the ending date of collection, and in some cases sooner.

SUMMARY TABULATIONS FOR SMALL AREAS

For small areas, such as census tracts, census documents indicate that geographically detailed general purpose files will be released, so that users can aggregate the geography as they wish. Continuous Measurement will produce small-area estimates with the following characteristics: "the CM estimate will be an average over a five-year period (three years for 1999-2001); the five-year average will be updated annually; and the CM estimates will typically have a 25% higher standard error" than current data.[2] Census Bureau staff told the transportation planning expert panel that the

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[2] CM-17, p. 5.

TABLE 3-1: ACCELERATED MASTER ADDRESS FILE-BASED CONTINUOUS MEASUREMENT DATA-COLLECTION ACTIVITIES

Fiscal year	Data collection activity	Objectives
1994	Cumulative Estimates Simulation Project.	- Demonstrate properties of cumulative estimates - Measure effect of population weighting controls on estimates - Illustrate data delivery system
1995	RDD test with 2,000/month total in 3-4 sites, starting November 1994. Convert to split-sample questionnaire test in July 1995. Small mail pretest.	- Test alternative versions of questionnaire - Measure effect on time of year and moving reference period on income data, etc. - Demonstrate ability to deliver timely data - Tentative decision regarding 2000 long form
1996	MAF-based test with at least 4,000/month total in 4 sites, starting October 1995.	- Develop/test field procedures - Measure coverage of MAF/SACFO - Decision regarding 2000 long form
1997	MAF-based "development survey" for congressional-district-level estimates, full speed in January 1998. Rural sample clustered in PSUs.	- Refine actual procedures - Produce annual estimates for areas of 500,000 or more - Final content determination
1998	Expanded MAF-based sample size; change procedures and questionnaire to fix problems found in FY 1997. Better rural spread.	- Further evaluation of quality - More annual estimates for areas of 500,000 or more - Phase-in full system
1999	Full MAF-based system. Complete rural spread.	- Collect small-area data to replace 2000 long form

KEY: MAF = Master Address File; PSU = primary sampling unit; RDD = random digit dialing; SACFO = sampling and address correction feedback operation (see CM-17, p. 2 for explanation).

SOURCE: Charles H. Alexander, U.S. Bureau of the Census, "A Prototype Continuous Measurement System for the U.S. Census of Population and Housing," document CM-17 in the Continuous Measurement Series, 1994.

Bureau would consider releasing annual small-area data, but that the estimates would not be "official" because they would be based on a statistically unreliable sample.

PUBLIC USE MICRODATA SAMPLES

The Census Bureau goal is to provide public use microdata for areas with a population of 100,000 or more, but confidentiality restrictions may require a higher population threshold. Public use microdata from the decennial census is a 1 percent or 5 percent sample of the overall census sample. However, the thinking by Census Bureau staff was for all the sample records from the annual Continuous Measurement sample to be released in a microdata file.

CHAPTER 4 DESIGN AND CONDUCT OF THIS STUDY

The study design was as follows: to assemble a panel of experts on many facets of transportation planning, to expose them to information on the census proposal and to expert opinions on Continuous Measurement's statistical implications at a first workshop, to give them the opportunity to think and write about the implications, and finally to form conclusions and recommendations, which were expressed at a second workshop.

PARTICIPANTS

USER PANEL OF TRANSPORTATION PLANNING EXPERTS

The panel selection began with lists of Transportation Research Board members on panels related to census issues, and was soon broadened through a networking process to include different transportation planning fields and user groups. Brief biographies were prepared for 16 potential panel members, pared from a list of over 30. Five of the 16 were chosen to be on the panel, with two additional members chosen from the network of knowledgeable persons in the industry, and another chosen as the facilitator of the second session. The selection of the seven panel members was designed to include recognized experts in the field of transportation planning, with additional criteria to add breadth to the study as follows:

- affiliation with metropolitan planning organizations, institutions of higher learning, consultants, transit agencies, and other users of transportation data;
- experience in the uses of data for land-use, travel forecasting, modeling, air quality analysis, traffic studies, and other applications;
- representatives from various regions of the country to provide additional perspective.

The final list of panel members with recent and current affiliations, and geographic work sites follows in table 4-1. Brief biographies of the user panel are included as appendix B.

STATISTICAL TRANSPORTATION PLANNING EXPERTS

To help the panel members fairly assess the statistical impacts of Continuous Measurement on transportation planning, preeminent members of the statistical community were asked to present their positions and debate the issue for the benefit of the panel members. The statisticians had to be knowledgeable about Continuous Measurement and the decennial census, and had to represent clear pro and con positions. A moderator was also desired. The project recruited some of the most noted names in the field.

- Dr. Leslie Kish, Professor Emeritus, Institute for Social Research at the University of Michigan, is a much-cited authority in the field of rolling samples and Continuous Measurement. Three of his papers were included in the informational packets sent to the user panel.
- Dr. Stephen Fienberg, Maurice Falk professor of statistics and social science at Carnegie Mellon University, is a member of the National Research Council Panel on Census Requirements in the Year 2000 and Beyond. As former chair of the Committee on National Statistics, he was instrumental in the creation of its panel on Decennial Census Methodology in the 1980s.
- Dr. Barry Edmonston (moderator) is the study director for the Panel on Census Requirements in the Year 2000 and Beyond conducted by the Committee on National Statistics for the National Research Council. He has also been involved in demographic research and teaching at Stanford University and Cornell University.

CENSUS BUREAU PARTICIPATION

Two key members of the Census Bureau associated with Continuous Measurement, Charles Alexander and Larry McGinn, were involved throughout the project. Charles Alexander provided papers he and others wrote, which became a major part of the background reading. Charles Alexander is Assistant Division Chief, Longitudinal and Expenditure Surveys Design, Demographic Statistical Methods Division. Larry

TABLE 4-1: MEMBERSHIP OF THE TRANSPORTATION PLANNING EXPERT PANEL

Name	Recent and current affiliations				Current location
	MPO	Other public	Academic	Consultant	
James Bunch		X		X	Silver Spring, MD
Bruce Douglas				X	Herndon, VA
Greig Harvey			X	X	Berkeley, CA
Keith Lawton	X			X	Portland, OR
Steve Putman			X	X	Philadelphia, PA
Karl Quackenbush	X			X	Boston, MA
Peter Stopher			X	X	Baton Rouge, LA
Alan Pisarski (Facilitator)		X		X	Falls Church, VA

McGinn is Chief of the Continuous Measurement Staff. Alexander and McGinn spent much time at the two workshops held for the transportation planning expert panel.

WORKSHOPS

Several weeks prior to the first session, all participants received background reading materials, including five papers from the Census Bureau describing various aspects and proposals for Continuous Measurement, three papers from Dr. Kish, and nine papers on different aspects of uses of census and other data in transportation planning. (A copy of the initial bibliography is included as appendix C.) Panel members were also requested to identify preliminary issues to be discussed at the first workshop.

FIRST WORKSHOP

The objectives of the first workshop were to ensure a common body of knowledge and identify issues requiring additional research. At the workshop, held in September 1994, Charles Goodman, Office of Policy Development of the Federal Highway Administration, reviewed the uses of census data in transportation planning. The Census Bureau staff then presented the most current thinking on the Continuous Measurement proposal, and answered questions from the members of the transportation planning expert panel. The moderator of the statistical panel provided background on the debate, and the two statisticians presented their viewpoints, briefly debated the issues, and answered questions from the transportation panel. The transportation planning expert panel then identified issues for further research and questioning, and determined topics and assignments for papers.

PAPER PREPARATION

During the nine weeks between the first and second workshops, the transportation planning expert panel members prepared papers on their chosen topics. Independent research included surveys of colleagues, additional reading, calls to Census Bureau staff for clarification, and further investigation of the implications of changes.

SECOND WORKSHOP

The objectives of the second workshop were to review the prepared papers, gain additional information as necessary from Census Bureau staff, and develop conclusions and recommendations on the topic, including recommendations for further research. At the two-day workshop, held in November 1994, the panel queried Census Bureau staff to clarify issues that had arisen during the paper preparation. Panelists presented their papers and resumed the discussion of issues from the first workshop. Finally, panelists agreed on issues, concerns, and recommendations to be made to the Census Bureau, Congress, and the U.S. Department of Transportation.

FINAL REPORT

This report is the final step in this project. The panel participants reviewed the paper to ensure that their comments and views are accurately represented. The paper expresses serious concerns, makes recommendations for greater involvement in testing, identifies requests for specific products, and defines needs for additional research.

CHAPTER 5 STUDY FINDINGS

An excellent partnership exists between the Census Bureau and the transportation community, with the Census Bureau developing new tools and products to make census data more usable and accessible. This has greatly increased the use of and reliance on census data. Many small metropolitan planning organizations (MPOs) rely almost exclusively on census data for their transportation modeling needs, while larger MPOs use the census results extensively as weighting controls for other surveys and to calibrate their models. Because requirements of the Intermodal Surface Transportation Efficiency Act (ISTEA), the Americans with Disabilities Act (ADA), and the Clean Air Act Amendments of 1990 (CAAA) have increased the data collection and modeling needs of states and MPOs, there is significant concern about any potential disruption to the flow of good census data, which after decades of development is now efficient and effective. The sources of potential disruption that generate the greatest concern are: 1) uncertainty about the "final" makeup of the Continuous Measurement proposal, 2) the potential that Congress will reduce or eliminate funding for continuous sampling, 3) the potential that data will be withheld at levels necessary for analysis due to confidentiality concerns, and 4) loss of single point-in-time, decennial census estimates with good reliability.

Continuous Measurement, if implemented as currently proposed, may provide significant improvement over current data and census products. The availability of data on an annual basis (taking into consideration the higher standard error due to sample size) will help transportation planners build more timely forecasting models. Using three- or five-year moving averages for small-area data for point-in-time models remains problematic, though. Before the transportation planning panel for this study would welcome the use of Continuous Measurement, considerable attention must be given to issues of timeliness, currency of data, program flexibility, cost, and impacts on small-area data. Any radical change must be viewed objectively, studied systematically, and implemented in such a fashion as to minimize risks to stakeholders.

The transportation community is a major stakeholder in the use of census data, both long form and short form. These data are significant in the planning and support of the multibillion dollar annual program of transportation infrastructure and improvements. The Census Bureau, the U.S. Department of Transportation (DOT), MPOs from regions large and small, and transportation planners from public agencies, academia, and the consulting environment must maximize information, communication, and cooperation in evaluating and possibly implementing this change.

DATA AVAILABILITY

TIMELINESS AND CURRENCY

Historically, the Census Transportation Planning Packages are released from three to four or more years following the conclusion of the decennial census. Thus, planners typically use data that are at least three years old, and possibly up to 14 years old, prior to the release of the next census data set. Planners, especially in larger metropolitan planning areas, have established numerous methods for updating small-area population and employment estimates, using data from such sources as building permits, utility hookups, vehicle registrations, and various state employment and labor files. However, significant changes in job markets, two wage-earner families, and other factors affecting traffic and travel patterns are best captured by detailed surveys.

If a Continuous Measurement system is implemented, the Census Bureau could produce census transportation packages within six months after the close of the year, each year after the third year of data collection. The data for traffic analysis zones will be available as statistically reliable moving averages and can be made available as single-year point estimates that will not be statistically valid. The data will be valuable for tracking trends and for maintaining an up-to-date picture of the region. Sociodemographic estimates for metropolitan areas and states, as large geographic units, for example, are expected to be more accurate under Continuous Measurement, due to continual updates.

The panel expressed concern that currency can in essence be a double-edged sword. First, most planners do not recalibrate models every year, so the utility of obtaining new data every year is questionable. Keeping up-to-date could demand major new resources. The Process/Implementation section below examines this issue more closely. Second, for legal and other considerations, it may be advisable to have a single "official" base year. For example, a CAAA plan established on base year 2005 values might be challenged by an organization using 2006 values. The legal concerns, which were discussed at the first workshop, were not revisited at the second workshop, and presumably outweigh the benefits of timeliness.

CONTINUITY AND COST CONCERNS

■ *Continuity*

Transportation planning relies on long-form census data to fulfill both congressional mandates (e.g., the CAAA, the ISTEA, and the ADA) and to carry out state-of-the-art practices of modeling. Transportation planners currently receive decennial census data once every 10 years. These data are needed for controls, to compare with other means of tracking (e.g., vehicle registrations), to expand other surveys with reliable data, and for other planning purposes. The papers by Karl Quackenbush and Peter Stopher in appendix D provide very thorough descriptions of the uses of census data and the implications of Continuous Measurement.

The transportation planning expert panel concluded that the transportation community and other users need a smooth transition between the two forms of measurement. Year 2000 data must be comparable in form and quality to the data made available in 1990. The transportation planning expert panel believes that an interruption of data, for whatever cause, would be very detrimental to transportation agency responsibilities.

■ *Cost Effectiveness/Funding: Efficiency of Size*

The cost of the decennial census and the long-form data is far less per unit than comparable surveys performed individually for specific uses. The Census Bureau estimates that the incremental cost of the decennial long form will be about $500 million for the 2000 census, or about $5 per sample household. The incremental cost of Continuous Measurement is estimated at $30 per observation (although the context and calculations were not provided to the panel), compared with the average cost of a typical individual household survey (from $90 to $150, according to Peter Stopher), or the cost of an individual household for the Nationwide Personal Transportation Survey at about $120. The panel states that the long form is a bargain in the context of the need for continuity of data.

The transportation planning expert panel was very concerned about the lack of assurance of continued funding for Continuous Measurement, which is needed to provide full sampling levels (at a minimum steady state of 250,000 per month) and to ensure census product processing and distribution once the samples are collected. There was concern about the general context of the decision to explore Continuous Measurement. Is it possible, for example, that this process of reduced sampling sizes is the beginning of a continued "ramping down" of sample sizes?

The transportation community needs additional cost data, and more openness on cost data. Most cost estimates identify the cost for just three years. What is needed is an identification of the full-cycle costs. It is necessary to identify the cost of data collection compared with data processing and the creation of products, to ensure that funds are available to present the data in a usable format after they are collected.

As a separate but related issue, Census Bureau cost projections typically contain only Census Bureau costs. There needs to be identification and recognition of the full costs to users, as well as to the Census Bureau. The Process/Implementation section below includes a discussion of this issue.

The Census Bureau expects to generate internal cost savings, in part through sharing of data with other surveys. The panel questioned the likelihood of such savings. Experience shows that overruns are likely in many new programs. It is not clear whether Continuous Measurement is intended to be cost neutral or to generate cost savings. The cost data presented to the panel appeared to indicate that Continuous Measurement would neither be cost neutral nor result in cost savings, but in fact appears to be more costly. However, the panel did not have access to the detailed information about related programs that might tie into Continuous Measurement efforts. The panel also questioned the likelihood of the Census Bureau achieving permanent staff increases in the face of the policy of downsizing government. There is concern that cost overruns and staff increases could jeopardize congressional support, force reductions in sampling, and thus jeopardize the entire data-collection effort. As stated above, continuity of data is essential. It should be noted that many countries in Europe engage in continuous sampling in part to avoid budget spikes. Maintaining a steady funding level is an additional benefit of Continuous Measurement.

Continuous Measurement promises more frequent, and in many ways, better data. The Census Bureau may wish to investigate and determine the cost for replacement of current data versus the cost for better data. Continuous Measurement benefits include new sources of planning data such as trend analysis, more flexibility, greater timeliness, and better quality. These benefits are difficult to quantify in dollar terms, but their value may be worth some incremental cost difference from the status quo.

■ *Potential Disruption/Diminution of Sampling*

There is a significant risk in embarking completely on Continuous Measurement, as it will rely on annual appropriations from Congress which can be cut back or eliminated. Funding may be assured through 2001, but the program beyond becomes a policy issue open to question by a Congress intent on cutting costs. At that time, the program could be halted, or the sample size reduced to a meaningless level. Even the first three years may be in doubt, if cost overruns occur. The Census Bureau states that there is also no guarantee that the traditional long form will be funded. The question remains: what happens if the Continuous Measurement effort is discontinued or cut to the point of uselessness a few years into the process? At least with the decennial long form, good data are available at least once every 10 years. Disruption of this availability would severely impact transportation planning and would result in more costly and possibly inconsistent data-collection efforts by individual states and MPOs.

Many different constituencies use census long-form data. Some uses are mandated directly by Congress, some mandated indirectly through regulations and related references, while other uses are made of the data by the private sector. The transportation community may need to coordinate with other constituencies and identify common ground and common requirements to ensure survival of the long form, whether in the decennial or Continuous Measurement format.

EVALUATING ALTERNATIVES

The panel recommends further examination of alternatives to the long form. Is this Census Bureau's Continuous Measurement proposal the only possible alternative? The National Conference on Decennial Data for Transportation Planning, held in March 1994, offered multiple recommendations that have not been fully examined. The following are indicative of the range of recommendations from that conference:

- Sample every five years using one-half or one-quarter the full long-form sampling rate.
- Establish a longitudinal panel to measure change.
- By the year 2010, administrative records will be available to improve sampling. The Census Bureau needs to test Continuous Measurement from the year 1999 on, to be ready for full implementation in 2010.
- Determine how much Census would have to reduce the sample size of the long form in order to test Continuous Measurement: could it be done with a one-twelfth sample?
- Investigate the savings if Continuous Measurement is not conducted all across the nation, and instead tested only in certain geographic areas.
- Determine what level of parallel testing of Continuous Measurement with the decennial census is feasible.

■ *Parallel Testing vs. Untested Replacement*

A significant research effort is underway at the Census Bureau, but so far it is not sufficient to let transportation planners clearly decide the pros and cons of Continuous Measurement by the 1996 deadline. The transportation community is not yet involved in the testing and research; such involvement in the future is critical, because of the community's extensive use of cross-sectional data. The user panel believes that good science demands testing and experimentation prior to implementation.

An example of such good science is the change in collecting Bureau of Labor Statistics unemployment statistics. In that case, parallel counts were conducted for several years to ensure the comparability of data. The decennial long form is no less important; the transportation community and others need a good count in the year 2000. The panel, therefore, strongly recommends a parallel process for the year 2000: conducting the decennial count, including the long form, with a Continuous Measurement system implemented in parallel for selected areas.

ACCESSIBILITY AND CONFIDENTIALITY CONCERNS

The trend in transportation planning has been to narrow the focus of analysis in geographic detail, from ZIP Codes to traffic analysis zones to census tracts to XY coordinates. The Continuous Measurement staff of the Census Bureau may have every intention of releasing extensive public use microdata for planning purposes, but the Census Bureau's Micro Data Review Panel (MDRP) controls the release of specific geographic levels of census data. The MDRP reviews census data applications to ensure confidentiality of respondents. The MDRP also has significant veto power over proposed uses of data. As microdata samples are spread out over time, the MDRP may become even more concerned about the possibility of identifying an individual. If the MDRP refuses to release small-area data to the public, then all research and data analysis must be done through the Bureau, possibly impacting planning work significantly.

The transportation community supports confidentiality and protection of individuals from disclosure in surveys in which they are required to participate. However, it appears that in some cases the MDRP may read meanings into Title XIII that go beyond the intent of Congress. In another context, for example, employers with more than 100 employees in regions of severe air quality nonattainment must release a geocoded file of their employees' addresses. Thus, if others release these data as a matter of course, MDRP standards may be excessive. Transportation planners lose valuable census data, used strictly for research purposes, because of excessive protection of confidentiality that suppresses such information as addresses. For accuracy in small-area studies, planners need access to data tabulated at fine-level detail.

There are means to protect identity and still generate the data needed by transportation planners, such as data switching and randomization.[1] As an alternative to releasing the information, Census can produce special tabulations. Another alternative strongly recommended by the panel maintains all legal and established constraints on confidentiality and data release: the Census Bureau can significantly increase its deputization of academics, consultants, MPOs, and so forth, to allow them to assemble and use the data.

The user panel strongly recommends the 100,000-population limit, rather than the 250,000-population limit, for the release of public use microdata from Continuous Measurement. The 100,000-threshold is critical to ensure the transportation community support of the Continuous Measurement proposal. A corollary desired improvement in public use microdata will increase acceptance of the proposal: namely that workplace be coded to public use micro areas, instead of to county as is done currently.

SUITABILITY OF DATA FOR PLANNING NEEDS

ACCURACY

The panelists as a whole agree that reliable data are the highest priority. Greater timeliness and flexibility are seen as bonuses, not tradeoffs for quality. The Census Bureau believes it will achieve better quality data with a Continuous Measurement system. The accuracy of the decennial count might be improved by the concentration of resources on the "headcount." The quality of the long-form results under Continuous Measurement may improve through a permanent dedicated staff, continuous training, continuous updates, and maintenance of the Master Address File, and the ability to return to problem areas and sample again or at higher levels to achieve the desired sampling levels. Quality also may improve through increased training for interviewers on followups to nonrespondents, and through improved data entry and geocoding.

■ *Standard Error*

General concerns about data quality and accuracy also involve sampling error. The Census Bureau states that the standard error of estimates will increase by about 25 percent for large geographic areas (from a 95-percent confidence level to a 90-percent confidence level), due to the change in sample size.[2] The standard error for small areas, which has always been large, will be larger. This element of data quality and accuracy will therefore be worse under Continuous Measurement. However, some panelists assert that the levels of confidence and standard error are acceptable for the types of applications performed with the data, and are less than the variances normally associated with survey data used in transportation planning.

Sampling Rates. The Continuous Measurement program for data collection would be based on a sampling rate of one in 34 housing units per year, rather than the one in six utilized in 1990. Using one in 34 housing units per year as the sampling rate would result in statistically valid data for large areas; however, the integri-

[1] For further discussion, see paper by Lawton, p. 6, in appendix D. Also see George T. Duncan et al. (eds.), *Private Lives and Public Policies: Confidentiality and Accessibility of Government Statistics* (Washington, DC: National Academy Press, 1993), for a full discussion of confidentiality and data optimization.

[2] Charles H. Alexander, "A Prototype Continuous Measurement System for the U.S. Census of Population and Housing," document CM-17 in the Continuous Measurement Series, May 1994 (included in appendix D), p. 3.

ty of the data would rely on the Bureau's weighting and expansion factors. This could be problematic if certain populations, such as households with zero vehicles, are underrepresented in the original sample.

Small-Area Data and Moving Averages. Further consideration should be given to the availability of small-area data and the meaning of moving averages at this level. (For further discussion of moving averages, see the section on Single Point-in-Time Estimate Data below.) If the samples are very small, there may be no statistical meaning to values in a cross-tabulation from a single year. (Papers by Lawton, Quackenbush, and Stopher, in appendix D, address these issues.)

■ *The Decennial Advantage*

The long-form survey is conducted during the decennial census. The decennial census is a well-publicized and highly visible public event. The combination of legal mandates, concentrated data-[2]collection efforts, and extensive census publicity campaigns yield a relatively high response rate for the long-form data collection. Essentially, the long-form questionnaire piggybacks on the success of the decennial census. In addition, the long-form surveying effort achieves high coverage at a marginal cost. By conducting the two surveys separately, the short form and the Continuous Measurement approach, the result may be lower response rates for Continuous Measurement. Efforts to improve the response rate could drive up the cost of the Continuous Measurement program beyond levels that Congress is willing to fund. As a result, less data could be collected and lower data quality achieved through Continuous Measurement.

■ *Income Data*

Travel modeling depends on having good household income data because, as discussed previously, income influences the number of trips made by household members and sometimes the modes chosen for those trips. The long form yields good income information, in part, because it is sent out in April when people have recently or are currently filing their tax returns. Continuous Measurement questionnaires would be sent out each month and many people may find it difficult to recall their prior year income. As a result, the quality of income data could diminish. Some panelists are convinced this is not likely to be a problem as most planning applications use quintiles of income data, which should not be affected by minor errors in recall.

FLEXIBILITY IN CONTENT AND SAMPLING

The Census Bureau has promised the advantage of significant flexibility in sampling in Continuous Measurement, in addition to more timely and more current data, including: 1) flexibility for heavier sampling on request, 2) flexibility and ability to experiment with content, and 3) flexibility to add questions for specific needs in a particular region.

■ *Heavier Sampling: General Population*

MPOs, state departments of transportation, and public agencies are promised the ability to contract with the Census Bureau to perform additional sampling. This could include heavier sampling in certain years to coincide with local sampling, before and after a major highway or transit facility opening, following a natural disaster or significant plant closing or opening, or other local interests. Similarly, agencies could contract for additional special-purpose questions of local interest, either in standard or heavier sampling frames. There may also be opportunities for overlapping samples to test changes in behavior over time.

Some panelists suggested the possibility of using larger samples in the year 2000, concurrent with the decennial census, perhaps a sample of one in 18 or one in 20, in addition to Continuous Measurement in 1999 and 2001. This could be used for analysis and comparison with previous data. It would have a higher sampling error than the 1990 long form, but could simulate the more complete sample and serve as a benchmark.

■ *Heavier Sampling: Rare Populations*

During the discussions at the first workshop, Census Bureau staff indicated that states or MPOs could contract with the Census Bureau for additional samples, that is, samples that capture rare populations such as transit users or disabled workers.

In later discussions, the Census Bureau indicated that these potential contractual efforts for rare populations would not occur during the Continuous Measurement process. Rather, the Continuous Measurement system could pull out populations with rare characteristics and followup interviews would be conducted later. In this way, other smaller surveys could obtain an oversample of the rare units, subject to Title XIII (confidentiality) constraints. The Census Bureau routinely conducts such follow-on studies for other surveys and does not see the need for further testing.

■ *Content Flexibility*

Because Continuous Measurement sampling takes place throughout the year, the natural variance over time and place also permits changes in wording to reflect the specific needs of the users, as in the journey-to-work (JTW) question. The decennial census asks "usual" day to avoid local or regional anomalies such as a transit strike or severe weather, on a single sampling day. However, this tends to hide the less common uses, such as telecommuting once every two weeks or carpooling once a week. The Census Bureau is willing to experiment and test changes in wording, such as changing the JTW question to "most recent work day" or "yesterday" instead of "usual." Further discussion on content, relevant to both Continuous Measurement and decennial long-form discussions, is in the section on Content and Geocoding Concerns below.

■ *Adding Questions*

Various participants expressed considerable interest in adding questions to the standard long form, such as access and egress modes from the "major" commuting mode. These questions could be tailored by region, so that only cities with a heavy rail or commuter rail system would be asked about that particular mode. There was also concern that the wording of the question, asking for (mode of) "longest distance," may actually be answered as "longest time" traveling. Costs of such changes to the user (and whether or not the Census Bureau plans to charge for question changes) have not yet been determined.

■ *Flexibility Concerns*

General concerns about the promised increases in flexibility include the unknown cost for changes, the ability of the Census Bureau to deliver on requests for increased sampling (in terms of human and other resources), the likelihood of access to sampling for rare populations due to confidentiality concerns, and the conflict between the desire for flexibility versus the need for the continuity of data over time. The conflict between continuity and flexibility has various facets, as shown in the following examples:

Example 1: The potential new category of ethnicity as "mixed." This new category is not an aggregate of others; there is no way of getting an average, but this is a growing element of the population.

Example 2: If the JTW question is changed, many models that build adjustments to the JTW data to match "reality" from other sources would require new relationships. (For example, JTW data do not, by definition, include nonwork trips. Based on current wording and information from other surveys, modelers develop relationships between work and nonwork trips. If the wording changes, these standard relationships that have been developed may also need to be changed.)

Example 3: If data are combined over three or five years (in moving averages), the questions for the years that will be combined need to be the same.

1999	*Question A*
2000	*Question A*
2001	*Question B*
2002	*Question B*
2003	*Question B*

Under this scenario, one would have to wait for year 2005 data to have a five-year accumulation of Question B, and Question A would not be available for a small geographic unit (except with unacceptably high standard error). If Question A is used consistently in every year, there could be a summary for each period (1999 to 2001, 1999 to 2003, 2000 to 2004, and so forth).

SINGLE POINT-IN-TIME ESTIMATE DATA

Census data are a major element in four different sectors of model development:

1. *allocation* of employment and population to geographic areas,
2. *factoring* base set of data—using census data and socioeconomic factors as multipliers for other surveys,
3. *calibration* and *validation* of models, and
4. *estimation* using transportation models.

Transportation planners usually interpret data over geographic space, rather than over time. Most planning is designed for a "snapshot" approach, compared with the continuous, "smoothed out" time series of moving averages promised in Continuous Measurement. Planners believe that a once-a-decade "slice" is necessary, and is currently used as a major input to travel forecasting models, including establishing a base year, developing model parameters, and checking model results. In addition, modelers frequently use surrogates such as vehicle registrations, utility connections, and employment to represent growth patterns and estimate changes in travel patterns during intercensal years. Once a decade they can verify or fine tune their use of these surrogates based on the detailed decennial survey and long-form sample.

One method of achieving this decennial slice under Continuous Measurement is to increase sampling during the decennial year. Barring this, some of the panelists questioned how to use Continuous Measurement for calibration, and what changes will be necessary in the paradigm to go from fixed point to time-based studies. Other panelists did not see this as a problem.

■ *Moving Averages*

One concern about using Continuous Measurement was the meaning and measurement of moving averages. Continuous Measurement would seemingly change the nature of fixed point-in-time data estimates for small areas. Problems would arise in application because the census data, assuming data varied over the three- or five-year period, would be inconsistent with point-in-time model input such as travel times, costs, and facilities. For example, census data would represent averages over three years. It would, however, be impossible to average facilities over three years. If Corridor X had four lanes in year one, six lanes in year two, and four regular lanes with two carpool lanes in year three, how would a moving average of capacity be calculated and what would such an average mean? Averaged census data would no longer be consistent with the underlying data used in the transportation and land-use modeling process. Panelists also expressed concern about the meaning of moving averages for multivariate statistics. For example, what is an average of a trip interchange pattern? What is an average of behavioral changes, which are neither cross-sectional nor time series? What is the meaning of averages over time in income, house values, and so forth, and how will they be used?

Karl Quackenbush's paper (see appendix D) examines these issues at length; he firmly believes that any such problems are quite manageable. A key argument, neutral toward Continuous Measurement or decennial long form, is that the "gross level" of the majority of models will not be sensitive to the fine differences normally occurring. Single-year data from Continuous Measurement may provide some of what is needed. However, smaller areas may experience problems if they use annual data with higher standard error as if they were reliable. Further research is warranted relative to the sample size involved.

■ *Annual Data*

Annual data are essential for transportation planners. Transportation and land-use models are used to predict a point in time, hence, data are needed that relate to a point in time. Problems associated with moving averages are noted in relation to origin-destination movements. Data from a single year are likely to be too sparse to create a meaningful OD matrix using small-area geography. An OD matrix would prove impossible to create or would be so full of empty cells that it would be of little value. In addition, over a period of years there are likely to be significant changes in work-trip patterns from new housing and employment locations. According to many of the panelists, moving averages of these changes will be inapplicable for transportation modeling uses.[3]

During the panel discussions, the Census Bureau indicated that annual point estimates for small areas could be made available from Continuous Measurement; however, the data would come with a "warning label." That is, the data would be provided, but would not be an "official" Census-certified estimate, because the annual estimates would not be based on enough cases for analysis and would have dubious statistical confidence. Even with dubious statistical confidence, the annual data are important to the transportation planning community, because they provide the point-in-time data items needed by transportation planners. Many panelists could not support the Continuous Measurement proposal without a guarantee from the Census Bureau that annual point estimate data would be received for each of the years included in the moving average.

■ *Seasonal Variation*

Another minor concern with Continuous Measurement is seasonal variation. Continuous Measurement surveying would occur throughout the year, while past modeling efforts generally used the spring or fall as the most "normal" period of travel. Annual averages may, thus, present some problems for application within the traditional modeling context. Issues relating to seasonal variation include:

[3] Note that Quackenbush disagrees. See his paper in appendix D.

- Households containing students who are away from home during the school year will likely report larger household sizes in the summer than during the rest of the year.
- Regions attracting many tourists will report larger populations during the tourist season than other times of the year.
- Retirement communities in Arizona or Florida, for example, having partial-year residents would also report higher populations during parts of the year.

Continuous Measurement may actually provide more accurate representations of "annual" or "average" population and related data for the typical region. Its utility, however, may be limited unless the date of the Continuous Measurement survey is included in microdata files, and unless additional data products that specifically address seasonal variation are provided. The Census Bureau staff indicated that seasonal data products may be available, but that further research was necessary.

CONTENT AND GEOCODING CONCERNS

The panel identified several longstanding concerns as very high priority to address—for the Census Bureau and the transportation community at large—whether Continuous Measurement is adopted or the decennial long form is maintained. The concerns are broadly described as content and geocoding.

CONTENT OF QUESTIONS

The journey-to-work data gathered by the Census Bureau on items such as travel mode, travel time, and location of employment are used in a variety of applications by transportation planners as described previously. The transportation questions asked on the long form differ in some respects from those questions asked by transportation planners in local travel surveys. The main differences between census survey data and local survey data are attributed to the definitions of trips, and "yesterday" versus "usual day." Infrequently used alternatives will be underreported in census data, while frequently used modes will be overrepresented. For Continuous Measurement to prove beneficial, the issue of questionnaire content needs to be addressed. Annual averages of "usual" behavior are likely to be more problematic and harder to interpret than current data.[4]

The statistical characteristics of location and land-use models are usually estimated and begin their forecasts from a cross-sectional data set. It is common practice to have a decennial census year as the main data time point with local estimate data for intercensal years. Locally collected data items that build on the decennial census journey-to-work data typically pertain to mode, vehicle occupancy, intermediate stops, time of departure, and time of arrival, and are used to "build" the journey to and the journey from work.

■ *Work-Trip and Nonwork-Trip Issues*

Work trips constitute approximately 25 percent of trips. However, the long form does not gather data on nonwork trips. In addition, part-time employment is missed. The realm of trip chaining, whereby, for example, a person picks up groceries and/or a child at day care on the way home, or otherwise combines a work trip with other necessary personal business, is also fertile ground for additional investigation, relating to the Continuous Measurement promise of content flexibility.

RECOMMENDED IMPROVEMENTS

The user panelists agreed that geocoding for place of work must improve. Work-trip destinations of some workers are misrepresented, since address files often reflect the business address (i.e., headquarters office site) rather than work site. Household data are coded by place of residence, while employment data are coded by place of work. Both trip ends must be accurate in order to effectively model the journey-to-work pairs critical to travel demand and land-use models. Generally, unreliable employment data is one of the major data problems for MPOs attempting to implement location and land-use models. The current Census Bureau plans for the Master Address File extend to household residences, not business addresses. Workplace Topologically Integrated Geographic Encoding and Referencing System (TIGER) files and their maintenance should be included in the ongoing Census Bureau budget. Having the Census Bureau maintain updated files of business addresses is a high priority for transportation planners.

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[4] See Lawton, Quackenbush, and Stopher papers in appendix D.

PROCESS/IMPLEMENTATION

The transportation community welcomed the opportunity to join the debate in the formative stages of the process. The discussions sensitized Census staff to specific transportation needs and concerns, and the Continuous Measurement staff promised service, flexibility, and data products at fine levels of detail. However, the proposal is still in development and the transportation planning expert panelists were faced with in essence a "moving target." Support for the Continuous Measurement proposal is contingent on many variables. A radical change in design, sampling levels, data release levels, costs, or any of several other critical factors could undermine data quality or availability. The panel had this single opportunity to respond to changing proposals; at another point in time, with a different proposal, the recommendation might be different. In summary, no statements herein should be construed as a blanket endorsement of Continuous Measurement.

IMPLICATIONS AND COSTS OF MAINTAINING AND UPDATING DATA

The panel was sensitive to the limited staff and funding available for planning, especially in small MPOs. Therefore, new responsibilities for states and MPOs, implicit in the Continuous Measurement proposal, were a concern to the panel. The new responsibilities include the costs of maintaining and updating data on a more frequent basis, geocoding, and revising plans. Specifically, the panel questioned what proportion of the cost does the Census Bureau assume will be handled by local agencies. A related concern is that the Census Bureau's Geography Division does not have in place a mechanism to integrate locally maintained geographical information system (GIS) files into TIGER. It is not clear that such a system will be in place by 1998 for use in 1999.

■ *Geographic Locators*

To support the Continuous Measurement program, the database of geographic locators, addresses, place names, and so forth, would require continuous maintenance. Most MPOs currently developing or maintaining a GIS will be able to integrate their GIS with the database of geographic locators. A continuous maintenance process may be easier for an MPO to staff.

MPOs typically volunteer to assist the Census Bureau with coding, including place-of-work coding. This offer, however, by MPOs was turned down by the Census Bureau in 1990 due to "time constraints." There was a question of how and whether the Census Bureau would use such MPO assistance. Either the Census Bureau or the MPO would seemingly have to produce monthly or quarterly files with workplace address, residence address (tract-level only perhaps), and travel time and mode. Some method of improving address geocoding, particularly for place of work, needs to be developed by the Census Bureau and MPO staffs with local GIS capability. Serious inaccuracies and omissions exist in place-of-work coding in the Census Transportation Planning Package data files. Properly maintaining such files on an ongoing nationwide basis would seem to be a huge challenge for Continuous Measurement.

Concern was also expressed about how information is updated. Providing manual files as was done in the past is not feasible. The Bureau could send an MPO the bare addresses, with census identification numbers known only to the Bureau. MPO staff could then do the geocoding in cooperation with the Bureau. During the process, complete confidentiality would be maintained through an identification number provided by the Census Bureau for each location (or location pair, if home and work).[5]

■ *Geographic Boundaries*

The Continuous Measurement program indicates that geographic boundaries will change annually. Census relies on local jurisdictions, mostly states, to provide political boundary changes. However, it is unclear how or when tract boundaries would change under Continuous Measurement. There is concern that data tracking will become unmanageable; analysis from year to year may be muddied by an annexation or other boundary change. Such changes could also jeopardize the Census Bureau's ability to deliver products on time. The Census Bureau needs to establish protocols to accept electronic files and facilitate the transfer and updating of information. The Census Bureau, in cooperation with the transportation community and others, needs to establish benchmarks for updating geographies, and a process for the continual tracking of changing geographies (e.g., tracts and zones).

The transportation planning expert panelists agreed that the annual data must be coded to a consistent geog-

5 For further discussion, see Lawton's paper in appendix D.

raphy from year to year for the data to be valuable, or, if updated, that a type of "red flag" reference file be associated with each zone to identify changes in geography. In addition, the geography level must be maintained at the block or census tract to be valuable.

INTERGOVERNMENTAL COOPERATION

A smooth transition from the decennial long form to the Continuous Measurement intercensal long form demands the participation of interested parties. The U.S. Department of Transportation (DOT) and groups such as the American Association of State Highway and Transportation Officials and committees of the Transportation Research Board need continued involvement in testing data, content, and methods, and in identifying products.

DOT and the Census Bureau need to establish a mechanism for interested parties to receive continued updates on plans and procedures. One possibility would be a newsletter. Another is to reopen the "Census 2000" (Census Bureau) computer bulletin board topic to the public.

DOT will need to establish an ongoing process and related funding to support and coordinate local efforts, including training state DOTs, MPOs, and others in the proper use of Continuous Measurement data. The change to Continuous Measurement may have significant impacts on users, for example, TIGER file maintenance. DOT may be expected to support state departments of transportation and MPOs in their continual updating of geographic bases and other planning activities. Further, DOT may be expected to support state DOTs and MPOs in funding special or super sampling efforts for specific needs. DOT needs to assess the costs of these activities and consider, for example, additions to planning funds for MPOs or increases in the planning and research set-aside from construction funds.

Finally the transportation community should establish contact with other stakeholders in census data (e.g., users of poverty data and household data) to establish common ground, and identify a framework for cooperation. The transportation community and other stakeholders will likely find it far less costly to cooperate and preserve key elements of the long form (whether decennial, Continuous Measurement, or both) for a transition period, than to reproduce the data elements, data quality, and sample size of the long form in individually sponsored surveys.

ENDNOTE

Subsequent to the second panel meeting, and during the writing of the final report, the National Research Council (NRC) issued its report, *Modernizing the U.S. Census*, the final report of the Committee on National Statistics Panel on Census Requirements in the Year 2000 and Beyond. The report is the culmination of a three-year study on the census.

The study reported here, *The Implications of Continuous Measurement for the Uses of Census Data in Transportation Planning*, was conducted independently of the National Research Council. However, the study did call on two people who were members of the NRC panel, Barry Edmonston and Stephen Fienberg, to assist the transportation planning users panel in better understanding the statistical implications of Continuous Measurement. The conclusions of the two groups are likewise independent. There is some overlap as well as differences in the general recommendations, which are noted below.

Modernizing the U.S. Census, Conclusion 6.4, states in part: "We conclude that it will not be possible to complete the needed research in time to make the critical decisions regarding the format of the 2000 census. We therefore do not recommend substituting Continuous Measurement for the long form in the 2000 census." Conclusion 6.3 states: "The panel recommends that the 2000 census include a large sample survey that obtains the data historically gathered through a long form." The transportation planning expert panel sees many advantages in Continuous Measurement, but is also concerned about dropping the long form prematurely. However, the transportation planning expert panel recommends a parallel approach, whereby Continuous Measurement is tested during the 2000 census, to compare results.

Appendix A: List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
AHS	Annual Housing Survey
BTS	Bureau of Transportation Statistics
CAAA	Clean Air Act Amendments of 1990
CTPP	Census Transportation Planning Package
DOT	Department of Transportation
GAO	General Accounting Office
GIS	geographical information system
ILF	Intercensal Long Form
ISTEA	Intermodal Surface Transportation Efficiency Act
JTW	journey to work
MAF	Master Address File
MDRP	Micro Data Review Panel
MPO	metropolitan planning organization
OD	origin-destination
PUMS	Public Use Microdata Sample
RDD	random digit dialing
SACFO	Sampling and Address Correction Feedback Operation
SIP	State Implementation Plan
STF	Summary Tape File
TAZ	traffic analysis zone
TIGER	Topologically Integrated Geographic Encoding and Referencing System
TMIP	Travel Model Improvement Program
TRB	Transportation Research Board
UTPP	Urban Transportation Planning Package

Appendix B: Brief Biographies of Panel Members (in alphabetical order)

James Bunch

Mr. Bunch is currently with Bunch & Associates, where he provides consulting services in transportation analysis and evaluation, travel forecasting, and demographic analysis. Throughout his career Mr. Bunch has developed his expertise in transportation policy evaluation and alternatives analysis, travel forecasting methods, and data development for travel forecasting. He has worked in varied planning environments including a regional metropolitan planning organization, a transit operating and planning agency, and private consulting.

Mr. Bunch attended Northwestern University, where (as an intern) he co-authored "Strategies and Options for Development of the Chicago Regional Passenger Transport Network to the Year 2000." At the University of Houston, he studied policy analysis. He has a bachelor's of civil engineering from the University of Michigan.

G. Bruce Douglas

Bruce Douglas, a nationally recognized transportation planner and traffic engineer, is a senior transportation planner at Parsons Brinkerhoff. Dr. Douglas has extensive experience in the application of new travel demand models using microcomputer and mainframe environments. These models include the Urban Transportation Planning System (UTPS) program battery; MINUTP (microcomputer model); TRANPLAN; QRS 2; EMME/2 and its forerunners, the Network Optimization System (NOPTS) and the Transit Network Optimization Program (TNOP). He is also accomplished in the use of TransCAD, a program that combines transportation analysis with geographic information systems (GIS) analysis. His research and practice have resulted in new uses for interactive computer graphics in transportation analysis and the development of new computer simulation models of modal choices for urban analysis. Dr. Douglas earned a Ph.D. in Civil and Urban Engineering from the University of Pennsylvania, an M.S.C.E. from the University of Pennsylvania, and a B.S.E. (Civil) from Princeton University.

Greig Harvey

Mr. Harvey's work includes a series of transportation planning and management studies for the Bay Area Metropolitan Transportation Commission, and preparation of reports on transportation—air quality planning and transportation pricing for the Federal Highway Administration, assessment of TCM cost-effectiveness for the Bay Area Air Quality Management District, and urban land-use and transportation demand model development and application for the Bay Area and Los Angeles. Mr. Harvey has published numerous papers on ground access to airports, demand forecasting, and organizational and institutional aspects of civil engineering.

T. Keith Lawton

Mr. Lawton is a specialist in transportation and land-use modeling for MPOs. He is the Technical Manager for Metro, Portland, Oregon. Mr. Lawton led the enhancement of Portland's regional transportation models to include urban design and heterogeneity of land-use effects on auto ownership and travel behavior in partnership with an environmental group's study (1000 Friends of Oregon). Mr. Lawton was closely involved with the choice of the GIS software (Arc-Info) and the development of the Regional Land Information System. T. Keith Lawton holds an M.S. in engineering from Duke University.

Alan Pisarski
(Facilitator, Second Session)

Mr. Pisarski is a private consultant who has been an active participant in the national transportation policy scene for more than 20 years. His work related to transportation and particularly commuting has been reviewed, discussed, and quoted in major national news magazines and newspapers. He has also appeared on major national radio and television network programs, such as *Nightline* and *20/20*, discussing national transportation issues. He currently serves as content advisor to a major new public television series on transportation.

STEPHEN H. PUTMAN

Mr. Putman has 30 years experience in combining theory development with practical application of mathematical models for urban and regional forecasting and policy analysis. He is Professor of City and Regional Planning, and Director of the Urban Simulation Laboratory at the Department of City and Regional Planning of the University of Pennsylvania. He teaches courses in quantitative analysis for urban and regional planning, in computer use in planning, and in integrated transportation and land-use modeling. He is Principal of S.H. Putman & Associates, a consulting firm with an international reputation for integrated land-use and transportation planning, forecasting, and policy evaluation. His EMPAL and DRAM computer models have been used by numerous metropolitan regions in the United States, and are currently licensed for use in a dozen such areas. As part of his ongoing involvement in research, teaching, and consulting, he has given numerous presentations, written four books, and published more than 50 papers on these topics.

KARL QUACKENBUSH

Mr. Quackenbush is Deputy Technical Director of Operations at the Central Transportation Planning Staff in Boston. He co-directs and coordinates the organization's technical work in the areas of regional multimodal travel modeling, small-area traffic forecasting, traffic engineering, air quality analysis, and transit service planning. Mr. Quackenbush earned a Master's in City and Regional Planning from Harvard University and a B.A. in Geography from the State University College of New York.

PETER R. STOPHER

Dr. Stopher is Professor of Civil and Environmental Engineering at Louisiana State University. He was director of the Louisiana Transportation Research Center from 1990 to 1993. He has served as consultant and/or project director for numerous studies, including impacts of capacity increases on air quality, household surveys for travel demand estimation, on-board transit passenger surveys, goods movement, short-, medium- and long-range transportation plans, forecasts and networks, and design, redesign, calibration and refinement of travel forecasting models. He is author or co-author of eight books and dissertations, including *Urban Transportation Planning and Modeling*, reprinted five times. His formal publications, refereed papers and presentations number over 100, including *Travel Forecasting Methodology: Transfer of Research into Practice* (1985); *Deficiencies in Travel Forecasting Procedures Relative to the 1990 Clean Air Act Amendment Requirements* (1992); and *Blow-Up: Expanding a Complex Random Sample Travel Survey* (1993). Dr. Stopher received the Bachelor of Science in Civil and Municipal Engineering from University College, London (University of London), and a Ph.D. in Traffic Studies, Faculty of Engineering, University College, London.

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- Martin Wachs, "The Future City: Its Changing Role and Prospects."
- George V. Wickstrom, "Data Needs To Meet New Transportation Planning Requirements."

Appendix D: Panel Papers

The papers presented in this section of the report were prepared by the panel convened for this study for their second meeting in November 1994. The contents and conclusions in these papers do not necessarily reflect the opinions of the Bureau of Transportation Statistics.

The papers by James Bunch and Bruce Douglas are not available.

COMMENTARY ON THE PROPOSED REPLACEMENT OF THE U.S. CENSUS DECENNIAL LONG FORM WITH A CONTINUOUS MEASUREMENT SURVEY PROGRAM

BY
GREIG HARVEY
DRAFT, NOVEMBER 17, 1994

Under pressure to focus resources on a more complete enumeration of the population, and in light of recent advances in computer hardware and software, the Census Bureau has proposed to replace the decennial long form with a continuous nationwide household survey that would yield about 250,000 completed long-form type questionnaires per month. Levels of precision for a five-year cumulation of such data generally would be comparable with the current long form (though meaning of the cumulation would be quite different from the current time series). Data would be released periodically (annually?) in microdata form and as five-year moving totals.

A continuous sampling strategy has many potential benefits:

- improving efficiency, greater consistency, and possibly higher quality resulting from a constant workload;
- immediate knowledge of shifts in key socio-economic indicators for large geographic areas (such as states and metropolitan regions);
- more timely information at all levels of geographic aggregation, particularly in the latter years of a decade;
- an opportunity to explore innovative, and potentially powerful, applications especially focusing on the dynamics of household structure, workforce participation, home ownership, etc.

On the other hand, a continuous sampling strategy would not yield the richly-detailed cross-section that users have come to expect, and this is perceived by many as an issue of uncertain, but potentially critical, import. And there is a political issue as well: a continuous sample divorced from the short form arguably would be more vulnerable to cancellation (or downsizing) in an era of tight federal budget constraints.

The transportation and urban planning communities are heavy users of census long-form data. Among the typical applications are:

- establishing a demographic and income baseline for small geographic areas (with local resources used to estimate changes within each decade);
- time series comparisons of regional and sub-regional journey-to-work patterns, including the long-term evolution of mode shares;
- in smaller regions that lack resources to collect independent data, use of journey-to-work trip tables to validate, and in some cases calibrate, models of daily work travel.

While more frequent household surveys and parcel-level GIS databases have begun to give some regions important alternative sources for certain elements of the census information, it hardly would be an overstatement to say that the decennial census continues to be the single most important source of data (indeed, the only source for most of the smaller urban areas).

Members of this expert panel have been asked to comment on the suitability of a continuous sample for transportation and urban planning applications. I have approached this question from two points of view: as a heavy user of the census for what might be termed non-standard applications, I have tried to assess how my own work would be affected by replacement of the long-form; and, as someone who interacts with a large number of regional-level census users, I have canvassed about 30 individuals to gauge their reactions as well. This informal survey focused intentionally on the needs of larger regions (other panel members have been asked to comment explicitly on the needs of smaller urban areas).

My own recent work has made heavy use of the census data in three ways:

- *As the source for household survey sample weights.* We have assembled all of the 1990-91 California household surveys into a database for model estimation, trip chaining analysis, and microsimulation of travel demand. During the process, observations missing certain types of data were culled, and the PUMS records were used to establish new sampling weights at the PUMA level.

- *As the basis for a synthetic population of households for use in microsimulation.* PUMS data are used to create a multi-way tabulation of household characteristics at the PUMA level, which then is combined with tract-level marginals to infer a tract-level multivariate distribution of household characteristics. Actual PUMS households from the PUMA are then drawn to create a full synthetic population for each tract.
- *As the best available source of data on commuters in the San Francisco-Oakland Bay Bridge corridor.* In planning for the first ISTEA congestion pricing demonstration, we needed as much detail as possible about commuters in the corridor. The PUMS for California contains about 8000 persons with an AM peak journey to work in the corridor. This subsample was extracted and used to carry out an exhaustive assessment of the commuting population, including income, ethnicity, occupation, and mode.

We could have used a rolling 5-year PUMS to carry out the same analysis. However, temporal effects implicit in the rolling data would raise questions of interpretation in each case. For example, a complex multi-modal system, such as the Bay Bridge corridor, undergoes almost continuous change in the conditions of travel. Frequencies, fares, tolls, and highway operating parameters all can vary significantly over a five-year period, leading to shifts in the populations of commuters. Thus, a five-year rolling PUMS tells us what the average population has been like but does not support inferences about how commuter characteristics relate to supply and performance conditions.

The broader group of professionals also saw that a continuous sample long form would be inappropriate for come current uses (or at least much more difficult to interpret). On the other hand, they could imagine new uses for a continuous sample, particularly to obtain an early indication of significant demographic change.

Both my own work and the reactions of a broader cross-section of the professional community lead to a similar, and fairly robust, set of conclusions:

- Transportation planning, especially the studies which guide and assess the impacts of our multi-billion-dollar annual transportation investment, is deeply dependent on census long-form data in the present format of delivery. At a minimum, software and locally-developed procedures would have to be modified extensively to accommodate the time-averaged information produced from a continuous sample.
- Absent a substantial increase in funds for local data collection, most small MPOs and perhaps many of the less-motivated larger MPOs likely would continue to apply existing procedures without regard to the significant differences between cross-sectional counts and moving 5-year totals.
- Statistically-reliable annual updates at a PUMA or smaller level of geography, as promised by the continuous measurement strategy, would be an extremely valuable addition to the regional database.
- Ideally, the census would provide both a detailed cross section coincident with the decennial count and a sample-based update at enough interim points to yield a reliable (and timely) barometer of change for the smallest possible geography. It might be possible to save some money with a smaller long-form sample, recognizing, however, that good tract-level data are critically important to local governments.
- Among practitioners who had heard about the continuous sample (and most had), a common inference was that the long-form eventually would cease to be available, if not for 2000 then probably by 2010. Uncertainty about the national political climate has led some to begin planning for an entirely local data collection strategy.
- If a continuous sampling strategy does replace the long form, DOT will have to undertake research and provide extensive guidance to users.
- If a continuous sample is to replace the long form, the two should be carried out in parallel in the year 2000, so that systematic differences due to sampling methodology can be explored and characterized.

Overall, reaction to the continuous sampling proposal was not nearly as negative as I expected. While the reasons for this may be quite complex, a common theme among both demographic modelers and travel modelers was that the evolution of analysis methods seemed to be leading inexorably to a household-based dynamic analysis framework for which continuously-sampled data might be quite appropriate.

CONTINUOUS MEASUREMENT POSITION PAPER

BY
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NOVEMBER 9, 1994

The basic thrust of my comments will address the opportunity to structure census data and access to them; to enable us to take advantage of advances in discrete choice modeling and disaggregate computer simulation that have occurred over the last 20 years. This combined with continuous measurement would give transportation and land-use modelers a very useful tool. The utility of the Census data would be greatly increased.

1. POPULATION AND EMPLOYMENT LOCATION AND ALLOCATION

The most important use of the census data for an MPO/COG is for the spatial allocation of population data concerning persons and households. The work location information from the long form is also important in varying degrees to most MPO/COG organizations, often combined with other sources. Problems with inadequate geocoding of the work location, combined with the 10 year interval and very tardy release of workplace location limit its value. If travel surveys for transport modeling are coordinated with the census, then a long wait for finished models ensues. Such a long wait becomes politically difficult when the cost of, and expectations for, travel surveys are taken into account.

It is thus often the case that only the population data are used, with estimates of employment location made from other sources.

1.1 DECENNIAL CENSUS NOT OFTEN ENOUGH

There is also a continuing need for base year data on population and employment for years other than the census years. This need includes model estimation, calibration or validation, for air quality and alternatives analysis (now Major Investment Studies). This leads to independent means of estimating the inventory of housing, persons and jobs for small areas. These methods include the use of more aggregate data that is published more often (by county for example), and monitoring building and demolition permits. The Census is then used to calibrate to a new datum line every 10 years for population and housing.

In comparing our between-census data estimates with census data in 1960, 70, 80, and 90 we find that our estimates drift away from the census base over the 10 year period. What this means, for example, is that our 89 estimates for a particular tract may be substantially different from the 1990 census count. A more frequent direct measure of the data, as in continuous measurement, would reduce this error for intercensal years. This is of great practical value.

Employment by small area is estimated more directly, accessing primary data files. Examples are: state employment files, commercial employer data files (e.g., Dunn and Bradstreet, Contacts Influential), direct yellow page based surveys of multi-location firms, and direct surveys of the public sector. Similarly for employment, as for housing and population, some agencies use the decennial census for a new datum, others, like Portland Metro, have more confidence in their alternative direct sources.

1.2 FORECASTING MODEL ISSUES

1.2.1 Arbitrary Time Span

The census years are for record keeping for data that undergo slow change in the aggregate. The record of change is not coordinated with cycles—business or growth, and can lead to unlikely results where sequences are important (lagging, leading variables etc.). This can be important for models of housing and employment location decisions, as well as auto acquisition and shifts in mode use. There is no link between the triggers for decision making and the decisions themselves. It would seem that the continuous measurement method would minimize this problem.

1.2.2 Disaggregate Data

As in transportation modeling, there is a strong case to be made for the development of disaggregate models of location decision making. Household location decisions, in this age of multi-worker households, are very difficult to link to the work location of one household member. Further, there is a multitude of variables besides work proximity that are important in the location decision. An understanding of the policy variables that affect the decision can only be obtained from a disaggregate analysis of households. This is an example of an issue that renders aggregate journey to work data irrelevant for the estimation of models of mode and destination choice (while being useful for model validation). This will be further addressed under "Data Output—Micro-Use Samples Enrichment" and "Content."

1.2.3 Frequency

For building models, a more continuous data source than once in 10 years is needed. For all the claims of usefulness of the census for creating temporal as well as cross-sectional data points for model development, I am aware that in almost all of the models used in this country, the estimation has been carried out on a single time series data point (cross-sectional) or with one 5 year lag. While, theoretically, models could be fitted with many years of data points, the development of the other necessary (non-census) data (e.g., transport level of service, neighborhood quality, vacant land inventories, etc.) for historical data points at 10 year intervals has proven impractical. My reading of the situation is that we are building models based on data availability rather than forecasting needs, essentially "looking for answers under the lamppost" rather than trying to shed an independent light, or defining the data needed to build the models. The availability of data on a gross area basis annually, with small area data on a 3 or 5 year moving average, also annually, will help build a more timely model-construction database.

As an example, my own organization is constructing a database of annual change in building activity and the consumption of land. The availability of GIS technology and access to assessors' data is helpful in this (including access to the value of land and improvements). However the information on socio-demographic change associated with location decisions is absent, and linkage to census information is distant and crude. A more current census source, even though different, would almost certainly have greater utility.

2. TREND TRACKING

This is the other primary use of the census. People and policy makers are always very interested in trends—so this makes the data seem more useful and more accessible.

2.1 PRO & CON DC/CM

Census is one of the few continuous sources of data that are collected with a constant methodology. This is therefore also the area most likely to be affected by a change from DC to CM. Continuation of the DC method means long-term comparability, a laudable goal. However, there is a need for trends based on something more current than that allowed by a 10 year interval.

The move to CM, while compromising the long term historical trend analysis to some extent, would quickly develop a new and much more continuous tracking of a time-smoothed trend. The trend junkies would get a continuous rather than intermittent fix—which they will probably find more satisfying once the transition is made. It will certainly be more useful for tracking reaction to situational and policy changes after they occur.

It is also to be expected that the expert statisticians assembled by the Census Bureau will be able to give assurance that appropriate continuous measurement methods will give data highly comparable to the decennial census.

2.2 BETTER?

Depends on the point of view. In the context of regional planning (COG or MPO), the more frequent short term trends exhibited by continuous measurement would be more useful, and used.

3. CONTINUOUS MEASUREMENT AND LOCAL RESOURCES

3.1 QUALITY

3.1.1 Geographic Locators—Conversion to Real Time

The database of geographic locators, addresses, place names and so on would become a continuous maintenance item. Experience at the regional level suggests that this would lead to a dramatic increase in coverage and accuracy. The same database is needed for other applications such as emergency dispatch and delivery route construction; there would be synergistic affects, and a sharing of the burden. The regional planning agency is not taken seriously if data is only "good" once in 10 years.

3.1.2 GIS Integration

Most agencies undertaking the development and maintenance of a GIS would be able to integrate the two sources of information. Again for improvement of job location geocoding. See also "Data Output—Micro-Use Sample Enrichment" and "Content."

3.2 Staff Allocation at MPO Level

A continuous process is very much easier for an MPO or COG to staff (and justify). There is a large difference between allocating half a person per year to the address geocoding database, and allocating 5 persons for a year, once every 10 years. There is also the training comparison—"spooling up" for Census takes concentrated training for a short period, which is never of high enough quality, and which is utilized for a short period of time.

What makes the justification easier is that annual information (within the attention span of most upper level bureaucrats and politicians) can be pointed to as the benefit. This is also easier if a practical use for the data, beyond just "interesting information," can be demonstrated.

4. DATA OUTPUT—MICRO-USE SAMPLE ENRICHMENT

If a way of involving the MPO/COG in the appending or addition of key data items, together with small changes in content can be accomplished, this data set can be the basis for a much stronger analytic capability, including the ability to estimate some important elements of the urban models directly from the data.

4.1 Key to Housing Location, Auto Acquisition, Revised Journey to Work Mode Choice, and Revised Work Location Choice Models

Important elements of the above models can be estimated from an enriched data addition to the households/persons completing the long form data. The less detailed aggregate data can then be used in the calibration or validation stage of model development, where they would be applied to the outcome of a model carrying within itself much more information on user optimization. These models would have the "point of view" of the household decision maker, rather than the descriptors of the observed aggregate phenomena.

This ability to enrich the microdata sample becomes even more valuable if combined with some changes in content.

All of the actions necessary for this enrichment are "post processing," in the sense that they add no burden to the respondent or the fielding of the survey, but do add burden to the act of editing and assembling the data. Much of this burden would fall upon cooperating MPO/COG collaborators.

4.2 What Enrichment?

This would consist of appending a set of variables associated with location ("Situational Variables," to use a term coined by David Hartgen), which would describe the environment or situation of the household or job location, and modal trip information (impedances, costs by mode), between the household and job locations.

4.2.1 Household Location Descriptors

For enrichment with household location variables, the geocode of the exact location of the responding household is necessary for an MPO/COG to be able to append this data.

For auto acquisition and mode choice models, some of the situational variables would be descriptors of aggregate modal accessibilities from a weighted utility calculation from mode choice equations (accessibility by mode), together with combined aggregate accessibilities (e.g., weighted logsums of mode choice models by purpose). They could be as simple or as complicated as the MPO/COG wished, depending on required modeling sophistication. An example of simple is the mixed use pedestrian accessibility measure and the measure of transit accessibility used in Portland's current models by Metro. These are number of retail jobs within 1 mile of the household, and number of jobs accessible by transit within 30 minutes unweighted transit travel time.

They could also include the presence (or measure of quality of) the pedestrian or bicycling environment.

For housing location models, variables describing the neighborhood average value of surrounding properties, criminal activity, school quality, and again, aggregate accessibility to jobs and shops (or even by stratifications of jobs) are some possibilities. These would be driven by the MPO/COG modeling strategy, and their ability to get the data items.

4.2.2 Employment Locator Variables

Employment locator variables would be similar, but would be the characteristics or situational variables of the location of the jobsite for each of the household members. The primary purpose here would be for a work location choice, or a combined work location and mode choice model development. They might also play a part in auto acquisition choices. The minimum here would be size (attraction) variables by zone or by fixed area surrounding the worksite (density), which would reduce the zone area problem in estimation. These would probably be employment by primary SIC, or occupational classifications, and possibly, floorspace, and developed acres by some classification. Modal accessibilities at the worksite may not be useful in destination choice, but might be useful in mode choice. Modal accessibilities are very likely to influence the location decision of a firm or establishment, but this is irrelevant when using census as a source of information.

4.2.3 Append Trip Modal Alternative Data

These data describe the impedances (time, distance and cost) by time of day, for the alternative modes available to the worker for the journey between home and work.

4.3 METHOD—MAINTAINING CONFIDENTIALITY—EASY!

The method suggested here is essentially an arms length method that would minimize loss of confidentiality. The geocode (by coordinate or proximate coordinate) of each location pair could be coded with an ID known only to the Census Bureau, and downloaded to the MPO/COG for appendments. The MPO/COG would in turn use its GIS and transportation software to append the variable values wanted to the locations of household and work, and the travel impedance values between home and work. This is essentially how we (Metro, Portland) currently geocode and append data for the household activity and travel survey currently underway. The GIS staff and the Transportation Forecasting staff do not have access to both the address information and the household characteristics. Neither of them have access to personal identities of respondents.

It is also clear that, with a lot of effort, confidentiality could be breached, and it might be necessary to use sworn staff in this endeavor. Some dithering could be employed, but concern about acuity of data for walk trips, and transit access (critical), would limit this.

4.4 ADDRESS GEOCODING

Some method of improving address geocoding, particularly of place of work, needs to be worked out between the Bureau and MPO/COG staffs with local GIS capability and familiarity.

Using Enhanced Tiger, local GIS, and four commercial sources of address matching, we are getting activity location matches of 95 percent of addresses (multiple filters). We will have difficulty matching this success rate with single address files sent to the Bureau. A hands-off relationship: send MPO/COGs the bare addresses with Census ID, let the local staff do the geocode, with the Bureau to match by own ID. Maintaining complete confidentiality assurance with the implementation of both 4.4 and 4.3 (above) will require some thought and negotiation.

5. EVOLUTION OF TRAVEL DEMAND—FUTURE MODELS

5.1 USDOT DIRECTIONS OR RESEARCH AGENDA

The USDOT in combination with EPA has embarked on a Transportation Model Improvement Program (TMIP). In terms of the evolution of travel demand and travel models, the work so far has suggested likely directions (with some unanimity), and is designed to set the research agenda. The primary objective is to obtain a better understanding of air quality emissions as well as modal use under varying Travel Demand Measures (actions to modify demand for travel).

5.2 NETWORKS/TRANSIMS

The output of the models deals with loading of vehicles and travelers to the travel networks (supply). The task of developing a prototype dynamic network simulator is being undertaken by the Los Alamos National Laboratory whose product, TRANSIMS, is ultimately expected to include travel demand models.

5.2.1 Fleet Consist & Use (AQ)

One of the elements of importance is the vehicle fleet and its use (how much, when, where). Different age and fueled vehicles emit pollutants at different rates. Not much is known about which vehicles are used for different trip purposes and trip lengths. Thus a track of vehicle year/model/type will be required, by how much used. In travel diaries for model development it has become important to track this greater level of detail. In the past, as in census, just the number of cars owned was recorded.

5.2.2 Brief Description—TRANSIMS

The object of dynamic network assignment in TRANSIMS is to simulate network and vehicle operation on a second by second basis—including idle, speed, acceleration and deceleration rates. This will include queue formation and dissipation, with upstream effects of downstream situations. Census information has little relevance to the data needs for this level of detail.

5.3 DEMAND MODEL ELEMENT

5.3.1 Direction

The general direction is to move away from modeling individual trips as independent choice sets. The sequencing and duration of activities is seen as the planning action that decision makers make over the whole day (or week). For instance, the choice of mode on the journey to work may be conditioned on the traveler's intention to retrieve a child from daycare on the way home that evening (a child who was, say, deposited at daycare by the spouse, whose choice of mode from work to home was then conditioned by the errand on the way to work). There is discussion on the way to accomplish this (traditional nested choice models—utility optimizing, versus microsimulation of sequential actions, and satisfying—not optimizing from a full set of choices, but embracing a plan that meets some criterion of acceptability, to use two examples). The data needs are common to all the methods currently contemplated for activity sequence model development.

In its simplest application this would require that trip chains (the linking of all decisions on destinations and mode for all activity stops on a tour which begins and ends at home) be explicitly considered. This means that the term "journey to work" be considered as a journey, and not a trip, and that the real need is for a consideration of the journey to and from work.

For the Journey to Work (JTW) data to be useful in this context, it will be important to remove ambiguities and add information. This will be discussed under "Content."

5.3.2 Trend—Chains, Auto Acquisition and Use Tied to Household Structure

It has become evident that household structure, or lifecycle, is a major element in the change of travel behavior, and more particularly, trip chaining and auto use. Research in Portland shows that more complex chains, concurrent with reduced auto occupancy (and possibly increased auto acquisition) are exhibited by households with the least free time—two worker households, with and without children, and single working parent families. This information is inherent in the PUMS data, hence the interest in enhancing this data set.

5.3.3 Relevance of the Journey to Work Data, Possible Additions

For the journey to work data to become relevant to both old and new model paradigms, the definitions of mode and frequency need to be unambiguous. At present, it is not clear whether people who have complex trips to or from work are reporting the time between home and work on days when the trip is direct, or the value including typical stops for errands. Specific questions on stops to complete errands on both the to-work and the from-work travel are needed. If the models get to the stage of whole day plans for activities and travel, the information gleaned from the journey to work data will be inappropriate for model estimation, only useful for calibration of an element in the "daily plan." A reasonable assumption is that the early (next 5 years) model development will not encompass whole-day activity scheduling and duration as an element. It is reasonable to expect that explicit trip chaining activity for at least the journey to work will be a part of the short term model improvements. The Journey to Work element of the census will be relevant as long as complex (multi-activity) chains are explicitly recorded in the trip chain which includes a work activity. This will be discussed under content.

6. CONTENT

This is an area where there is very little (if any) room for change, as this affects the number of questions and the length of the form.

6.1 WHAT DO WE WANT: RECOMMENDATIONS FOR YEAR 2000

6.1.1 House Information

Very little extra information is needed here.

The date of move-in (H8) should be more detailed for the previous 5 years, which could be easily accomplished.

A listing of vehicles owned with model year, year of acquisition, and miles per year estimated added—important for air quality analysis. This is a significant addition and would be more difficult.

6.1.2 Journey To Work: Should Be To and From Work!

This is where most change is needed if this data is to be made relevant. I think that "usual" is essentially useless for most purposes. A listing of modes used (frequency) is not difficult and can be used to create "usual" for comparative purposes.

Define as *journey* to <u>and from</u> work.

Mode: Which modes did this person use last week—number of days each? Which mode was used last workday, to work, from work?

Occupancy: To work and from work, last workday.

Intermediate stops: Did this person stop for an errand on the way to work, last workday? On the way home from work, last workday?

Time of Departure: From home, last workday. From work, last workday.

Time of Arrival: At work, last workday. At home, last workday.

Address of Work: This could be the firm/establishment, with a locator such as street and town.

The place of work address coding depends on the development of an establishment file—similar to the

Master Address File already proposed. This is a function for MPO/COG cooperation.

6.2 What Do We Get That We Don't Use?

Who uses:

Plumbing facilities, kitchen facilities, fire, hazard and flood insurance, mortgage payment details, military active service detail? We should find out.

7. DECENNIAL CENSUS OR CONTINUOUS MEASUREMENT?

From the point of view of a regional planning agency, the move to continuous measurement would improve the timeliness and usefulness of the data.

Enrichment of the data at the PUMS level would significantly increase the usefulness of the data for direct discrete modeling. This would be of much less value without continuous measurement.

In light of developing travel analysis techniques, the content changes to consider more information on the travel tour which includes a work activity will be necessary.

The combination of all three actions: continuous measurement, enrichment of PUMS and content change would make this data relevant. Without these changes the data will become less relevant over time (in which case I would be relatively indifferent to the loss of these data).

CONTINUOUS MEASUREMENT: IMPLICATIONS FOR TRANSPORTATION PLANNING

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Position Paper submitted to COMSIS Corporation and its Transportation Planning Panel formed to evaluate Continuous Measurement's impacts on transportation planning.

INTRODUCTION

This paper presents my position on the subject of Continuous Measurement. The primary perspective from which this paper derives is that of travel modeling as practiced at one large Metropolitan Planning Organization (MPO). However, this perspective is also shaped by my general knowledge of travel forecasting practice in this country, and by my experience in areas of transportation planning other than travel modeling.

The paper begins with a brief statement of my current position on Continuous Measurement. That is followed by a presentation of the ways in which Census data are used in transportation planning at the Boston MPO. That presentation includes a description of the travel modeling process. The heart of the paper, consisting of a discussion of issues I considered in the course of arriving at my position, follows that. Conclusions and a summary of my position come afterwards, and the paper closes with a set of recommendations for the Census Bureau and the U.S. Department of Transportation (U.S. DOT).

POSITION ON CONTINUOUS MEASUREMENT

Given a choice between just two alternatives—the long form administered during the decennial Census and Continuous Measurement—I would prefer the latter. However, that preference is mild, and is completely contingent on Continuous Measurement being implemented in the manner described in current Census Bureau documents. That is, it must yield data of a quality that is equal to or better than the long form, must result in the range of products that are promised, and must provide promised flexibility in the form of higher sampling rates when desired by an MPO. Furthermore, my preference for Continuous Measurement is contingent on any increased costs to MPOs associated with higher sampling rates, more data processing or any other facet of the program being funded by the U.S. DOT.

BACKGROUND—MPO USES OF CENSUS DATA

This section describes the ways in which the Boston MPO uses Census data.[1] Its use of Census data is typical of their use in many large MPOs; however, Boston does not use these data in all the ways in which they can supposedly be used. This is due, in part, to the existence of recent survey data. In addition, though, Census data are simply not suitable for many of the transportation planning applications noted in the literature.

This section is divided into two subsections, one on general transportation planning applications; the other on travel model-related applications. The former is meant to be illustrative rather than exhaustive. There are too many general planning applications to enumerate, and the impacts of Continuous Measurement on them would either be neutral or clearly positive. The

[1] The Boston MPO is composed of the: Massachusetts Executive Office of Transportation and Construction (EOTC), Massachusetts Highway Department (MHD), Massachusetts Bay Transportation Authority (MBTA), MBTA Advisory Board, Massachusetts Port Authority (MASSPORT) and Metropolitan Area Planning Council (MAPC). The Central Transportation Planning Staff (CTPS) is the technical support group to these agencies. It performs travel demand forecasting for them.

section on modeling applications, on the other hand, is meant to be complete, since that topic is the focus of this paper and most crucial to the Continuous Measurement debate.

General Regional Transportation Planning Activities

Census data are used in several ways in general transportation planning. Continuous Measurement would have nothing but a positive impact on these uses. Some of them involve large-area data which would be far more plentiful than now, and others that involve small-area data use them in such an approximate way that there could not be any harm caused by Continuous Measurement.

Census data are often used in a descriptive manner. For example, data describing travel-related household characteristics and work trip patterns appear as background information in the Regional Transportation Plan and other documents the MPO is required to produce. In addition, the MPO produces reports whose main objective is to disseminate selected Census data in graphical and tabular format to various interested parties.

Census data are also used quantitatively in a wide variety of applications. Some recent, typical applications include the following:

- The MBTA annually certifies that its bus routes are equitably deployed with respect to minority and Spanish-origin residents of their service area. CTPS compares bus route locations with Census tract-level data to assist the MBTA in making this certification.
- The MBTA needed to establish the ridership potential of extending certain bus routes into a recently developed area. CTPS used origin-to-destination work trip data from the 1990 CTPP to perform the required market analysis.
- The Massachusetts Department of Environmental Protection evaluated how a strengthened statewide rideshare regulation might help meet air quality goals. CTPS helped by summarizing 1990 CTPP work-trip vehicle occupancy data for specific geographic areas.

In addition to using Census data for its own general planning purposes, the MPO acts as a clearinghouse for these data. State agencies, city and town officials, businesses and citizens provide a constant stream of requests for all manner of Census data. Developers, for example, frequently request summaries of work trips to and from specific areas, as well as information on household income, to assist in market analyses.

Travel Modeling

The most extensive and intensive uses of Census data at the Boston MPO, as well as at many other large MPOs, are those related to travel modeling. It is these uses that would be potentially most impacted by Continuous Measurement. This section begins with a description of the travel modeling process, followed by discussions of Census and other data used in that process. These discussions relate both to modeling in general and to modeling as practiced at the Boston MPO.

The Four-Step Modeling Process

Most MPOs, including that for Boston, use the so-called four-step process to forecast urban travel demand. This process was originally designed to forecast demand for major highway improvements, but afterwards also came to be used to forecast demand for transit improvements. The name refers to the four major steps in the process: trip generation, trip distribution, mode choice and trip assignment. The first three steps yield travel demand, and the last step combines this demand with transportation supply to obtain estimates of vehicle volumes on roadways, ridership on transit lines and other measures.[2] Many MPOs now link land use allocation models to the travel models in what one could call a five-step process.

Travel models are set up and run for an entire MPO region, or for corridors and medium-sized subareas within those regions, or even for very small areas such as individual towns and transit station site areas. The models track trip-making according to different trip purposes, and are generally used to forecast weekday daily or peak-period trip-making. In the course of developing a model set, a region is subdivided into small geographic areas called traffic analysis zones (TAZs). These TAZs, most of which are either Census tracts or otherwise similar in size to those tracts, serve as the basic

[2] In practice, there are also several other steps in which data are processed and submodels are run, but these are all subordinate to the four main steps.

geographic units for which trip-making is forecast. The region's transportation supply, in the form of roadways and transit lines, is represented in computerized networks which contain travel times and costs by travel mode from each TAZ to every other one.

Travel models are generally developed using cross-sectional data collected in or near a given season of a given year. They are often built using spring or fall data because travel during those seasons is, in many urban areas, higher than at other times of the year. Once developed, models are used to simulate current (base-year) travel and to forecast travel for another specific point several years in the future.

The Boston MPO, among several others, has begun to use land use allocation models which spatially allocate total regional households and employment among TAZs. Integrating a land use model with the travel model chain permits analysis of the interactions between land use activities and the transportation system. Employment by type is allocated to a given TAZ on the basis of historical levels of employment and population in that TAZ, total land area in the TAZ and the accessibility (as measured by the transportation networks) of that TAZ from other TAZs where people live. Households by income quartile are allocated to a given TAZ based on its historical population, employment level in the year of interest, amount of residential land, vacant developable land and the accessibility of that TAZ to other TAZs where people work.

Trip generation models take as input household and employment estimates that have been allocated among TAZs either manually or by a land use allocation model. Within each TAZ, households are stratified into market segments defined by characteristics such as auto ownership and household size that influence trip-making. Employment in each TAZ is stratified by type (retail, manufacturing, etc.) because different types of sites attract different numbers of trips per employee. These stratified data are translated to trips into and out of each TAZ using trip rates appropriate for each stratum of households and employment. There are different models for each trip purpose (work, school, shopping, etc.), and trips generated by households are produced separately from those attracted to stores, offices and other locations. Trip generation is an extremely important model step because it yields the basic number of trips in the regional transportation system. Subsequent steps simply allocate those trips spatially, modally and temporally.

Often a model is also run to predict household auto ownership which is subsequently input to trip generation and mode choice. Auto ownership in Boston is forecast on the basis of household size, number of household workers, and residential and employment density.

Trip distribution models spatially allocate trips that are generated into and out of each TAZ by the trip generation step. Generation deals solely with how many trips begin or end in a given TAZ, without reference to where the other ends of those trips are located. Distribution links trips among TAZs: it deals with where all trips begin and end. Trips that start in a given TAZ are forecast to end in another given TAZ as a function of the travel time and cost between the two, and of how many trips each TAZ generates in total. The times and costs are brought in from the networks. The longer the travel time between two TAZs, the fewer trips will flow between them, all other things being equal. On the other hand, the more total trips a TAZ generates, relative to all TAZs, the greater the "pull" it will have on a given origin TAZ; hence, the more of that origin TAZ trips it will attract to itself. Distribution results in a matrix of trips among TAZs for each trip purpose.

In the mode choice step, the matrices of trips by purpose output from distribution are allocated to competing travel modes and auto occupancy levels. The model considers the times and costs associated with the competing modes, most of which enter here from the transportation networks, and certain characteristics, such as income and auto ownership, of the travelers being modeled. Mode choice yields matrices of trips among TAZs by purpose and travel mode.

The final model step is trip assignment in which trips split by mode from the previous step are assigned to the appropriate networks in order to predict which routes those trips will choose in going from one TAZ to another. At some point prior to this, trips will have been split by time period, and assignments will be done separately for each. Traffic volumes along specific roadways and transit ridership on specific lines are produced. Statistics such as regional vehicle-miles-traveled, vehicle-hours-traveled and average operating speed are also produced. If a land use allocation model is present, highway travel times under congested conditions, also produced by assignments of peak-period traffic, are combined with transit travel times, and entered back into that model to forecast how transportation system accessibility, measured by travel times, might lead to a reallocation of households and employment.[3]

Overview of Data Needs for Travel Modeling

Household travel surveys are an extremely important source of data for developing travel models in large and medium-sized MPOs. These surveys ask individuals about all their travel behavior on specific days. Detailed questions about the numbers of trips made, where each trip began and ended, its purpose, travel modes used and costs associated with each trip are among those asked. Also asked are questions about the household's income, auto ownership, and other characteristics related to the household's travel behavior. These and other major data collection activities are often conducted at or near the decennial Census in order to be able to reliably expand the survey results.

Household travel surveys are often supplemented with a variety of special surveys and counts that glean targeted information about such things as regional travel made by non-residents, travel on little-used travel modes, truck and taxi traffic, and trips to sites with major and unique trip attracting power. In addition, employment data and traffic and transit ridership counts are a necessary part of the travel modeling data base.

The Census is also an important source of data for travel modeling. Census data items of chief interest are those having to do with the journey to work, and those such as income, auto ownership and household size that have a bearing on a household's overall trip-making. Travel modelers also rely on the Census to represent the population to which to expand survey results. Census products used include the summary tape files (STF), the Census Transportation Planning Package (CTPP) and the Public Use Microdata Sample (PUMS). Both short-form and long-form data are used.

Census data have limitations. The CTPP data relate only to work trip-making. Work trips, while an important component of urban travel, particularly during peak travel hours, make up only 20 to 25 percent of the weekday travel in most large urban areas. Census data are further limited by the way in which long-form questions are posed. Those questions elicit information about what individuals usually did the previous week—where one worked at any point during the week, one's usual mode of travel to work, one's usual occupancy, if in a carpool, etc. Transportation analysts, on the other hand, need information about specific behavior on a specific day in order to know what aggregations of travelers do on an average day. In consequence, Census data have to be adjusted before being used by modelers, if they are used at all. Employment data gleaned from the Census are also limited. In Boston, these data are only used to allocate community level employment estimates from other, more reliable sources down to TAZs.

Current Census Data Applications

There are four distinct but inter-related modeling activities at CTPS that involve Census data. The first three are conducted in the process of developing, modifying and otherwise readying a model chain for use in forecasting. The fourth activity occurs when the model chain is run, both during and after it is being developed, to simulate base-year travel conditions. There are several other less formal activities as well. Each activity is discussed below.

Survey Sampling Plan and Expansion

A household travel survey was conducted in the Boston region in the Spring of 1991. The survey sampling plan was designed to obtain a requisite number of completed interviews for specific market segments, defined by the number of automobiles owned by the household, household size and location within five subareas in the region. Each of these characteristics has a bearing on a household's propensity for trip-making.[4] Census data were used to determine how many of the region's households fall into each market segment.

After household survey data were collected, they had to be expanded and weighted to represent the region's entire population. This process corrects for the fact that the distribution of interviews across market segments in the sample is not equivalent to the proportion of the population represented by each group.[5] Census data, as allocated to market segments, were used to create the necessary expansion factors.

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3 To be precise, these times are frequently also entered back into the trip distribution and mode choice steps as well, and for any given model scenario, all of the model steps are run through a second or even third time in order to reach a rough equilibrium among all steps of the combined land use/transportation model set.

4 For example, as the number of autos owned by households increases, the number of trips made per day by motorized vehicles also increases, all other things being equal.

5 Statistical validity requires the same minimum number of completed questionnaires in each market segment, rather than a number that varies proportionally.

Parameter Estimation

Travel and associated models contain parameters that describe the relationship between independent variables and a travel-related phenomenon. These parameters are variously referred to as coefficients, factors or rates, depending on their specific location in the model chain. They are either estimated statistically or "transferred" from other urban areas. A mode choice model contains parameters that relate such things as a particular mode's travel time and cost to the probability of a traveler selecting that mode for a particular trip. Trip generation models contain parameters, known as trip rates, that relate household characteristics to the number of trips the household is expected to make on an average weekday.

Census data are not used at the Boston MPO to estimate travel model parameters. Census CTPP and STF data are aggregate, in that they describe characteristics of groups of people. Some of our models are disaggregate. That is, although applied using aggregate data for TAZs, they are developed with household travel survey and other disaggregate data that describe characteristics of individuals in sampled households. Census data which are released in disaggregate form—the PUMS data—do not, for reasons of confidentiality, contain the home or work tracts of the sampled households. Their utility for model development is therefore limited.

Boston has used Census data to estimate the parameters of its land use allocation model, which is an aggregate model. Households by income quartile, population and employed residents at the block group level are used for this purpose.

Validation and Calibration

A common application of Census data in travel modeling at the Boston MPO is in model validation and calibration. Validation refers to running the models and comparing the simulated outputs to "observed" travel as measured by counts and surveys. Calibration is the process of altering model parameters to force the models to closely replicate that observed travel prior to forecasting future travel.

Since the CTPP data are based on a one-in-six sample, they are, by far, the most complete aggregate work trip data available anywhere, and are thus quite important in validating behavior simulated by models developed with data from much smaller samples. The CTPP aggregate work trip data by block group of residence, block group of employment site and by the interchange between the two are used to validate modeled work trip distribution and mode choice. Census data are also used to validate the auto ownership model.

Inputs for Base-Year Applications

During validation, certain Census data items are used as input to the travel models. After validation is complete, but before forecasting future-year travel, the models are run again with Census inputs to create base-year travel simulations for analysis purposes, and for comparison to future-year forecasts. Census data, by TAZ and market segment, are input to land use allocation, trip generation, auto ownership and mode choice. Census data are essential for this application since there is no other source of such detailed household information at small areas of geography.

Miscellaneous Model-Related Applications

CTPS occasionally uses Census data in various other, less formal model-related applications. In updating the TAZ system recently, 1990 Census households by block groups were used to disaggregate some TAZs. Matrices of CTPP work trips are sometimes adjusted and used directly in small-area traffic and transit forecasting studies. Historical trends in mode usage for a given corridor are developed from 1970, 1980 and 1990 Census data to judge the reasonableness of future-year transit patronage forecasts. A simple, route-level ridership model was developed with Census data in order to predict the impacts of some minor bus route re-routings contemplated by the MBTA. Such uses occur intermittently, as the need arises.

ISSUES

This portion of the paper discusses issues that I considered in forming a position on Continuous Measurement. These are divided into four groups. The first consists of two issues that I cannot help but mention prior to discussing the specifics of Continuous Measurement. The second group consists of broad issues associated with moving to Continuous Measurement. The third relates to specific technical issues related to Continuous Measurement that the Census Bureau has to address. The fourth group contains issues that MPOs would face assuming the Census Bureau were able to implement Continuous Measurement flawlessly and to provide high-quality data.

Two Preliminary Issues

Although the Transportation Panel was asked to focus on the relative merits of the long form and Continuous Measurement, I cannot do so without first making the following two points.

Content Problems

As stated earlier, the long form does not ask the kinds of questions of interest to travel modelers. Current modeling methods require information about "average" day travel, but the long form elicits "usual" day information. As a consequence of what people "usually" do, less popular modes are under-represented, carpool occupancies are under-estimated and the amount of overall work trip-making is over-estimated. The long form does not elicit any information about non-work trips. Part-time employment is missed, and the work trip destinations of some workers are misrepresented.

If Continuous Measurement were to elicit this same information, then it would yield equally problematic information for travel modeling. In fact, such information might even be more problematic with Continuous Measurement. Annual rolling cumulations of "usual" behavior are apt to be harder to interpret and use than what we have now. This issue will likely be of greater interest to many transportation planners than whether or not Continuous Measurement is implemented.

Rationale for Continuous Measurement

It seems that cost is the major impetus for the Census Bureau investigating Continuous Measurement at this time. Members of the U.S. Congress have apparently expressed a desire to reduce the Census Bureau's budget, and eliminating the long form is seen as a way of serving that objective. It is not sensible for cost savings to be the driving factor here. While the cost of the long form may be a significant portion of the Census Bureau's budget, it is a tiny fraction of U.S. DOT's budget. Net cost savings from moving to Continuous Measurement would either be relatively minor or nonexistent. Therefore, a move to Continuous Measurement should be evaluated primarily on the other potential merits of the idea, and the federal government should fund whichever option is deemed to best further this country's urban transportation planning program.

BROAD ISSUES ASSOCIATED WITH CONTINUOUS MEASUREMENT

Issues in this group relate generally to the notion of moving to Continuous Measurement. The first four are those being cited by the Census Bureau as the chief advantages of Continuous Measurement. I agree that these would be tremendously important benefits of Continuous Measurement, if they came to pass as currently envisioned. Unfortunately, nobody can know for sure whether they would.

Enhanced Data Quality From Better Staff

The Census Bureau cites higher quality data from a permanent, better-trained staff as a major benefit of Continuous Measurement. This would, indeed, represent a significant benefit compared to the status quo, if it were true. However, this, like many of the Census Bureau's assertions is somewhat speculative, and would have to be subjected to testing and verification prior to implementing Continuous Measurement. The Census Bureau's own documents, at times, sound a little uncertain about this benefit.[6]

Timeliness

The Census Bureau asserts that it could deliver Continuous Measurement products into the hands of end-users fairly rapidly. If so, this would also be a definite improvement over the status quo. Some end-users of long-form data now have to wait up to over three years before they receive all of it. Again, though, the performance of the data delivery system cannot be known in advance, and would have to be thoroughly tested beforehand.

Currency of Data

By far, the greatest advantage of Continuous Measurement over the status quo would be the fact that MPOs and others would annually, or even more frequently, receive current information about households and trip-making for large areas and semi-current information for small areas. Decennial Census data are, by definition, out-of-date most of the time, and dangerously so in the latter part of each decade. This would not be so with Continuous Measurement.

Continuous Measurement would provide more options for MPOs. In any given intercensal year, a modeler could re-validate work trips and produce new base-year forecasts of total trips. MPO travel surveys could also be conducted in intercensal years instead of decennially.

[6] C.H. Alexander, Bureau of the Census, Report #CM-17, "A Prototype Continuous Measurement System for the U.S. Census of Population and Housing", May 5, 1994, p. 4

Flexibility of Program

The Census Bureau cites flexibility as another advantage of Continuous Measurement. Some survey questions could be altered over the years to respond to new data needs. "Super sampling" could be conducted to obtain information about rare populations. Sampling rates could be increased to respond to a particular need in a certain area. This last facet of flexibility is the truly valuable one. As discussed later, there may be instances in which an MPO needs stable small-area data for a more compressed period than five years. This could only be accomplished by the Census Bureau temporarily conducting more sampling in that period.

Cost Underestimation Leading to Lower Quality Data

Possible cost underestimation by the Census Bureau is an extremely important issue that is in need of further examination. That is, the net cost savings of moving to Continuous Measurement could be less than estimated or even nonexistent, and Congressional reaction, once this became apparent, could be to deny the Census Bureau the funds necessary to conduct Continuous Measurement as desired. The result would be less data collected, hence lower than anticipated data quality.[7]

I see nothing in the Census Bureau's literature that addresses this issue, and I heard nothing at the first Transportation Panel meeting to dissuade me of the central importance of this issue. Continuous Measurement is being marketed on the basis of 200,000 usable interviews being collected each month, and that is the basis on which I give my support to the idea. That level of surveying implies a 25 percent increase in the standard errors for small-area data items accumulated over five years.

Impacts on Small MPOs

Small MPOs and some medium-sized MPOs rely more on Census data in travel forecasting than do large MPOs. The latter can more often afford to conduct household surveys and other large data collection activities than can small MPOs. My perspective is chiefly that of a large MPO modeling practitioner, so I will not discuss this issue. However, the Census Bureau and U.S. DOT need to seek and carefully consider the small MPO perspective on Continuous Measurement.

SPECIFIC TECHNICAL ISSUES CENSUS BUREAU MUST SUCCESSFULLY ADDRESS

There are several technical issues, most of which have been raised by Census Bureau staff themselves, that their organization would have to address in order for my support of Continuous Measurement to strengthen. Each issue will have to be subjected to research and testing, and the Census Bureau will have to either find that there is no serious problem, or if there is one, find a way to solve it. These issues all ultimately have to do with data quality. The Census Bureau asserts that data quality with Continuous Measurement will improve due to there being permanent, well-trained staff. That gain in quality could be more than offset by the technical issues that have been cited. Some issues of particular concern are described below.

Response Rate w/o Piggybacking on Decennial Census

Although Census Bureau staff do not seem to be concerned with response rates, I believe it ought to be a real concern. Although people would have a legal obligation to complete and return Continuous Measurement questionnaires, the fact that these questionnaires would not be piggybacked on the much publicized, highly visible decennial Census may result in a lower than anticipated response rate. Efforts to improve response could drive up the cost of Continuous Measurement beyond what is being anticipated, to a level that Congress might not fund. In consequence, there could be less data collected, hence lower data quality than envisioned.

Quality of Income Data

Travel modeling depends on having good household income data because, as discussed previously, income influences the amount of trip-making conducted by household members and sometimes the modes chosen for those trips. The long form yields good income information, in part, because it is sent out in April when people's prior year household incomes are fresh in their minds. With Continuous Measurement, questionnaires would be sent out every month, and many people who receive them towards the end of a year would likely find it difficult to recall their prior year incomes. The quality of these data could, in consequence, worsen. Income would also have to be inflation-adjusted for a five-year

[7] See, for example, Stephen E. Fienberg, Department of Statistics, Carnegie Mellon University, "Replacing the Census Long Form with Continuous Measurement: Some Implications for Transportation Planning Users," Sept. 12, 1994.

period, thus further contributing to the complexities involved in obtaining these data under Continuous Measurement.

Standard Errors of Small-Area Data

Various Census Bureau staff papers note that the standard errors of small-area data items collected with Continuous Measurement would exceed those associated with long-form data by an average of 25 percent. This would probably not be an unacceptable increase. They further note, however, that under some circumstances, standard errors would exceed those of the long form by more than 25 percent.[8] This is troubling because it is an unknown whose upper-bound could be high enough that data quality could suffer. If data items have a high enough standard error, they become useless in many applications.

There is already enough instability associated with long-form data that its utility suffers at disaggregate levels of geography, including the tract interchange level. These data cannot afford to become much less precise; the Census Bureau needs to perform testing on this issue with the simulated data sets it says it is going to produce, in order to place some, hopefully acceptable, upper bounds on standard errors.

Miscellaneous Technical Issues

Census Bureau literature says that intercensal population estimates will be improved, but there is no mention of increasing the frequency at which subcounty estimates are produced.[9] They are now produced biennially. With Continuous Measurement, such estimates would be needed more frequently, and at a finer level of geography, as controls for sample data.

Currently, there are serious inaccuracies and omissions in place-of-work coding of CTPP data files. Properly maintaining such files on an ongoing basis would seem to be a huge challenge in Continuous Measurement.

ISSUES FOR MODELING PRACTITIONERS

In this section, I discuss issues that modeling practitioners would be concerned with under Continuous Measurement. These issues would occur assuming Continuous Measurement were thoroughly tested ahead of time, modified on the basis of the test results, fully funded and implemented without any major problems. In other words, if Continuous Measurement were designed and implemented to perfection, these are issues inherent in Continuous Measurement that modelers would be concerned with.

Lack of Fixed-Point-in-Time Estimates/Cumulative Averages for Small Areas

By far, *the* major modeling issue inherent in the Continuous Measurement design is that it would do away with fixed-point-in-time estimates for small areas. Instead of having a huge cross-section of household, employment and work-trip data for small areas for April of each decennial Census year, such data would be collected at a reduced rate every month, and would only be reliable once cumulated and averaged over 60 months.

Theoretically, these demand-related data, if household characteristics varied over a five-year period, would be inconsistent with supply-side data, as represented in the four-step modeling process. Travel times and costs embedded in the computerized transportation networks and other supply-side files in the model process relate to a particular point in time. In addition, Census data might be theoretically inconsistent with other demand-side data sources such as household travel surveys conducted during fixed periods of a few weeks.

Despite these theoretical limitations of five-year cumulations, I believe that, as a practical matter, problems for modeling practitioners would be minimal or nonexistent, and that Continuous Measurement would actually be beneficial. In the following paragraphs, I discuss why this is so in the context of the four primary modeling-related categories of Census data use at the Boston MPO.

Survey Expansion and Weighting

Large-area, not small-area Census data for an entire region, and perhaps for large subareas within a region, are generally used for household survey expansion and weighting. These large-area data would be available annually under Continuous Measurement. The large-

[8] C.H. Alexander, Bureau of the Census, Report #CM-10, "A Continuous Measurement Alternative for the U.S. Census," Oct. 28, 1993.

[9] C. H. Alexander and S. I. Wetrogan, Bureau of the Census, Report # CM-14, "Small Area Estimation With Continuous Measurement: What We Have and What We Want," Mar. 22, 1994, pp. 8-9.

area population characteristics of interest are not likely to vary from one month to the next to such an extent that a 12-month average would be inconsistent with the population's characteristics in the particular month in which one's household travel survey is conducted.

These large-area data would be based on a 1-in-34 sampling rate, rather than the current 1-in-6 rate, but they would be statistically valid. Of course, the integrity of these data would depend on the quality of the Census Bureau's own weighting. It is assumed that the 1-in-34 sample would be expanded in intercensal years with good population and demographic estimates.

Not only would Continuous Measurement not pose a problem for household survey sample design and weighting, but it would represent an improvement over the status quo. Currently, practitioners key major data collection activities such as household surveys to decennial years in order to take advantage of the decennial Census for survey expansion. If one now wants to conduct such a survey mid-decade, one must either expand it on the basis of out-dated household characteristics or attempt to extrapolate those characteristics. In either case, one is not working with observed data for the intercensal year of interest. With Continuous Measurement, observed household characteristics would be available for each year.

Parameter Estimation

Continuous Measurement would not pose any more parameter estimation-related problems than are currently represented by the long form. We do not currently use long-form data to estimate work trip travel model parameters. As discussed earlier, most of the Census data are not suitable for disaggregate model parameter estimation, and that which could be used—PUMS—is limited.

Estimation of aggregate land use model parameters would probably not be hampered under Continuous Measurement. Certainly, five-year changes in the small-area data cumulations of interest would not be great enough to pose any consistency problems in Boston, given that some of the non-Census data now used to represent 1990 conditions—land use data, for instance—actually represent other years. Continuous Measurement might actually pose advantages for land use model development. Unlike the travel models, the land use model was developed in a time-series fashion, using Census data from successive decennial years. If data were available for more time points, as with Continuous Measurement, one might be able to do a better job developing the model.

Validation/Calibration of Work Trips

If one does not have a household travel survey, and is updating an older work trip distribution model, then the Census CTPP data, aggregated to districts, serve as "observed" data against which to update and calibrate the model. If one has a household travel survey, then that survey is the source for the observed data. However, even in those cases, the Census data spatial patterns may be used as an independent check because its 1-in-6 sampling rate is much higher than that of the travel survey one is working with.[10]

Five-year cumulative average trip matrices are theoretically inconsistent with distribution model-derived trip matrices, and using the former as a benchmark is therefore theoretically undesirable. On closer examination, however, there would not be much of a problem. First, trip distribution models are not all that accurate. They have to be modified with so-called K-factors to correct for influences on urban trip patterns not accounted for otherwise in the models. Even then, these models yield only approximately correct trip patterns and average trip lengths. When one compares model results to Census data, one should do so only after aggregating both sets of data to large districts because even the Census, with its high sampling rate, does not yield stable zone-to-zone interchange-level data. Flows among these large districts are not likely to change substantially in a five-year period. Therefore, given the low level of precision of the model, and the necessarily aggregate nature of the validation, comparison to a five-year average trip pattern would not represent a serious inconsistency in any real sense.

After the parameters of mode choice models are statistically estimated, the resulting models are adjusted and run repeatedly until they output trip flows by mode that match "observed" data. For those who do not have a household travel survey, and have transferred parameters from another urban area, the observed data may be the Census CTPP data aggregated to districts. For those who have conducted a household travel survey, the observed data are the weighted results from that survey. Even if household survey data are available though, as

[10] For perspective, the Boston area 1991 household travel survey netted usable responses from about 1 in 400 of the region's households.

with distribution, modelers may use the Census CTPP data as an independent check.

For work trip mode choice model validation, there are two reasons why Continuous Measurement would not pose any serious problems. The first is the same as that cited for distribution models. That is, validation of mode choice models occurs at a coarse enough level of geography that any changes in household characteristics and work trip mode choices that do occur over five years would probably be inconsequential. Second, there are often other data available with which to validate work trip mode choice models. On-board transit survey data, if available, could be aggregated to yield reasonably good estimates of district-to-district transit trip flows. Systemwide ridership counts, factored to represent work trips, could also be used to check the performance of the model at a regional level.

The preceding discussion assumes that gradual, secular trends in household and work trip characteristics would prevail in an urban area. What if something were to occur to cause potentially significant changes in a short period? One potential way for this to happen would be a major transportation supply change occurring during the course of a five-year period. If, for instance, a major highway were widened, or if a rail transit line were opened, work trip distributional patterns and mode choices, at least in a given corridor, could change from year 1 to year 5. One might think that comparing model results for a fixed point in time against a five-year average that spans a major system change is inconsistent.

There would be ways to deal with this. Suppose a major corridor improvement occurred in 2003, and that in 2004, modelers wished to validate work trip models, having collected other survey and count data in 2004. At this point, the system change would still be recent enough that its influence on the 1999-2003 cumulation, aggregated to districts, would be minimal. (Work trip location is less elastic with respect to travel time than, say, shopping trip location, so any distributional change in work trips would need time to appear.) There would, therefore, be no practical inconsistency between the cumulative data and the other 2004 data available. If the modelers were performing their data collection and model building in 2005, the influence of any changes would still be overwhelmed due to their being only two years in the past, and because travelers would still not have fully responded to the change. The modeler's 2005 data and the 2000-2004 cumulative data would not be all that inconsistent.

If the modelers were working in 2006, the 2003 system change would have occurred right in the middle of the 2001-2005 cumulation—the most recent one available at that time. Here, the modelers could do one of two things. First, for their subregions of interest, they could check the large-area annual data for 2001 and 2005 to see if, at that level, there are even any detectable trip time or mode changes. If there were no changes detectable at this level, they might not want to worry about the issue further, given the coarseness of the validation process. If there were detectable changes, the modelers could globally modify their 2001-2005 small-area cumulation according to the larger area changes to render it more consistent with their other 2006 data. Alternatively, they might try throwing out the 2001-2003 small-area data altogether, combining the 2004 and 2005 small-area data and aggregating them to large districts.[11]

Another option available to these hypothetical modelers working in 2006 would be to contract with the Census Bureau to perform much more sampling in the years after the system change of interest. In that way, they would be provided with sufficient data to cumulate over a shorter, post-system change period, and they could throw out the small-area data collected before the change. By year 2007, modelers would be supplied with 2002-2006 small-area cumulations. At that point, they could either not worry about inconsistency, given that the Census data would overwhelmingly reflect post-system change conditions and thus be compatible with their 2007 data, or again, they could have contracted with the Census Bureau for additional sampling in post-change years.

Model Input for Base Year

Long-form-derived Census data are used at the TAZ level when travel models are applied to simulate base-year travel conditions. In contrast to validation and calibration activities in which Census data are used only for work trips, here these data apply to all trip purposes.

[11] I am assuming, on the basis of Census Bureau materials, that annual small-area data would be made available to MPO's, even though it would not be statistically valid unless cumulated over five years. I am further assuming that the Census Bureau has considered the issue of confidentiality where data are sparse, and has concluded that would not seriously reduce the quality or quantity of small-area data available to end-users.

A theoretical problem with Continuous Measurement is that the five-year cumulative averages of these variables may be inconsistent with other demand-side data and with supply-side data, all of which supposedly represent conditions at a single fixed point in time. If the allocation of households among market segments changes over time within a five-year period, their average allocation will be different from their allocation at any single point in time. Alternatively, if the allocation among market segments remains constant over time, but the absolute number of households within TAZs changes, their average number will differ from their number at any given point in time. Trips generated with such data would represent, by definition, five-year average numbers of trips, and would be conceptually inconsistent with the computerized networks to which they are assigned.

In reality, inconsistencies between five-year cumulations and other model data would not pose serious or insurmountable problems. First of all, there are already inconsistencies in the data. For instance, the base year for the Boston MPO's travel models is 1990. The supporting database is also loosely said to reflect 1990 demand and supply conditions. In reality, however, that database contains individual data items that range across the early 1990s. The household travel survey that forms the centerpiece of the data was conducted in 1991. Technically speaking, those data are not consistent with the decennial Census data. In addition, the employment database was constructed from various sources, no two of which represent employment at the exact same point in time. The counts in the database are also not from the exact same point in time. The traffic volume counts, for example, are from three different years.

Furthermore, inconsistency is not likely to be great because, in most TAZs, the Census data items of interest in model application would not change to such an extent over a five-year period that five-year averages would be seriously unrepresentative of conditions in a given year. In most TAZs, the allocation of households among market segments would not change a great deal. It is more likely that the absolute numbers of households would change.

Where the number of households is suspected of having changed in certain TAZs, that would probably show up in the Census Bureau's intercensal subcounty population estimates. If so, TAZ households could be adjusted according to these estimates. Where characteristics of households were suspected of having changed dramatically over a five-year period, there would be ways of dealing with it. Assuming annual small-area data are made available to MPOs, one could aggregate and examine those data and/or examine the annual large-area data for subregions of 100,000 or so to look for changes. If changes were detected at that level, one could re-weight or otherwise adjust one's five-year cumulations to approximate those changes at the TAZ level.

As with model validation, another solution to the potential problem of five-year cumulations being inconsistent with other data items, if that were really so, would be to contract with the Census Bureau for greater sampling rates in a one, two or three year period around the year of one's model base year. One could then use the small-area data for a much more compressed period.

IMPLICATIONS—COST AND OTHERWISE—FOR MPO DATA COLLECTION PROGRAMS

In the above discussion, I have assumed that MPOs would have the ability to contract with the Census Bureau for extra sampling in years and/or locations of special interest. The ability for this to occur is crucial to the overall success of Continuous Measurement and to an MPO's ability to overcome problems they do encounter with five-year cumulations. How would this extra sampling be paid for? Without added resources, many MPOs would not be able to afford it. Would U.S. DOT pass along extra funds to enable this to occur?

Continuous Measurement implies much more data being produced much more frequently. How would data processing be divided between the Census Bureau and end-users such as MPOs? If MPOs are provided with much more data by the Census Bureau and then have to process it in order to make use of it, would they have the staff resources available to conduct this processing? How would this added staff time be paid for? Once again, would U.S. DOT provide funds for this? For MPOs that do not currently have any data resources staff, would the Census Bureau do their processing for them, or would funding be available for new positions in MPOs or perhaps in State DOT's in order to carry out this function?

IMPLICATIONS FOR FUTURE MODELING IMPROVEMENTS

Recently, ISTEA and the CAAA have placed new demands on models. These models are increasingly being called upon to forecast the impacts of various policies, programs and projects on regional air quality, travelers choices of travel modes, including non-motorized modes, long-run land use activity allocations and other things. It is generally recognized in the travel modeling community that the four-step model process contains inherent drawbacks that limit its ability to adequately respond to all of these needs. For that and other reasons, the U.S. DOT is leading an effort—the Travel Model Improvement Program (TMIP)—whose objective is to substantially change and improve travel modeling.

It is envisioned that the four-step modeling process described earlier will completely disappear within a couple of decades. In its place will be very different methods based on research into how households make decisions that affect their out-of-home activities, and ultimately their travel behavior. Travel will probably be simulated on networks far more complex than those used now.

This new modeling approach will require changes in the ways in which MPOs collect and use data. There will be far more reliance on highly disaggregate household information. There will be more emphasis on how travel behavior changes over time, and this will be measured for sampled households in panel surveys. It seems as if MPOs will have to engage in more data collection activities than they do now. In addition, they will have to use the data they collect from household travel surveys and other sources in more ways than they customarily do now.

Nobody knows exactly how travel models will look in fifteen years, or what the exact sources and nature of their data inputs will be. This means that it is difficult to say precisely how Continuous Measurement would affect travel modeling in the long term. It is possible that, without major improvements in Census content, and with the advent of new data collection methods, the Census will become an increasingly less important data source for certain travel modeling activities. If so, whether the Census uses the long form or Continuous Measurement could prove to be irrelevant to some degree. The Census will probably continue to be relied on for its wealth of data about household characteristics at small areas. It is unlikely that anything else could provide these data which will continue to be needed for survey expansion and weighting.

It is difficult for me to see any specific ways in which Continuous Measurement would seriously conflict with the assumed nature of future travel modeling. In fact, Continuous Measurement might be more compatible with future sources and uses of data than is the current long form. The five-year rolling cumulations could not be termed true time-series data. However, they would certainly be closer in nature to true time-series data, such as that from panel surveys, than once-every-ten-years long-form data are now. Certainly, the annual data provided for large areas would be true time-series data.

SUMMARY AND CONCLUSIONS

If Continuous Measurement were to operate as currently envisioned by the Census Bureau, the amount, quality and currency of data would represent substantial benefits for many general transportation planning activities performed by MPOs and others. These activities include analyses performed in support of transportation policy development, trend analyses and various certification activities conducted by MPOs. The annual availability of large-area data would clearly be better than having such data only once every ten years. The annual availability of five-year cumulations of small-area data would also benefit some of these activities.

This paper focuses on the potential impacts of Continuous Measurement on travel modeling because that MPO activity makes the most intensive and extensive use of Census data, and could potentially be most harmed by major changes in Census data collection procedures. Travel modeling relies on small-area Census data, and uses these and other data to represent travel demand and supply conditions centered around a fixed point in time. If the quality of small-area Census data declined, or if these data became truly incompatible with other data used in modeling, the quality of MPO modeling would decline.

I conclude that Continuous Measurement, if operated as described by the Census Bureau, would not harm MPO modeling practice, and if anything, would benefit that practice. It would not be harmful for a variety of reasons. First, despite five-year cumulations being theoretically inconsistent with other travel model data, they would not, as a practical matter, be inconsistent. Large travel modeling databases already contain data from different points in time, and those data contain measurement errors that sometimes increase their variability still further. Thus, even if five-year cumulations of Census data spanned a period in which household characteristics were changing in some tracts, they would not differ terribly from other travel data.

Further diminishing any practical inconsistency is the fact that, even if real changes were to occur in small areas over five years, they would not matter in some common model applications. When work trip model outputs are compared to Census data, they are compared at coarse levels of geography. At that level, changes occurring in individual tracts would either not show up, or if they did, would not matter, given the coarseness of the exercise.

The preceding two paragraphs assume small-area changes in key variables would actually occur over five years. However, for the majority of tracts, most variables of interest would not change so much that a five-year average would be unrepresentative of the period. For instance, auto ownership, household size and average trip time to work for residents of a given tract might vary over five years, but not so substantially that data for years one and five would differ greatly.

To be sure, key variables would sometimes change enough over time that modelers would be uncomfortable using five-year cumulations in some applications. Major transportation system changes or rapid population and demographic changes could indeed occur in part of a region. However, analysts would not be forced to work with five-year cumulations blindly. They would be provided evidence of changes by virtue of having both large-area and small-area data available annually. They could determine themselves whether there were worrisome changes occurring.

If there were such changes, MPOs would, according to current Census Bureau literature, have the option of contracting with that agency for higher-than-normal sampling rates in a particular period. Such sampling could be conducted over a year, or perhaps over two or three years in order to construct more compressed cumulation periods.

Continuous Measurement, if implemented as envisioned, would actually be beneficial for travel modeling, as it would be for other transportation planning activities. Long-form data are out-of-date for most of the decennial cycle during which they are used. That would not be so under Continuous Measurement. MPOs would have more recent data to work with, and would be able to conduct other major data collection activities in intercensal years. Furthermore, Census data would supposedly be of higher quality due to more capable staff collecting and processing it.

If given the choice between continued use of the long form during the decennial Census or moving to Continuous Measurement, I somewhat prefer the latter, on condition that it be implemented and operated as described in current Census Bureau literature, and that it not ultimately cost MPOs more. Unfortunately, it is not clear that these conditions could be met. The Census Bureau has much work to do to test and overcome various technical issues associated with the program, any one of which could more than offset the supposed improvements in data quality stemming from better-trained staff.

There may not be any cost savings to the federal treasury with this program, especially if costs to MPOs associated with having to process more data and occasionally contract for higher-than-normal sampling are accounted for. My preference for Continuous Measurement is contingent on U.S. DOT ultimately paying for most or all of these activities. Since the MPO transportation planning process is already overwhelmingly funded by U.S. DOT, this does not seem unreasonable.

My preference for Continuous Measurement is specifically contingent on MPOs':

- having the ability to periodically contract for extra sampling,
- being provided with annual small-area estimates and population control data,
- being provided all of the products now available from the long form,
- receiving products in as timely a fashion as the Census Bureau asserts, and in general,
- being given data whose quality is equal to or higher than that from the long form.

It is imperative that the Census Bureau thoroughly research and test all of the issues that have been enumerated in its literature. It must, indeed, create and use simulated data sets, and test all of the assumptions made regarding how well Continuous Measurement would work in practice. There is a great deal of research that must occur between now and the end of 1996.

RECOMMENDATIONS

The following recommendations parallel some of the issues discussed above. These are aimed at both the Census Bureau and the U.S. Department of Transportation.

- Try to work towards removing cost savings as the major factor driving the move towards Continuous Measurement. The cost difference between the status quo and the new program, regardless of which is actually cheaper, will be minuscule compared to federal expenditures on transportation. Evaluate this program primarily on its technical merits—on whether it would be better for end-users.
- If cost savings must remain central to the debate, re-evaluate those presumed savings to see if they

would even exist from the perspective of the federal treasury after accounting for MPO costs of having to process more data and of contracting for higher-than-normal sampling.

- Between now and the end of 1996, establish processes to involve a wide audience in the Continuous Measurement research and testing program. Establish a process for disseminating test data sets and research results to interested parties, and one for getting findings and opinions back from this audience to the Census Bureau.
- The Census Bureau and U.S. DOT should work closely together on the evaluation of Continuous Measurement and on long-term transportation end-user needs, including those that may arise as the U.S. DOT's Travel Model Improvement Program progresses.
- The Census Bureau and U.S. DOT should consider forming a peer review panel to monitor the research conducted in the next two years. This panel should be composed of Census Bureau staff, outside statisticians, U.S. DOT representatives, transportation planning generalists and travel modelers.
- The Census Bureau research program should include explicit testing of the impacts of five-year cumulations at small areas. I have argued that these cumulations would not pose any major difficulties for travel modeling, but this cannot be known with absolute certainty without testing.
- The Census Bureau should be open to compromises, if the need becomes apparent. For instance, if other end-users articulate problems with Continuous Measurement that have not occurred to me, there might be hybrid solutions such as one involving copying certain key long-form questions onto the short form in order to continue to have a decennial benchmark for certain data items.
- The Census Bureau should address the content problems that transportation professionals have been citing for so long. Some practitioners will surely be more interested in what is asked of people rather than when it is asked or when those responses are made available to end-users.

TECHNICAL MEMORANDUM

IMPLICATIONS OF CONTINUOUS MEASUREMENT ON THE USE OF CENSUS DATA IN TRANSPORTATION PLANNING

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BACKGROUND

In this document, a brief overview is presented first of what census data are of concern to transportation planners and in what primary areas those data are used. Second, the current understanding of what continuous measurement involves is reviewed briefly. In the remainder of the document, a number of the specific uses are examined to which transportation planners have put census data or may do so in the future, and the implications of continuous measurement with respect to each of these are discussed.

CENSUS DATA USES IN TRANSPORTATION PLANNING

It is probably helpful at the outset to review briefly the census data that are used currently in transportation-planning activities. Primarily, two subsets of census data receive the greatest use in current transportation-planning practice. First, descriptions of the population, such as income, vehicles owned, household size, etc. are used in a number of different scenarios. Second, the data collected specifically as the "journey-to-work" element of the long form of the decennial census are used as a supplement or as an alternative to transportation-specific surveys.

There are a number of uses to which basic census demographics are put. These range across

- expanding survey data,
- providing the means to update survey data,
- providing the means to update models developed from survey data to most recent population demographics, and
- providing detailed descriptions of the basic analysis units of transportation planning, the Traffic Analysis Zones (TAZs).

These various uses are very important to the functioning of transportation planning, because the surveys conducted directly for transportation planning are usually very small samples and provide no basis to determine descriptions of the total population. Transportation planning involves planning for entire metropolitan areas, usually covering a part of the Metropolitan Statistical Area (MSA) or the Consolidated Metropolitan Statistical Area (CMSA). Expansion of the small samples collected about travel can be done only by making use of census demographics, as is explained in more detail later in this document.

More specifically, although the journey-to-work data have a number of shortcomings compared to the collection of original data on travel by persons within an urban area, many Metropolitan Planning Organizations (MPOs) use the journey-to-work data either as an alternative to collecting travel data, or as a supplement to a very small sample survey. In order to forecast travel into the future, as is required in order to plan for future transportation strategies and investments, it is necessary to start with an understanding of how people travel at present. Based on information about such current travel, using various assumptions and supplemental data, estimates can be made of probable future transportation needs and travel patterns. Most of the larger MPOs periodically (every ten to twenty years) collect a sample survey of data on travel movements and the demographics and other descriptors of people and households. The data collected usually pertain to a weekday, and are usually supplemented by various traffic-counting programs, and an assortment of additional surveys that complete the picture of travel patterns and the land uses that describe the make up of the urban area. In the past twenty years, most urban areas that have collected data have used samples that range in size from 2,000 households to possibly 10,000 or more households. These samples will usually represent no more than one-half percent of the urban population, although there are limited instances where the sample size may come close to one percent.

Because travel patterns vary not only by the demography of the individuals and households making the travel, but also by the geographic position of the household in an urban area, these small samples provide only limited information for planning purposes. Augmentation of the data from census sources is highly desirable, in order to provide more information about geographic and demographic variability. Hence, the journey-to-work data are used as a supplement, in many cases, even when a travel survey is conducted. On the other hand, because data collection is a major cost item for small MPOs, in relation to the total planning budget, a large number of smaller MPOs do not collect original travel-survey data, but rely on the journey-to-work data and census demographics to provide the entire basis of their planning efforts.

DEFINITION OF CONTINUOUS MEASUREMENT

It is also probably essential to preface any further discussion in this paper with a clear definition of what is understood to be the proposal for continuous measurement. All of the data currently collected every ten years on the Census "long form," which includes most of the demographics of interest to transportation planners, as well as the journey-to-work data, would be collected instead through a rolling sample that would be measured continuously. As currently proposed, continuous measurement would involve collection of data from some number of households throughout every year, with the sample being drawn continuously, month by month, and drawn so that some minimum number of households would be drawn from each geographic area defined for collection in each month of the year. Thus, continuous measurement may provide some small number of samples from every census tract in the nation every month of the year. Currently, the sample sizes proposed would result in 320,000 completed household surveys, nationally, per month for the first three years of continuous measurement. Thereafter, the sample size would decrease to about 200,000 household surveys per month. These monthly samples are expected to be obtained from distributing surveys to 400,000 households per month in the first three years, and to 250,000 per month thereafter. Responses would be solicited initially by mail, followed by telephone and in-home retrieval efforts, and with the expectation that a response rate of 80 percent will normally be achievable. The samples would be drawn through nonreplacement That is, once included in the sample, a given address cannot be sampled again until the entire Master Address File has been used to generate samples. On the assumption that there are approximately 100 million households in the U.S. today, and assuming that the sample consists of 4.8 million households in each of the first three years, followed by 3 million households per year, it would take approximately 32 years to sample all household addresses. Hence, no household is likely to be interviewed more than once, except when a household move takes a household from an already-sampled address in the Master Address File to one that has not been sampled. Supplemental samples could be purchased by an area and these could be additional nonreplacement samples, or could be repeat samples based on prior years. Additional questions could also be purchased, although there would be limits set on the number and complexity.

Of course, when sample sizes become very small within a census tract, there is a necessity to provide confidentiality protection to participating households. This is likely to result in the fact that data for a tract for a year will not normally be available. Instead, the Bureau of the Census will estimate "rolling averages" based on three to five years worth of data. It will be these rolling averages that will provide the basic data that a region will be able to use at the tract or block group level, although annual data may be provided at the level of the MSA and CMSA. The STFs will continue to be the primary product for the user of census data, and it is the STFs that will be based on the three- to five-year averages. It is currently expected that there will be an annual element available for the STFs, based on actual counts in the past year. Cross-tabulations would also be available, although at a geography that is yet to be determined. The other primary public output of the census data would continue to be the Public Use Microdata Sample (PUMS). There would be an annual PUMS release, with the PUMS containing the entire year's observations (3 to 4.8 million households). PUMS, however, would continue to be limited to areas of 100,000 population, and it is suggested that annual PUMS data would be available only for urbanized areas with 250,000 population and above. A number of the details of the proposed measurement could be added to this description. However, this description provides sufficient information for the purposes of understanding the points made in the balance of this document.

USES OF THE CENSUS DATA IN TRANSPORTATION PLANNING

DESCRIPTION OF THE PLANNING REGION

Current Uses

Probably the most basic use to which census data are put in transportation planning is to describe the characteristics of the planning region, in terms of such items as:

- population;
- number of households;
- average household size;
- vehicle ownership;
- income;
- proportions of the population by different age groups, especially distinguishing between children, those in the working ages, and those most likely to be retired;
- employment in terms of both industry and occupation; and
- number of workers in the household.

Currently, these are estimated from a decennial census and will be updated by most regions through the ensuing decade. Typically, new figures for population alone are available within a year or two after the census is actually taken, and the other demographics become available about three years after the census, when STF3 is released. Thus, the breakdowns by demographics, including cross-tabulations, are usually about three years old when they are first available and will age to being thirteen years old before the next new values become available. Beginning with the 1990 census, the Census Transportation Planning Package is providing data on demographics down to the level of the TAZ for all regions that have provided a mapping between census geography and TAZs. However, these data were made available initially only to those MSAs and CMSAs that are rated as being in non-attainment for air quality, and it took four years or more from the census to release these data. Other locations are now receiving the data, nearly five years after completion of census measurement.

Implications of Continuous Measurement

There can be little question that this use of census data will be benefitted by the move to continuous measurement, particularly because the implication is that rolling averages would be updated every year, so that each MSA would have much more up-to-date information available about the regional demographics. Data would presumably never be as much as three years out of date, and certainly being thirteen years out of date will be impossible. Questions will need to be dealt with as to what is the meaning of a three- or five-year rolling average. However, it has been pointed out correctly that, by taking the differences between two successive years of rolling averages, one can always derive a snapshot of the changes (albeit not very accurate, statistically) that have occurred in the demographics in the past year. Therefore, similarly, trend data would become available for each MSA or CMSA, which could also be of value to transportation planners.

A primary issue that needs to be addressed under this use of census data is that of the availability of small-area data and the meaning of rolling averages at this level. Again, if the uses are viewed here principally as being descriptive of the region, particularly using single variables at a time and not cross-tabulated variables, the issues are rather trivial. However, if some analysis and model-related work is to be done, then there are significant issues to be raised about reliability and availability of the data. For example, in an area that is experiencing rapid change, one may need to know how the distribution of households is changing on two or more demographic variables. Given the small number of observations that would be made in a year within one census tract or within the geographic area covered by a TAZ, confidentiality issues will arise if, say, household size and vehicle ownership are cross-tabulated. In addition, if the samples are very small, there may be no statistical meaning to values in a cross-tabulation from a single year. Within small geographic units, one household that has unusual characteristics will tend to have an over-exaggerated impact within one year, and possibly even within two or three years, depending on how small the samples are within small geography units, and depending on the extent to which that household is an extreme on one or more variables.

One additional issue of concern with continuous measurement that takes place through the year is that of seasonal variation. For example, households containing children that go away from home for schooling (both K-12 and university level) will likely report larger household sizes in the summer than during the rest of the year. Unless explicit measurement is made of this, there will tend to be some odd results arising, particularly if, in one year, many such households happen to fall into the summer sample in a specific location, while in the following year, there are almost no such households in the same area's summer sample. Such happenings are well within the realms of possibility with the use of equal-probability sampling.

INPUT DATA FOR LAND-USE MODELING

Current Uses

Probably the next logical step in the process where transportation planners would use census data is as an input to land-use models, or as an input to estimates of regional growth in employment and population that might be used in place of a land-use model. In this instance, there are probably two items that are key. The first is the relationship between population and certain descriptors of the population, and employment. Relationships of this type may be used in the land-use models, or may be used as a substitute for land-use models. The second is the actual values of population, employment, and selected population demographics by small-area geography that are needed to provide the starting point for estimating future distributions of population and employment.

Implications of Continuous Measurement

In this writer' s opinion, the relationships are probably affected relatively little by age of the data or by use of rolling averages, except insofar as the case where a region may have experienced significant changes in an influential factor. In this latter respect, if a region has experienced a significant change to its transportation system, or there has been a dramatic change in land-use or zoning policies, then either data from prior to the changes, or data that are averaged across the time when the changes occurred will likely be of dubious value. Another way of looking at this is to say that current land-use modeling and estimation is based on cross-sectional data and relationships derivable from cross-sectional data. Even if lagged relationships are constructed, whereby the land-use models include information about characteristics at prior cross-sectional time points, the models will remain cross-sectional in nature. In this case, aged data may be less of a problem to use than data that are actually derived from multiple years as a rolling average. The problem that would arise here is that the rolling average no longer represents a cross-section in time. Therefore, the data are no longer consistent with the underlying rationale of the modeling process. Furthermore, land-use models, like other models discussed later in this paper, represent a form of demand and supply modeling. The census data represent the demand side of the equation and are used to determine the description of the equilibrium between supply and demand at a particular point in time. The supply, however, is measured in terms of actual land uses available at a specific point in time. It is imperative that the demand and supply be consistent in measurement at a specific point in time.

Again, a comment is worth making here that, typically, census data are notoriously inaccurate about employment, particularly with respect to the location of the job, as opposed to the location of the worker. To some degree, census data are also inaccurate about the nature of the work, and may group together people who work in a headquarters with those who actually perform the work of the industry, and not distinguish between these two groups of employees. Problems of this nature are endemic to census data, whether collected in a decennial sample or by continuous measurement, and require attention if the data from any method of sampling are to be of real use in the transportation-planning arena.

USES FOR DATA EXPANSION

Current Uses

Because many MPOs collect original data for the purpose of building models, a major use of census data is for the expansion and adjustment of the sample survey data. As noted in the introduction to this document, the typical household-travel survey has a sample size that ranges between 2,000 and 10,000 households from regions that typically contain from 75,000 to several million households. Samples of this size have adequate error properties for the purposes of developing various relationships that are formed into models for forecasting household behaviors relating to travel in the urban area. Typically, household data might be segmented into as many as 20 subgroups, for which a sample of 2,000 households spread equally among the subgroups will provide an adequate level of precision in the means of such things as numbers of daily trips made for different purposes. At subsequent steps in the modeling process, the sample may be used in terms of persons and even in terms of trips. A sample of 2,000 households will produce a sample of roughly 5,000 persons, making as many as 20,000 daily trips. The sample of 10,000 households may produce on the order of 25,000 persons making 100,000 daily trips. These are very adequate sample sizes for the purposes of building models (i.e., calibration of models).

Two issues arise with respect to census data in relation to such survey data. First, those for whom the data are collected on household travel wish to know what these figures mean for the entire planning area, and also to what extent the data may be biased, compared to the actual population. To answer these questions requires that one has a comparison base of the entire population to use for the small-sample survey. This is provided by the most recent census data. For this reason, also, most urban areas schedule their collection of data on household travel as close as they can to the times of the decennial census. This is done to ensure that the census data will approximate as closely as possible the population that was surveyed in the household-travel survey.

In fact, census data may be used in two ways with respect to the collection of small-sample household travel surveys. Census distributions may be used initially to help define the needed sample sizes for accurate measurement of household travel behavior. Thus, a distribution of households by vehicle ownership and household size might be generated from the most recent (updated) census data, and this distribution may then be used to construct prior estimates of sampling errors. It is also used, frequently, to determine what categories should be used for sampling through a stratified sample design. Second, once the data are collected, other underlying distributions that were not controlled in the sample design may be examined as a means to check for biases. An example of this would be a sample that is drawn by strata defined by vehicle ownership and household size, that is subsequently checked for income distributions. While the sample may have met the requirements of sample size for vehicle ownership and household size, it is very possible and, indeed, usually the case that biases will be found by income groups, such that the highest and lowest income groups may be found to be significantly under-represented in the sample data.

Current practice involves one of two options. Either data are collected, in many cases, within twelve months of the decennial census, so that unadjusted census data can be assumed to be a good approximation to current conditions. Alternatively, data are collected more than a year from the census and the data from the most recent census are used, with updating of population figures and the assumption that distributions of other demographic variables remain unchanged from the census. In this method, new population estimates are used as control totals and are applied, often by geographic area, to the demographic cross-tabulations from the census data.

More generally, although not used for modeling purposes, it is usually desired and sometimes necessary to expand the data to the full regional population and to adjust the distributions to approximate those of the most recent census. For data expansion, it is necessary to have the total population cross-tabulations that correspond to the sampling stratification scheme (or other sample design, if used). These numbers are used to provide the population totals from which expansion factors can be obtained. In many cases, a second step is taken to compute adjustment factors that help to replicate a more accurate representation of other variables in the population, such as income and numbers of workers. This is not the same as simply determining if the survey sample is biased, but is an actual use of the census data to estimate adjustments to the expansion factors within multiway cross-tabulations.

Implications of Continuous Measurement

For this purpose, the implications of continuous measurement are unclear, at present. On the one hand, a decennial census of population is still a part of the proposed new design. Therefore, availability of the total population numbers is likely to be no different under continuous measurement than under the present regime. If the data collected in the same year as the population data can be used to provide a reliable estimate of the distributions and joint distributions of household and person demographics, then surveys collected close to the census year will only be affected to the extent that the distributions now have a greater error than under the decennial census, as it has been collected in the past thirty or forty years. The key here is the word reliable. Three to five million households, collected across the entire year in which the population count is done (particularly bearing in mind that the population count will likely continue to be done on a single day), may be totally inadequate to define reliable estimates of joint distributions of demographic variables for the entire population at small geography levels.

A potential benefit of continuous measurement is that, for a sample survey collected several years from the decennial census, the most recent year's measures may provide a basis to adjust underlying distributions and joint distributions of household and person demographics, which is generally not available now. This would mean that there should be some potential to arrive at more accurate distributions of household and personal demographics for the actual time of the survey than is offered by current decennial data with estimated population updates. This would be the case, because the assumption of the same distributions as at the most recent census would no longer be required. On the other hand, the data on the distributions of interest is likely to have a higher error level than is the case with current decennial census data. The exact impact of this on computation of expansion factors can probably be determined only on a case-by-case basis.

On the negative side, the data from a single year will probably represent too small a sample to provide sufficient accuracy in all but the largest metropolitan centers. Even in the large metropolitan areas, because sampling often has a geographic stratum (e.g., a county), the small sample size for any given year may still present significant problems in terms of the accuracy of joint distributions of demographic characteristics. It is unclear how a rolling average, obtained from the previous three to five years, could be used for expansion of data. The average for the preceding five or three years is not representative of the situation when the survey was undertaken. It is unclear whether use of such values would reduce or increase error over current procedures. However, it seems likely that mid- and late-decade surveys would be helped by continuous measurement, while those surveys done early in each decade would be expanded less accurately than now.

It also seems clear that use of the data from continuous measurement will, if it is available on a more timely basis, provide a generally better basis for sample design than is provided by the decennial census data as obtained in recent years. This will be the case, because it is more likely that a very recent estimate can be made of the distribution of household and person demographics that would provide for an efficient survey design. As an example, if auto ownership is changing rapidly (as it apparently did in the 1980s), information, even from a rolling average, in 1988 would have shown a much lower proportion of zero-car-owning households than the 1980 census. It would also have shown that the fastest growing segment was of two-car-owning and three-plus-car-owning households. This would have been sufficient to indicate that the sampling should probably collapse together the zero-car-owning households into no more than one or two household-size groups, while the traditional two-plus-car-owning group should be split into two-car and three-plus-car households, with the potential of collecting data on multi-car-owning households at a fully-detailed level of household sizes.

In contrast to the sample-design aspects, the advantages or disadvantages of continuous measurement for data expansion and adjustment are less clearly defined. In this case, the real issue is that a rolling average is not applicable, and the requirement is for accurate cross-sectional data. However, because the latter have only been available for transportation surveys conducted at the turn of the decade, it remains unclear as to whether or not surveys conducted well after a census will benefit from more up-to-date data, and whether data from the year in which the survey is conducted will provide a sufficient level of accuracy for the purposes of data expansion

DETAILED DESCRIPTIVE ANALYSIS

Current Uses

Following collection of transportation-survey data, a frequent use that is made of the data, in conjunction with census data, is the provision of descriptive statistics for small-area geography, and preparation of input data for modeling purposes. For this purpose, either the PUMS or the Census Transportation Planning Package data (or its earlier equivalent, the Urban Transportation Planning Package or UTPP data) are used in conjunction with local survey data (when available). The first purpose of this step is to provide descriptive statistics about TAZs, often consisting of single census tracts, in terms of joint distributions of households by vehicle ownership, household size, numbers of workers, income, and other pertinent variables. Where joint distributions are not available (which is often the case), at least means or medians for each variable at the level of the TAZ are estimated, and relationships may be used to estimate the joint distribution from the information on the correlation of means and medians with distributions from larger geographic units. This information is used in a variety of ways, including communicating to policy makers and the general public what is known about the various portions of the metropolitan area, and what population segments are most likely to be impacted by various proposed projects and investments in the transportation system.

The second purpose of this step is to provide the input data for using the travel-forecasting models. Typically, as is discussed further below, the trip-generation and mode-choice models use certain demographic variables as independent variables, on the basis of which forecasts of future travel and travel-related decisions are made. Most commonly, the variables used will be from the following:

- **Trip-Production Models**
  - Household size
  - Vehicle ownership per household
  - Household income
  - Workers per household
- **Trip-Attraction Models**
  - Employment by major category
  - Household income
- **Mode-Choice Models**
  - Workers per household

- Household income
- Licensed drivers per household
- Vehicle ownership per household
- Employment status

Each of these variables is required in the form of the number of households in each TAZ that possess each unique combination of the categories into which the variables are divided. For example, household size is usually categorized as each integer size from one through four, and then those households with five or more members. Income is often categorized into quartiles, and most other variables fall into natural categories, with an open-ended top category, where appropriate. Employment data are required, based not on the households where employees live, but rather on the location of the workplaces. These are the variables that largely drive the estimation of total travel in a region and, together with variables that describe the available transportation options, provide the means to estimate use of auto, bus, train, and other options.

Because joint distributions of these variables are not usually available at the level of a TAZ, transportation planners generally resort to the use of some form of estimating process for joint distributions. These may be derived from PUMS and then applied, based on specific means and medians, to the individual TAZs, or used as a supplement to the transportation survey data to provide estimates at the TAZ level.

The variables discussed here are required in joint distribution, first, for the base year, which is usually the same year as that in which the survey data have been collected. Second, they are required for each forecast year. Under the pre-1990 regimes of long-range forecasting and transportation planning, this would generally have been just for a year set as the long-range horizon year at about 18 to 23 years in the future, and usually being a turn-of-the-decade, or mid-decade year, e.g., 2010, 2015. Because of new requirements laid out by the Clean Air Act Amendments and further expanded in the Intermodal Surface Transportation Efficiency Act, there are now frequently multiple years for which forecasts must be prepared, including each milestone year towards attainment of air-quality standards.

Implications of Continuous Measurement

It seems that the major impact of continuous measurement on this element of the transportation-planning process will be a negative one, resulting from the fact that the information required for the base year is again in the form of accurate cross-sectional data, towards which continuous measurement is clearly not geared. Most probably, in this application, we will experience a significant increase in error, if the option is to use the most recent year's data, at the level of a PUMA, from which to develop base-year estimates of the joint distributions.

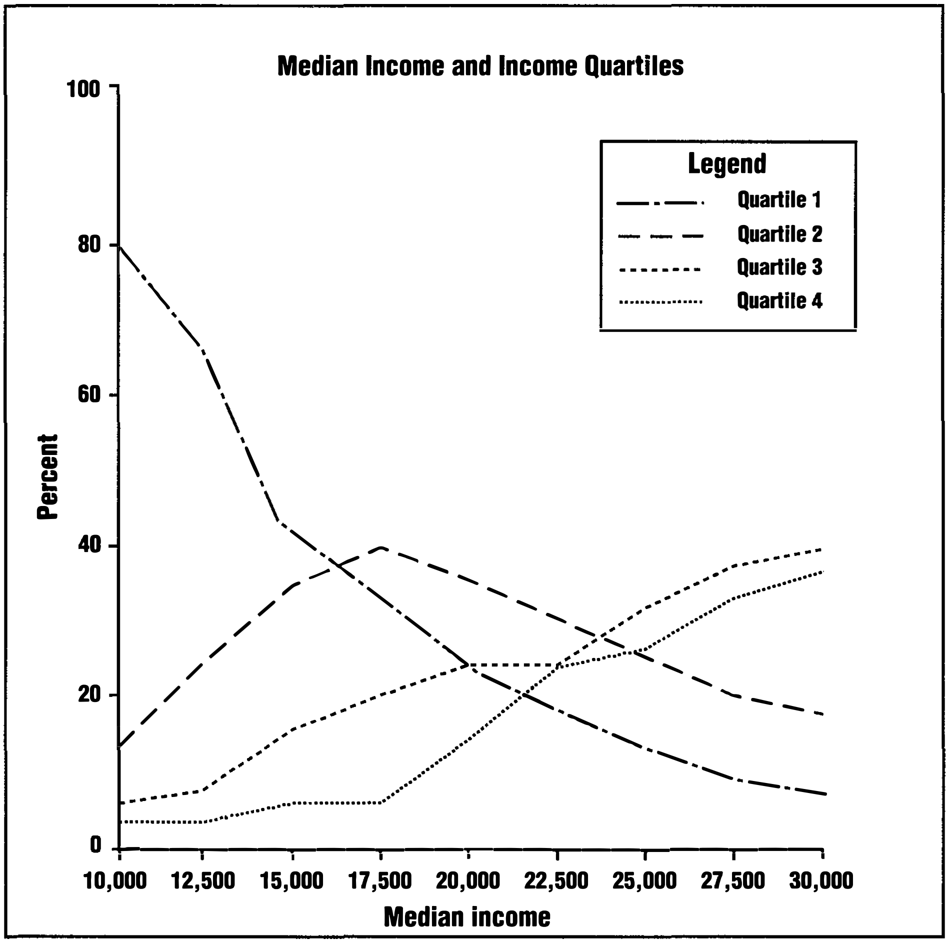
On the positive side, it would seem that relationships between means and medians and the percentages of households falling into different categories may be improved by the time-series component of continuous measurement. This could permit, for example, the correlation of the means and medians with percentages in an area for each underlying category using several recent years of data, with the rolling averages used each time against relevant rolling averages of households falling into a category. This might yield a more accurate relationship than can be developed from current data. To illustrate the type of relationship envisaged, a hypothetical illustration of the type of relationship is shown in the figure (see following page).

Using this figure, if one knows that the median income of a TAZ will be $24,500, for example, the graph shown in Figure 1 would provide estimates that there are 18 percent of households in the first income quartile, 26 percent in the second quartile, 27 percent in the third quartile, and 29 percent in the fourth quartile. So far as the future-year forecasts are concerned, there would seem to be some reason to expect that continuous measurement would have a positive impact here. The basis for this statement is that the trends provided by continuous measurement may provide a better basis for producing future-year forecasts, and the base from which the forecasts will be made will often be more current than is the case with decennial census data. Indeed, by using the changes in rolling averages over several years, one may expect that trend lines will become much more obvious and forecasts to the future become more realistic.

TRAVEL-DEMAND MODELING—CALIBRATION AND VALIDATION

Current Uses

Travel-demand modeling is the process in which locally-collected travel-survey data are manipulated and analyzed to produce a set of locally-defined computer models describing the relationships between current travel making by the population and characteristics of both the population and the transportation systems. The input data described in the preceding section are part of the package of information normally used for this



process, although, when a full household-based travel survey has been conducted in an area, the values of the input variables collected from the households in the survey would normally be used, rather than the values from census sources.

Usually, two restrictions are observed in selecting the demographic variables. First, these are restricted to variables that are to be found in the census databases, in order that the models can be applied to the full population, using the joint distributions discussed above. Second, the variables are restricted to those for which forecasts are either available or can be produced from relationships among other variables. Typically, population, employment, and income are the only variables for which either local demographers or U.S. Bureau of the Census demographers produce long-range forecasts. Therefore, it usually falls to the transportation planner to develop procedures to estimate such measures as vehicle ownership, based on income and any trend information that is available from the census. Some variables that have a major influence on travel decisions are simply not forecastable, such as licensed drivers. For such variables, the decision is usually made either to leave them out because they are not forecastable, or to include them but project their values at the household level to remain unchanged.

In areas that do not collect their own household-travel data, there is usually reliance on borrowing models from other regions and updating them to local conditions. The updating process is partly based on volume counts that may be available in the region that is borrowing the models, and will partly utilize census-derived data. An important current source of such data is the journey-to-work data collected on the long form. These data, while not corresponding to standard procedures of measurement used in travel-demand models,[a]

[a] This issue is discussed further towards the end of this paper.

nonetheless provide some good base indicators of relative market shares for different travel modes and also origin-destination patterns of work trips and work-trip generation rates. Each of these can be used to check the applicability of the transferred models and may provide a basis for adjustment of model parameters to obtain a better fit to local conditions.

For validation, only those models that are newly calibrated to an area are usually subjected to validation, because the transfer process already effectively includes the validation step. In validation, the calibrated models are now applied with base-year data on the entire population of the region, in order to estimate an "average" Spring or Fall day's travel. Usually, there exist a variety of volume counts, such as road-traffic counts at various locations, along cordons and screenlines[b], transit boarding and alighting counts, etc. Using the data on the entire population of the region, the models are run so as to provide an estimate of total base-year travel in the region. This is then analyzed to determine the predictions from the models of the various counts that are available from actual ground movements. If substantial errors are found between model-predicted values and the observed values, after allowing for the normal errors that exist through the various aggregation and other procedures involved in such a modeling exercise, the models are recalibrated or adjusted until a better fit between prediction and observation is attained. Serious errors in the creation of the full-population data can have major impacts on this process, if such errors result in incorrect predictions by geographic location for household demographics that have a significant impact on travel behavior.

Implications of Continuous Measurement

Because census data are not usually used directly in travel-demand model calibration, the impacts of continuous measurement will be fairly indirect on this aspect of transportation planning. The primary impact may arise if the nature of continuous measurement and the added richness of time-series data permits more variables to be forecast to the future, based on trend analyses and the like. If such advantages are found to exist from the continuous measurement census data, then there may be a significant impact on what demographic variables can be included in the travel-demand models, as well as providing potential forecasts of more of the variables that seem to affect people's travel behavior.

However, in the case of those regions that have relied on journey-to-work data, a different result may arise from continuous measurement. Applying continuous measurement will now result in data being provided as rolling averages. A rolling average of mode share seems to be a concept that lacks obvious usefulness in this context. Because the models are used to predict at a point in time, data are needed that relate to a point in time. Under current procedures, the reporting of "usual" mode of travel, as is done under the journey-to-work section of the census creates numerous problems for transportation planners, who are interested in behavior on a specific day, and wish to have the average of usual and unusual behaviors included in this representation of a day. Even using one year's average from the continuous measurement seems likely to create significant problems for the transportation planner, particularly because there are seasonal variations in travel of some significance, and past modeling efforts have always tried to use the spring or fall as representing the most "normal" period of travel. An annual average will present some significant problems for application within the traditional modeling context. However, it should be noted that work trips are probably somewhat less subject to seasonal variability in most cases, other than metropolitan areas that have significant seasonal attractions that involve major changes in employment, such as college towns and sunbelt communities that are populated by "snow birds." The meaning of a three- or five-year rolling average is much more problematic in the context of application to modeling and model transfer.

The problems of continuous measurement in this regard become even more marked when one considers the use of the data for defining origin-destination patterns of movement through the urban area. First, data from a single year will likely be so sparse that a meaningful origin-destination matrix, using small-area geography, will be impossible to create, or will be so full of empty cells as to be of little value. Second, even such a matrix will contain problems with respect to averaging over the year, particularly in the same cases noted in the preceding paragraph. Third, if the alternative is to use rolling averages from the past three or five years, much more significant problems arise. Over a period of years, there are likely to be significant changes in work-trip patterns, resulting from development of new housing locations, new business locations, differential business

[b] A screenline is an imaginary line through the study area, that crosses relatively small numbers of roadways. Volume counts are taken at each roadway that crosses the screenline, thereby providing a count of total movements across the line in both directions. Screenlines may follow such natural lines as a river with relatively few bridges, or man-made lines, such as a rail line with few crossings, or a freeway with few crossing points.

expansion and contraction, and migratory patterns of population within the urban area. These changes over time will render the production of a multiyear average origin-destination pattern of work trips an exercise in futility from the point of view of transportation planners. Essentially, continuous measurement probably renders the journey-to-work data completely inapplicable for such uses.

For validation, there are also potential problems that will arise, because of the need again to create a single point in time as the reference base. Estimation of the demographics for the base year at a level of sufficient accuracy for purposes of validating the calibrated models appears threatened by continuous measurement, because of the problems already discussed of averaging over a year, lack of sufficient sample for a single year, and lack of applicability of rolling averages. This represents a serious problem for model building, because the general results of most modeling efforts in the past have produced the requirement for significant model adjustments to reproduce base-year conditions. Potentially, this will result in the requirement that transportation planners collect considerably larger samples than in the past, which will have large negative impacts on the frequency with which such data can be collected. It may also require that transportation planners develop other methods for model validation, possibly based on small-area enumeration and application of the models.

EVOLUTION OF TRAVEL-DEMAND MODELS

Current Situation

The transportation-planning profession is probably in substantial agreement that the current travel-forecasting models are deficient in many respects, and frequently unresponsive to emerging policy issues. It is not the intent of this paper to provide any details on the nature of the deficiencies, which have been written up in various places.[c] The emerging direction for modeling improvements appears to be one that is oriented increasingly to looking at individuals and households as the basic decision-making units of concern (thereby moving away from the concentration on TAZs as the unit of analysis), and conjoining this with increasing use of geographic information systems (GIS) to permit location of the resulting decisions in coordinate-based geographic space. In addition, the focus seems to be moving towards that of understanding decisions relating to choices of activities and the allocation of roles for performing activities, from which travel implications can then be derived. This view of transportation modeling also brings with it an increasing orientation to family life cycle as a major determinant of the behaviors of interest. Life cycle is defined in terms of numbers of adults in the household, numbers of those adults who work or are in school, numbers of children present, and ages of children with respect to preschool versus K-12 school, day care, and other issues.

Development of this new paradigm is still in its infancy so far as potential application and use of census data. However, its pursuit will clearly anticipate use of population descriptions, such as are provided by traditional census data. The description of life-cycle groups as provided above is clearly within the range of current traditional census data, where cross-tabulations, at least in PUMS, can be obtained that would determine incidence of households in such life-cycle groups as the following:

- Single, working-adult households
- Multiple-adult households including one or more workers
- Households with no workers and no children
- Households containing a child or children, all of whom are under 5 years of age
- Households containing a child or children, with at least one child in K-12

Other life-cycle groups may be found necessary, but these represent a minimum set that may be of interest to the transportation planner. It is likely that household-activity surveys will be used as the means to collect basic data for the purposes of developing models under this paradigm. However, application to the entire metropolitan region is again likely to require that estimates be made of the incidence of each of the life-cycle groups by some level of small-area geography, and that total numbers of households in each life-cycle group in the metropolitan population would need to be estimated.

Implications of Continuous Measurement

Because of the relative infancy of such concepts as are described here, it is not entirely feasible to assess the implications of continuous measurement on the devel-

[c] For example: Stopher, P.R., "Deficiencies of Travel-Forecasting Methods Relative to Mobile Emissions," *Transportation Engineering Journal of ASCE*, 1993, vol. 119, No. 5, pp. 723-741, among others.

opment of new travel-forecasting procedures. However, if the new methods require an accurate portrayal of the locations of households by life-cycle group within the metropolitan area, there are likely to be problems with the use of data from continuous measurement. Furthermore, given the potential for households to evolve through these groups at a fairly rapid rate at certain stages in their evolution and for that evolution to precipitate relocation of homes within the urban area, there seems to be some likelihood that rolling averages will not be helpful to the transportation planner.

On the other hand, one potential direction that the work may take is to develop methods of micro-simulation of the evolution of households, for which continuous measurement may provide much better information than can current decennial census data. By tracking how rolling averages change, and by noting time-based trends, the simulation may be able to be built on a richer database, thereby providing a more realistic simulation of changes in household life cycle. The availability of annual PUMS data would, for example, provide a means to obtain some added richness in the data on which a simulation could be based.

It must be emphasized that the implications here are rather speculative, and will likely remain so until considerable further development of such procedures has taken place. There also exists the potential for the adoption of continuous measurement to be viewed as an opportunity and for the methods of application of this new procedure to be attuned to the potential existence of continuous-measurement data from the census.

CONTENT ISSUES

For some time, the transportation-planning profession has attempted to influence the actual content collected in the journey-to-work portion of the census. It is hoped that any evolution in the methods of collecting the data may also open up the potential for changes in content that would make the data more usable by transportation planners. Some comment has already been made in this memo about content. The principal issue is the use of the notion of "usual" in the census data collection, compared to the transportation-planning use of a specific day. To make the data of greater value to the transportation planner, changing the requested information to ask how the person traveled to and from work, and where they went on a specific day (e.g., the last working day prior to the day on which the household fills out the instrument) would provide consistency with current measurement in the profession. In addition, the identification of a "main" mode of travel to work is also problematic, and it would be more useful to find out the sequence of modes used by an individual. In most large cities, this is not very difficult to do, but aids the modeling process enormously. In small cities, the issue is fairly trivial, unless it also provides the means to measure the number of bus transfers that are made. Only in New York City may this present some major difficulties, because of the large number of modes available in that city, including ferries, various types of rail services, etc.

Knowing the time when the travel takes place is important, and probably of more value than a report on how long the travel took. Knowing if stops were made on the way to work on that day would also be important information. In more general terms, some significant redesign of the journey-to-work portion of the census long form would provide enormous benefits to the transportation profession. Some of these changes may also be essential in transitioning to continuous measurements in order to take care of new problems that may arise relating to seasonality and other issues that are not encountered in the current census, because it is fixed to a specific day of the year.

It is probably important to point out, in this connection, that transportation planners are interested in determining what travel looks like on an "average" day. On an average day, some workers are on vacation, some are traveling out of town, some are sick, and some are doing unusual activities in relation to workplace, or other aspects of their normal occupation. All of these occur on any given day and are assumed to be measured well by asking respondents to report about a specific day, without regard to whether it was a usual or unusual day. More importantly, however, the newer thinking about travel behavior is shifting the focus away from regarding a "trip" as an isolated event, and is shifting towards a focus on a pattern of activities as controlling the set of trips and trip chains that take place in a day. This means that the census journey-to-work data may need serious rethinking towards collection of more than information on a person's travel to and from work.

On the other hand, such considerations as these also lead one to re-evaluate whether the census is an appropriate vehicle for the collection of travel-behavior data. It is possible that the profession should be looking more at pushing for appropriate allocations of funds to states and MPOs that would allow consistent and frequent collection of household travel surveys, with the recognition that the census may not be an appropriate tool for collecting such data. Certainly, if the data requirements of transportation planning result in a need for significantly greater complexity and detail in the data that would be collected by the census long form, or its equivalent, the conclusion to be drawn may well be that this is not the correct way in which to collect such data.

SUMMARY, RECOMMENDATIONS, AND CONCLUSIONS

This paper has attempted to summarize a number of the areas in which census data are used currently by the transportation-planning profession and to discuss the potential advantages and disadvantages of continuous measurement of census long-form data in relation to those uses. Overall, there appear to be a number of potential gains that will arise, particularly relating to trend analysis and the determination of underlying structural relationships in household characteristics and evolution. However, there are a number of areas in which the major application of census data is to define a specific point in time, and these appear to be subject to considerable threat from continuous measurement. It is not clear at this stage whether alternative procedures can be developed by the transportation-planning profession to respond to the availability of continuous-measurement data in these instances, or if the need for point-in-time estimates is an overriding need that is not subject to any type of modification. This is clearly a topic that requires further research to determine if there will be unacceptable impacts on the transportation-planning profession resulting from a change in the collection of these census data.

The paper has also identified a number of areas in which there is an issue of reliability of the data that would be available from continuous measurement, and where the impacts of continuous measurement on the data available at small-area geography levels need to be known. Impacts of changes in the levels of accuracy are unclear in many instances. There are also a number of issues that have been alluded to only in passing in this paper that are key. In particular, these concern the reasonableness of the Bureau's expectations of response rates from households in the continuous-measurement scenario, and the ability of the Bureau to produce the products within reasonable time frames. Should response rates turn out to be significantly lower than anticipated, and should it take the Bureau much longer than anticipated to process and produce public-use data from continuous measurement, the value of continuous measurement could be severely compromised.

It also seems to be apparent that there are a significant number of unanswered questions about continuous measurement data. It seems to be a questionable procedure to introduce an untried, untested, and questionable procedure to completely replace an existing well-tried and well-understood procedure as part of the 2000 census. Rather, it seems that a more prudent procedure would be to engage in a two-pronged approach for the 2000 census, in which the long form, as it has been administered for the past several censuses, would be used again, possibly with a lower sampling rate than in the past. It would be quite reasonable to propose halving the sample size in 2000, for the purposes of the two-pronged approach. The second "prong" of this approach would be to introduce the continuous-measurement procedure, also possibly at a lower level of sampling than is proposed for full implementation. Conducting both procedures side by side in 2000, and the years immediately around 2000, would permit comparative measurements to be made between the two approaches. A number of the questions raised in this paper could be addressed in this approach, and definitive answers obtained.

It is also very important that the transportation-planning profession, as a major user of census products, be involved in the ongoing research and investigation of the alternatives to the current decennial long form. In particular, issues of the use of continuous-measurement data in such activities as demographic forecasting, household-survey design, and expansion of small-sample data are key transportation uses that should be investigated through joint research by transportation planners and staff of the Bureau of the Census.

There is no doubt also that this paper is an incomplete review of the uses of census data. It has been drafted with the intent to provide an overview of the modeling- and data-oriented uses of census data and to examine the specific issues that may arise within these from the change to continuous measurement of census data.

APPENDIX E: KEY CENSUS BUREAU PAPERS

SMALL AREA ESTIMATION WITH CONTINUOUS MEASUREMENT: WHAT WE HAVE AND WHAT WE WANT

BY

CHARLES H. ALEXANDER AND SIGNE I. WETROGAN *

BUREAU OF THE CENSUS

I. INTRODUCTION

The Census Bureau is considering replacing the traditional long form content sample in the 2000 Census with a "Continuous Measurement" program which would collect this information throughout the decade. The Continuous Measurement system would consist of i) a continuously maintained Master Address File (MAF), ii) a large Intercensal Long Form (ILF) survey, and iii) a Program of Integrated Estimates (PIE) to combine data from the ILF, the previous census short form, and administrative sources, to make small-area estimates.

The primary goal of the ILF is to produce the same small-area and small-domain estimates that are now uniquely available from the long-form sample. The main difference is that the ILF's small-area estimates would be averages over a three-year period (1999-2001) rather than estimates as of a single reference day. Updated ILF estimates would be available annually thereafter, starting with a four-year period 1999-2002, and then using five-year averages 1999-2003, 2000-2004, etc. The ILF sample size would have 400,000 mailouts per month for 1999-2001 and 250,000 per month thereafter. In the rest of the paper, we shall consider the "steady state" situation when five-year averages are used.

The ILF sample cases would be spread across all geographical areas, with a sampling fraction of about 0.25% per month. Each housing unit would be in sample once, giving a total sampling fraction of about 15% over a five-year period. The proposed design involves further subsampling of cases which cannot be completed by mail or telephone; see Alexander (1993, 1994) for further details about the design, which evolved from proposals by Kish (1981-1990) and Herriot and Bateman, and McCarthy (1989).

This paper discusses the problem of making estimates from the Continuous Measurement program. The Continuous Measurement database would contain an unprecedented amount of information about small geographical areas. It will be a major methodological challenge to use this information effectively in estimation. Our goals in this paper are to start a discussion of this challenge: what data will be collected, what estimates are needed, what are the research issues, how should we conceptualize the statistical problem?

We have some general ideas about how we would make "direct" estimates from the ILF. However, there are many details to be worked out, especially concerning adjustment to "population controls" at various geographical levels through some form of ratio or regression estimator.

The biggest research challenges, however, are found in the Program of Integrated Estimates. The MAF potentially can bring together an unprecedented amount of information about individual addresses and blocks. Methods for using all this information need to be developed. The greatest payoff would be "indirect" methods, using models to combine data from different sources. For example, high-quality measures of income from the Survey of Income and Program Participation (SIPP) or the Current Population Survey (CPS) Supplements,

* This paper reports the general results of research undertaken by census Bureau staff. The views expressed are those of the authors and do not necessarily represent those of the Census Bureau. This is report #CM-14 in the Continuous Measurement Research Series. This paper was originally presented at the 1994 Census Bureau Research Conference, Mar. 22, 1994.

which have relatively small sample sizes, could be used to adjust for reporting bias in small-area income estimates from the "cruder" but larger ILF.

Methods for direct ILF estimates will be needed by 1997. The plan is to test some rudimentary forms of direct estimation as early as 1995 and 1996 for test samples in a few selected areas, and to refine these methods further on national pilot surveys in 1997 and 1998. Indirect PIE estimates would probably not be used in production until after the 2000 census, say in 2003 or 2004, but the methods must be developed well before then so that tests can be done to establish their credibility. We have tentatively set 1998 as a target for developing the candidates for the indirect PIE method, including proposals for what administrative data should be used. Some proposals of this kind have already been advanced (Herriot and Schneider (1990)).

The rest of the paper is organized as follows:

Section II:	Data "traditionally" available from the Census long form
Section III:	How important are the joint distributions of the estimates?
Section IV:	Current methods for producing intercensal demographic controls
Section V:	Data available from the ILF and PIE
Section VI:	Goal of the estimation: How should we define the 5-year average rate?
Section VII:	Direct estimates from the ILF
Section VIII:	Some nasty details
Section IX:	Direct vs indirect estimators
Section X:	Some Ideas for Indirect Estimation—Aggregate Level
Section XI:	Some Ideas for Indirect Estimation—Housing Unit Level
Section XII:	Conclusion

This paper deals with the statistical problem of how to make estimates for the ILF or PIE. It does not get into the issue of the "data delivery system", i.e., what data files or publications should be released and on what schedule. Data delivery is an urgent topic for the newly formed Continuous Measurement Development Staff, which is supposed to produce a detailed plan by the end of 1994.

II. DATA TRADITIONALLY AVAILABLE FROM THE CENSUS LONG FORM

The topics collected in the 1990 census "short form" (questions asked of all households) and "long form" (questions asked of a sample of households) are given in Attachment A.

The primary data delivery vehicles are the summary tape files, STF-1 and STF-2 which give short-form data for blocks and other higher-level geographic areas, and STF-3 and STF-4 which give long-form estimates for block groups and higher-level areas.

Short-form data are in principle complete counts with no need for estimation. In practice, a small fraction of short-form households are completed by "last resort" methods which do not directly observe all the characteristics of the household. In these cases, missing data are imputed from nearby units. Estimates for blocks are made by summing the individual records in the blocks. For very small blocks, a block group will be used instead.

Long-form estimates are based on a systematic sample of 1 in 2 for blocks in small governmental units of less than 2,500 people, 1 in 6 for blocks in tracts of less than 4,000 housing units but not in small governmental units, and 1 in 8 in other blocks. (See Navarro and Grifffin (1990).) The estimates start with a basic weight equal to the inverse of the probability of selection. Additional post-stratification weights control the weighted long-form estimates for the number of persons in age/race/sex/Hispanic-origin cells to agree with the corresponding short-form estimates at the tract level. Because cells must be collapsed when the short-form counts are too small or the post-stratification factors are too large, the agreement is not exact.

The long-form data have characteristics imputed for item nonresponse. Also, for about 8.5% of households designated for the long form, only short-form data are collected. These cases are treated as unit nonresponse and are omitted from the long-form data set, with correspondingly higher weights given to respondents.

The block-level STF estimates are given for a variety of characteristics, mainly corresponding to frequency distributions related to the topics in Attachment A. Most of the estimates are the weighted number (or proportion) of households or persons with a particular combination of characteristics. For some important items, means or medians for the block group are derived from the frequency distribution.

The Continuous Measurement program is intended to produce all the estimates available from the 1990 long form, except as the 2000 census content determination adds new requirements or deletes old requirements. The main exception is that the current proposal does not include the 1 in 2 oversampling of small governmental units, but has the same targeted sampling fraction everywhere. No decision has been made on whether such oversampling would be included in the 2000 long form sample design, if there is a long form. However, the Continuous Measurement research concluded that current guidance on census objectives seems to suggest that there may not be such oversampling unless it is required by Federal law. However, some form of oversampling would be added into the Continuous Measurement design if it turns out to be part of the 2000 census content requirements.

III. HOW IMPORTANT ARE THE JOINT DISTRIBUTIONS OF THE ESTIMATES?

The traditional long-form estimates are "direct" estimates made by summing weighted data from complete observations.[1] Consequently the joint distribution of variables will be estimated unbiasedly or nearly unbiasedly. If X_1, X_2, and X_3 are variables, then the joint distribution refers to probabilities such as $P(X_1 = x_1$ and $X_2 = x_2$ and $X_3 = x_3)$. If these probabilities are estimated correctly, then the correlations or other measures of association between the variables would be estimated correctly. Direct estimates based on weighting ILF sample data would also have this property.

Most research on "indirect" small-area estimates has focussed on estimating a single variable. (See, for example Ghosh and Rao (1994)). If applied one variable at a time, these methods would not necessarily preserve joint distributions. While similar methods exist which do preserve joint distributions (Little and Rubin (1987), chapters 10 and 11), this requirement certainly complicates the problem.

We think that the general-purpose nature of the basic census products like the STFs make it important to get the joint distribution right. Either direct or indirect methods for the basic estimates should have this property. However, there still would be a place for single-variable indirect methods to improve estimates of a few important estimates such as income or poverty.

We are still grappling with the extent of the requirement to preserve joint distributions, since our understanding about the statistical uses of long-form data is incomplete. Conceivably, applications which seem to require joint distributions could be converted into univariate problems by recoding or transforming variables, but the practicality of this is questionable.

Although we do have extensive information about what topics from the questionnaire are used in response to what Federal laws (U.S. Department of Commerce (1990)), we have much less information about exactly what statistical inferences are to be made. As research on Continuous Measurement continues, we will try to focus on specific statistical techniques applied in using the data, and compare more precisely the properties of ILF and conventional long form estimates.

The following examples suggest that joint distributions are important:

A. *Consistency of numerous crosstabulations.* Census variables are "crosstabulated" in different ways for different purposes. There is interest not only in the number of households in poverty and the number of female-headed households, but also in number of female-headed households in poverty. It is desirable for the various estimated variables and their crosstabulations to be consistent, although this may not be essential for all purposes. This puts some constraints on the joint distribution of the estimates.

B. *Complex allocation formulas involving several variables.* Formulas for allocating Federal funding may rely on a single variable such as median income or percent of households below the poverty line. However, some formulas are based on either the union or intersection of two conditions, such as an area's being below a certain income quartile *and* having a certain proportion of units with substandard housing conditions. Applications relating to Voting Rights legislation similarly involve relationships of several variables.

C. *Small-area data used in regression models.* An important example is the use of long-form data in predicting trafffic patterns. The unit of analysis is the Trafffic Analysis Zone (TAZ). Variables describing the characteristics of the TAZ, especially the number of people who work in other TAZs, are used as independent variables in models to "explain" non-census

[1] In this Section, and the remainder of the paper, we ignore problems due to nonresponse or missing data except when stated otherwise. The Continuous Measurement plans generally envision missing data adjustments similar to the current long form.

dependent variables measuring traffic volume on various roads. Here the covariance structure of the census-based independent variables may be important

D. *Use of small-area characteristics as "ecological" variables.* The association between various small-area characteristics may have inherent interest. For example, it may be of interest to see how tract-level income and proportion elderly are related. Frequently such analyses are used as a second choice when household or person-level data are not available, but sometimes the interest is in the characteristics of the area. An important use of census data, where this seems to be the case, is the use of factor analysis to identify "neighborhood types" of interest to market researchers.

A possible outcome of this discussion is that there would be a set of general-purpose estimates preserving the joint distribution of all variables, supplemented with special-purpose methods to give the best estimates for specific variables or special uses of the ILF data.

IV. CURRENT METHODS FOR PRODUCING INTERCENSAL DEMOGRAPHIC CONTROLS

Although we produce estimates of the population for various geographic areas and by demographic detail, we do not incorporate all of the available data as independent controls for the various household surveys. This section outlines the current population estimates program, discusses some plans for enhancing the population estimates program, and presents an overview of the methods used to develop these estimates.

A. *Regularly Produced Population Estimates:*

1. National Level:

a. Monthly population estimates by single years of age (ages 0, 1, ...100 and over), race (White; Asian Pacific Islander), sex (male, female), and Hispanic origin (Hispanic origin, non-Hispanic origin). Uses estimates of components of population change—births, deaths, immigration.

Lag time: Available within approximately 80-90 days of estimate date.

Definition: Total including armed forces overseas, resident, civilian, and civilian non-institutional populations.

b. Monthly population controls for surveys:

Same detail as available for monthly population estimates. Survey controls are always based on at least a "one-month out" projection of data in order to get to the survey reference date.

Lag time: Available within approximately 30 days of survey date.

Definition: Civilian non-institutional populations readily available. However, data are available to compute estimates for other 3 universes (total including armed forces overseas, resident, and civilian populations).

2. State Level:

a. Annual estimates of the total population and population by single years of age (ages 0, 1, ...85 and over) by sex (male, female). Uses estimates of the components of population change—births, deaths, immigration, and internal migration.

Lag time: Available within approximately 9 months of estimate date.

Definition: Resident and civilian population.

b. Monthly population controls for surveys. Data available for the population aged 16 and over by state. Population total is extrapolated based on latest estimated changes in the state population.

Lag time: Available within approximately 2 months.

Definition: Civilian noninstitutional population, aged 16 and over.

c. Annual estimates of the number of housing units. Uses most recent census and updates based on estimates of housing permits, demolitions, and temporary housing.

Lag time: Available within 18-24 months of estimate date.

Definition: Total housing units.

3. County Level:

Annual estimates of the total population.

Lag time: Available within 15 months of estimate date.

Definition: Resident population.

4. Subcounty Level:

Biennial estimates of the total population.

Lag time: Available within 18 months of estimate date.

Definition: Functional local governmental units —incorporated places and minor civil divisions.

B. *Enhanced Population Estimates Products:*

We have identified several areas where we would like to introduce some enhancements. These include:

1) Increased Demographic Detail

2) Improved Timeliness

3) Flexible Subcounty Geography

4) Improved Methodology

We will be phasing in these enhancements over the next several years. Within the next year, we plan to expand our regular products to include 3 additional products.

1. State Level:

Annual estimates of the population by single years of age (ages 0, 1, 2, ...85 and over), sex (male, female), race (White, Black, American Indian, Eskimo, Aleut, and Asian Pacific Islander), and Hispanic origin (Hispanic origin, non-Hispanic origin).

Lag time: Available within 18 months of estimate date.

Definition: Resident population.

2. County Level Detail:

Annual estimates of the population by five year age-groups (ages 0 to 4, 5 to 9, ...85 and over), sex (male, female), and race (White, Black, other races).

Lag time: Available within 18 months of estimate date.

Definition: Resident population.

3. County Level Total Population:

Annual estimates of the total population of counties developed using zipcode based coding.

Lag time: Available within 6 months of estimate date.

Definition: Resident population.

C. *Methodology for Developing Independent Estimates:*

All of the population products produced within the Population Estimates area are independent estimates developed using variants of the component approach. This approach includes separate estimates of each of the components of population change—births, deaths, international migration, and internal migration. The methodology estimates the current population as follows:

$$P_2 = P_1 + B - D + IMM + INT$$

where:

P_2 = Population at Estimate Date

P_1 = Latest Census or Estimate

B = Births from latest census (estimate) to current estimate date

D = Deaths from latest census (estimate) to current estimate date

IMM = Net international migration from latest census (estimate) to current estimate date

INT = Net internal migration from latest census (estimate) to current estimate date

We use this overall approach to prepare each of the various series of estimates. However, while the overall approach is similar, the amount of detail required to produce the estimate changes. To produce estimates of the population by age, sex and race, we must have each of the components of population change by age, sex and race. To produce estimates of the population of counties, we require these data disaggregated into small geographic parts.

We rely upon a combination of direct and indirect estimates from various sources of administrative data to develop these components of population change. Because these data come from different sources of administrative data, issues of consistency are important. In addition to issues of accuracy and accessibility, we want to ensure that the data come from the same basic universe, and that concepts and definitions of age, race, and geography mean the same across the data sets and across time.

D. *Integration of Population Estimates with Survey Component:*

The current sets of surveys (CPS, SIPP, etc.) do not incorporate the full range of available population estimates as survey controls. In addition to issues of timely availability of some of the detailed estimates, concerns are raised about the increase in the number of control cells given the sample sizes.

However, some evidence shows that the lack of relevant population controls can lead to bias in the survey results for some characteristics.

For the near term, we would use a variant of current survey weighting procedures to develop continuous measurement based results. Independent sets of population estimates would be introduced as population controls. However, issues remain as to the level of survey control and the use of monthly versus annual survey controls for subnational areas.

In the long term, we would like to examine an approach that more fully integrates survey results, administrative records, and census results. This approach could draw upon the Master Address File (MAF). Through modeling and combination of data from the three sources, we would prepare estimates of the population associated with each address and the associated population characteristics.

V. DATA AVAILABLE FROM THE ILF AND PIE

It is simplest to describe all the data at the "basic address" or housing unit level. For points in time when the occupants are interviewed, the "household" characteristics will include some information on individual persons or families. Block-level or tract-level data can also be considered as ecological characteristics of the household.

A. *Basic ILF/MAF data available for each housing unit in any given month*

1. Month when the unit first appeared on MAF.
2. Whether the unit seems to be part of a multi-unit structure.
3. Short-form characteristics of the unit at the previous census, if it existed at that time.
4. Current ILF (long form) characteristics, for units currently in sample.
5. Past ILF characteristics, for units in sample in previous months.
6. Possible determination of whether the unit is likely to be vacant; however, only for sample units are we sure of vacancy status.
7. All the above information for the other units in the block, tract, place, etc.
8. Some limited information about previous characteristics of the unit or the unit's occupants. The 1990 long form asked where the occupants lived five years before. Other such retrospective information could be collected and used to estimate transition probabilities, if this would sufficiently improve small-area estimates.

B. *Additional information available from the PIE*

If Continuous Measurement comes to pass, then the Census Bureau's current household surveys will use the MAF as their sampling frame. These are the Current Population Survey (CPS), the Consumer Expenditure Surveys (CES), the Survey of Income and Program Participation (SIPP), the American Housing Survey (AHS), the National Crime Victimization Survey (NCVS), and the National Health Interview Survey (NHIS). For NHIS, this assumes we will find a way to share MAF addresses with the survey sponsor. If addresses can be shared, other surveys such as surveys on energy use could be candidates for the MAF-based System.

Research on administrative records may permit us to have a substantial portion—possibly 50% or more—of IRS returns geocoded to the block level.

Potentially this would make the following additional information available for each housing unit:

9. Data from IRS for the block, ZIP code, tract, etc. in which the unit is located.
10. A measure for the unit's block of how many occupants have moved since the previous census, based on IRS returns or other administrative data, which could be used to identify blocks with extensive turnover.
11. Current household survey data for households in sample for the surveys.

C. *Targeted listing and interviewing*

The Continuous Measurement plan assumes that a small number of blocks, about 1,000 per month, will be targeted for special listing to update MAF, based on indications of a large number of new or unlocatable mailing addresses, or problems found when attempting to locate sample addresses. In these or other unusual blocks, a special oversample of ILF units could be interviewed. This would be very valuable, if blocks which were likely to be outliers in the models used for estimation could be identified. Devoting a small proportion of the work to collecting direct data for these blocks could dramatically reduce the MSE for indirect model-based estimates.

VI. GOAL OF THE ESTIMATION: HOW SHOULD WE DEFINE THE 5-YEAR AVERAGE RATE?

Before looking at estimation methods, we must first ask what we are trying to estimate. This section will focus on the definition of a 5-year rate for a particular small area. For i = 1, ..., 60 representing the months in the 5-year period, let $N_1, ..., N_{60}$ be the actual population sizes (housing units, households, families, or persons) in the geographic area of interest and let $X_1,..., X_{60}$, be the numbers of population units having a specific characteristic. For example, N_i might be the number of families, and X_i the number of families in poverty. Supposing we knew these numbers exactly, how would we want to define the 5-year poverty rate?

There are two basic choices for the 5-year average poverty rate:

(6.1) Combined rate: $R_c = \bar{X} / \bar{N} = \sum_{i=1}^{60} R_i \, (N_i/60\bar{N})$

where $\bar{X} = \sum_{i=1}^{60} X_i/ 60$ *and* $\bar{N} = \sum_{i=1}^{60} N_i/ 60$

(6.2) Separate rate: $R_s = \bar{R} = \sum_{i=1}^{60} R_i/60$

The "separate" rate R_s is just the average of the sixty monthly rates. The "combined" rate weights each monthly rate proportionally to the population in that month. The difference doesn't matter much if the population is static. However, consider the following example, in which a large increase in population at the middle of the five-year period changes the poverty rate:

	N_i	R_i
months 1 = 1,...,30	100	0
months i = 31,...,60	1000	.90

$R_c = .818$ and $R_s = .45$

The larger rate R_c in effect looks at the total number of "family-months" and determines what proportion were spent in poverty. In this example, R_c may seem preferable because it reflects more recent experience. That should be ignored with respect to a general comparison of R_c to R_s; consider the opposite example where the 90% rate occurs in the first 30 months.

There is no universally right answer to the question of which rate is preferable conceptually. An average over time is most meaningful when the phenomenon being measured is stable, either in the sense of having a nearly constant value or in the sense of a "stationary" random process where the expected value is constant throughout the time period. When this is not the case, the average value needs to be accompanied by some indicator of variation over time, in order to be interpreted correctly. The development of such indicators for CM small-area estimates is a topic for future research.

Our basic approach will be to estimate the components N_i and X_i for each month and each small area, and let data users build up other estimates from these. For this purpose, the basic small-area unit would be the block, although very small blocks would be combined into groups (possibly smaller than 1990 census block groups.) This lets the user choose between combined and separate estimators. However, for the smallest areas, and for small population domains in medium-sized areas, excessive variation in monthly rates may preclude the separate rate (6.2).

VII. DIRECT ESTIMATES FROM THE ILF

(METHODS FOR 1997)

In this section we describe simple methods which could be used to make direct estimates from the ILF for such population quantities as N_i and X_i For definiteness, we will focus on tract-level estimates. Some complexities will be ignored until the next section. The visualization of the data as sequential data files is suggested to help interpret the notation, and is not meant to exclude the possibility of storing the data in a relational database.

These simple methods are presented to illustrate the possibilities. There are many potential variations and extensions, and much more research is needed to determine the best "direct" method.

A. *Notation*

Let k denote a particular block. All variables in this subsection have an implicit subscript i denoting the month.

Let j = 1, ...,J denote mutually exclusive strata which can be identified for MAF addresses, e.g.,

j = 1 means low housing value/rent from previous census

j = 2 means high housing value/rent from previous census

j = 3 means not in previous census, apparently single-unit structure

j = 4 means not in previous census, apparently multi-unit structure

j = 5 means extended period of vacancy; possibly demolished.

Let H_k denote the number of addresses (housing units) on the MAF in block k, and let a, $1 \leq a \leq H_k$ represent a particular address.

The following notation will be defined with respect to a hypothetical monthly address-level file indexed by (k,a). These values are defined only for sample units. Undefined value would be replaced by zeros.

W(k,a) = sampling weight for unit (k,a)

H(k,a) = occupancy indicator = 1 if (k,a) is occupied

V(k,a) = vacancy indicator = 1 if (k,a) is vacant

D(k,a) = "disappeared" indicator = 1 if (k,a) is destroyed, invalid address, deleted duplicate address, etc.

F(k,a) = number of families at address (k,a)

P(k,a) = number of people at address (k,a)

$(X_s(k,a))$ = a vector of s different characteristics measured for unit (k,a), where s = 1,...,S.

All variables would be defined at the address level. Thus, $X_s(k,a)$ could be the total number of families or persons at the address with a particular characteristic, e.g., the total number of persons age 65 or older. Alternatively $X_s(k,a)$ could be a zero-one variable indicating whether the housing unit (k,a) had complete plumbing facilities.

The sampling weight would be a *basic weight* equal to the inverse of the overall ILF sampling fraction (approximately 1 in 400 each month) times a *subsampling factor* for personal-visit cases. The ILF prototype assumes a *subsampling rate* of 1 in 3 in most areas, with 1 in 5 in sparse rural areas.

Thus in this simplified prototype

W(k,a) = 400 for mail and telephone sample

W(k,a) = 1,200 for regular personal-visit

W(k,a) = 1,500 for sparse rural personal-visit.

Vacant units would be treated as personal-visit cases, since they would never be contacted by mail or telephone.

B. *Basic Direct Estimates*

The basic direct estimates would be the following tallies by block x stratum for each month. These data can be visualized as a block-level data file with the "record" for block k containing information for various values of j, i, and s. Recall that there is an implicit subscript i in the expressions for a, W(k,a) and V(k,a) on the hypothetical "monthly address-level file" described in the previous section.

$$(7.1) \quad H_{kji} = \sum_{a \in \; Stratum\, j} W(k, a)\, H(k, a)$$

= weighted estimate of the number of occupied units in stratum j in block k in month 1.

Similarly F_{kji} and P_{kji} are weighted estimates of families and persons.

$$(7.2) \quad V_{kji} = \sum_{a \in \; Stratum\, j} W(k,a)\, V(k,a)$$

= weighted estimate of number of vacant units in stratum j in block k in month i.

Similariy D_{kji} estimates the number of "disappeared" MAF addresses.

$$(7.3) \quad X_{skji} = \sum_{a \in \; Stratum\, j} W(k, a)\, X_s(k, a)$$

= weighted estimated total for the variable X_s for block b and stratum j in month i.

A direct sample-based estimate for the five-year average number of occupied units for block k would be given by

$$H_{k..} = \sum_{j} \sum_{i=1}^{60} H_{kji}/60.$$

Similarly $F_{k..}$, $P_{k..}$, $V_{k..}$, and $X_{sk..}$ would estimate respectively the average number of families, persons, vacant units, and the average block total for the characteristic X_s.

A combined rate for block k, say the average rate of families in poverty, could be calculated using an expression of the form $X_{sk..} / F_{k..}$, where $X_{sk..}$ is the estimated average number of families in poverty.

For a larger area such as a tract, a "separate" estimator of the form (6.2) could be applied using the monthly rates,

$$R_i(T) = \sum_{k \in T} X_{sk.i} / \sum_{k \in T} F_{k.i}$$

where $\sum_{k \in T}$ represents the summation over the blocks in the tract T. A "separate" rate would probably not be calculated for an area so small as a block because of the extreme variability of the individual monthly rates.

C. *Control to MAF counts*

The MAF counts provide potentially useful information on how the distribution by stratum of the ILF sample in a given month compares to the distribution of the population in that month. In the spirit of "direct sample-based" estimates, this information would be applied through a post-stratification factor.

Ignoring for a moment the problem of zero or small sample sizes in a cell, this factor would be defined as

$$(7.4) \quad PSF_{kji} = M_{kji}/(H_{kji} + V_{kji} + D_{kji})$$

where M_{kji} is the number of addresses in stratum j on the MAF in block k for month i. This factor would be used to adjust the estimates in (7.1), (7.2), and (7.3) to give

$$H^*_{kji} = PSF_{kji}\, H_{kji}$$

$$V^*_{kji} = PSF_{kji}\, V_{kji}$$

$$X^*_{akji} = PSF_{kji}\, X_{skji}$$

It may seem odd to include occupied, vacant, and "disappeared" units in the same factor. However, which of these categories a MAF address belongs to would not be known (for sure) until an attempt at an interview is made. Depending on how the strata are defined, some strata may be mostly vacants, or even "disappeared" units.

The post-stratification estimator using factors like (7.4) is slightly biased but can reduce the variance of estimates for characteristics where the mean value differs among the cells, provided there are a sufficient number of cases in each "cell". If the expected number of cases in a given cell, i.e., with a given (k,j,i) combination, is too small, then the bias can be substantial. Common rules-of-thumb require 20-30 observations in a cell. Since the 1 in 400 sampling rate corresponds to 10 cases per month for a "typical" tract of 4,000 housing units, it is clear that the factor (7.4) could only be applied to larger cells formed by combining blocks, strata, or months, or some combination thereof.

It is a matter for empirical research whether blocks, strata, or months would be the first choice for combining. The optimum may be different for different estimates. Alternatives in which factors are computed for marginal distributions (blocks, strata, months) and then the joint factor for (k,j,i) cells calculated by "raking" methods could also be considered.

Another problem is that if the post-stratification factors are applied for each small area within a large area, and separately calculated for the large area, the small-area estimates do not necessarily sum to the estimate for the larger area.

Even assuming these problems can be solved, the benefits of applying the post-stratification factors may be marginal because the sample will be allocated evenly (proportionally) across blocks and months, and possibly the j strata within blocks, so the factors will tend to be close to 1. However, some variation can still be expected due to unpredictability in the number of cases which need subsampling for personal visits, and unpredictability in the month in which a given case is completed. Post-stratification would correct for this variation.

D. *Control to independent estimates for larger areas*

As is currently the case for CPS and many other household surveys, ILF estimates will probably be controlled to agree with intercensal demographic estimates such as those described in Section IV. If the demographic estimates are available only for large areas such as states, controlling will have little effect on the variance of ILF estimates for small areas such as tracts. However, the variance of state and national ILF estimates would be improved, and any systematic coverage biases (Fay, 1989; Shapiro, Diffendal, and Cantor 1993) which may be present in the ILF would tend to be reduced across the board. In this Section, we assume that the demographic controls are produced without using ILF data.

The method for forcing agreement with the independent estimates could be complicated, especially if the independent estimates for persons and households are at different geographical levels. Methods for controlling survey estimates to agree with both person and household controls have been developed in the last decade (Oh and Scheuren (1978), Zieschang (1990), Bankier, Rothwell and Majkowski (1992)). The methods are somewhat computationally intensive, but increased computer speed has reduced the importance of this problem.

These methods are convenient because in the end a weight is attached to each sample housing unit and this same weight is used for all people in the household when calculating estimates of the characteristics of persons. However, when there is substantial within-household undercoverage of persons, it may be preferable to have one set of weights for housing unit characteristics and another set for person characteristics. One such method, the "principal person" method, is used for CPS. Variants of this method, based on various assumptions about undercoverage, are used for other household surveys. (Alexander, 1990) Studies of ILF's coverage of the population will be needed to guide the choice of a method for incorporating population controls.

VIII. SOME NASTY DETAILS

We have omitted some awkward details from the basic statement of the problem in the previous Section, for simplicity. They will need to be dealt with eventually, but we think they can be ignored in proposing initial solutions to the basic estimation problem.

A. *Changes in definition of geographic areas*

If block boundaries change, for example if an existing block is split in half by a new road, it may not be possible to incorporate the change on the MAF until next time the block is visited and updated. Some approximate allocation of sample units and counts of total units on MAF (M_{kji} in the notation of Section VII.E) to the new blocks will be necessary. Eventually the new blocks will be relisted, for the next census if not sooner, and any errors will then have to be corrected retroactively.

If larger areas such as tracts or "places" are redefined by moving blocks from one place to another, this causes some ambiguities for computing five-year averages for the place. Our proposed solution is to define the place by the blocks it contains at the end of the time period, and give the five-year average for that set of blocks even if the blocks were not in the place as defined earlier in the time period. Estimates for other standard geographical definitions, such as definition as of the previous census, could be supplied as alternatives.

B. *Lack of one-to-one correspondence between MAF addresses and housing units*

In this paper, "address" is used to refer to "house number, street name, unit designation," e.g., "100 Main St. Apt. 101." The unit designation would be defined so that each "address" corresponds to a "housing unit." The term "housing unit" has an operational definition in terms of separate living and eating quarters and direct access from outside or a common hall; the ILF definition may or may not be identical with that used by current surveys.

Unfortunately, there will not always be exactly one MAF address for each housing unit. In some cases a single housing unit may appear on the file as more than one MAF address, typically because of multiple mailing addresses which could not be unduplicated with certainty. Sometimes there will be information that the redundant addresses are "possible duplicates", but this situation may not always be detected. In other cases, a single MAF address may turn out to have several housing units associated with it.

Our assumption is that procedures for updating addresses at the time of interview can be developed so that for every MAF address selected for sample, the list can be updated correctly. This means that all housing units associated with the address can be identified, and all duplicate addresses corresponding to these units will be identified. Additional housing units not included on MAF may be detected during updating; we assume that they can be associated with one MAF address that would have brought them into sample so that there is not a problem with multiple chances of selection.

C. *Housing units with unknown or erroneous block*

Some of the housing units in the MAF system will not be assignable to a specific block. We hope these will be well below five percent of all units. The ZIP code will be known, at least the five-digit ZIP and perhaps the nine-digit, in almost all cases. These units will have to be allocated to a block in calculating M_{kji} values.

If units with unknown block are designated for personal-visit interviews, they would have their block determined at the time of interview. If, instead, we try to get additional information by mail or telephone to pin down the block, sometimes the information will be insufficient to identify the correct block, and we will have completed interviews with unknown blocks. It may not be possible to visit this unit right away to determine the correct block. Often the ZIP code would be known for these cases, and could be used to allocate the unit to a likely block.

For units with either missing or erroneous block designation, the correct block will eventually be determined. Ideally we would go back and correct the designation on data files for the previous five years, so that each five-year cumulative estimate would be based on the most recent information. These revisions will complicate some uses of the cumulative estimates.

D. *Vacant units and timing of the "interview"*

There are conceptual issues about how vacant units should be counted in five-year average estimates. The direct estimators proposed in Section VII implicitly assume that a vacant unit is simply counted as zero occupied units with zero people and zero income, etc., but is counted for housing characteristics such as type of heating fuel and housing value or potential rental value. We think this approach will be adequate for most purposes.

There are operational problems with this approach that need to be investigated and solved. Initial contacts for the ILF will be by mail. There may be timing problems such as the units being vacant at the time of sample selection and initial mailing, but being identified as occupied by the time a followup mailing or personal visit takes place. If biases of this sort cannot be eliminated by suitable operations during the data collection, they may need to be adjusted for during the estimation.

Even for occupied units, seasonal variations in the lag between initial mailing and time of completion of the interview may affect the estimates. To simplify the operations and reduce recall errors, the present plan is to use a reference period which corresponds to the date of interview, whatever that turns out to be, rather than using a fixed pre-assigned date.

E. *Partly deterministic variables*

For simplicity, the discussion in the rest of the paper assumes that all variables for units not in sample are completely unknown and must be estimated statistically. In fact there are some variables, especially those relating to a housing unit's physical structure, where it may be possible to use the previous census value as a good proxy for the current value. More complex rules such as "assume a unit is owner-occupied if it was owner-occupied at the previous census, and administrative records indicate the census-time occupant still lives at the address" could be applied to get values of other variables for some units.

F. *Variance estimation*

This is beyond the scope of the paper. The different estimation methods described in Sections VII, IX, and XI have specific variance estimation methods associated with them. Research is needed to determine the best method in practice.

IX. DIRECT VS INDIRECT ESTIMATORS

"Direct" estimators base each area's estimate mainly on data from sample units from that particular area. "Indirect" estimators make use of data from other areas, typically to estimate the parameters of models describing the relationship between those variables observed only for sample units and other auxiliary variables observed for all population units. Direct methods are less dependent on explicit models, but often involve implicit assumptions on the distribution of values in the population, assuming that sample sizes are sufficiently large to apply asymptotic results to give approximate confidence intervals.

Direct methods are natural for surveys with a large sample size in the domain of interest, and with limited information about non-sample units. Indirect methods are necessary when the sample size is small, and are particularly attractive when there is important information available for non-sample units. The small-area estimation problem for Continuous Measurement clearly favors indirect methods, especially when the additional data from the Program for Integrated Estimates become available.

However, our strategy for introducing Continuous Measurement is to rely on "direct" estimates[2] in the first few years, while pursuing research on indirect, model-based methods. The indirect methods will be introduced only after there has been time to convince users of long-form data that the methods will give acceptable estimates. We hope that in time, indirect methods will give better estimates from a smaller sample. (Alexander, 1993)

This strategy was adopted because we foresaw a problem convincing users that indirect methods will be an acceptable replacement for the direct long-form estimators used in previous censuses. Partly the problem is familiarity. But a more basic problem is that we cannot evaluate the fit of the models upon which indirect estimators depend, until we have actual CM data. By the time we could collect data, test the models, evaluate the results, and disseminate the evaluation throughout the user community, it would be too late to make the basic decisions for the 2000 census. Therefore we were forced to start out with a prototype based on direct estimation.

[2] Post-stratification to high-level population controls is included as part of the "direct" method because of the familiarity and relatively weak model-dependence of this method, although it arguably makes use of "indirect" information.

Indirect estimates are part of the longer-term PIE. Even if CM does not replace the 2000 long form, we expect to develop and test indirect methods for the PIE, using the information from MAF and the ongoing household surveys. This could lead to a CM option for the 2010 census based on the PIE, relying heavily on indirect methods.

X. SOME IDEAS FOR INDIRECT ESTIMATION—AGGREGATE LEVEL (METHODS FOR 2003)

Indirect estimates are those which derive the estimate for a particular area in part from information about the relationships of variables observed for other areas. These estimators are often "model-based" in the sense that they rely on assumptions about relationships of variables. This section deals with methods which use only the aggregate values for the areas under consideration. The discussion assumes tract as the level of analysis; these methods would probably be applied to areas at least the size of tracts. Such an aggregate approach is used in Fay and Herriot (1979).

A. *Regression and Time Series Methods for Individual ILF Variables*

For tract k and month i, let $\overline{Y}(k, i)$ be the mean value of some characteristic of interest, say the mean number of persons per housing unit, or the mean income. Let

$$X(k,i) = (X_1(k, i), \ldots, X_s(k, i))$$

be a vector of S characteristics describing tract k, including previous census data as well as region of the country or other basic geographical characteristics. One class of indirect methods would be based on a model of the form

$$E(\overline{Y}(k,i) \mid X(k,i)) = f(\theta ; X(k,i))$$

or a time series model of the form

$$E(\overline{Y}(k, i) \mid X(k, i); \overline{Y}(k, i\text{-}1), \overline{Y}(k, i\text{-}2), \ldots) =$$

$$f(\theta ; X(k, i); \overline{Y}(k, i\text{-}1), \overline{Y}(k, i\text{-}2), \ldots),$$

where θ denotes the vector of unknown parameters of the model.

The parameters of the model would be estimated based on the observed values of X(k,i) and direct estimates $\hat{\overline{Y}}(k, 1), \hat{\overline{Y}}(k, 2), \ldots$ such as those in Section VII from the ILF.

Methods for estimating the parameters of the model have been studied for models making various assumptions about the probability distribution of the error terms in the model. A common feature is to include somehow a random effect corresponding to particular features of each (k,i), in addition to fixed effects describing general relationships of X and Y.

Several methods are described in Purcell and Kish (1979), Prasad and Rao (1990), and Platek, et al (1987). These articles give additional references. Some time series methods are suggested in Nandram and Sedransk (1993) and Singh, Mantel, and Thomas (1991).

Determination of the best form of the model and the best variables to include is a matter for empirical research. For time series models, some of the most informative variables might be measures of previous characteristics for sample units. Additional questions about previous characteristics can be added if they have suffficient value for estimates. Once the parameters are estimated, the model produces a "indirectly estimated" predicted value $\hat{\overline{Y}}^I(k, i)$.

B. *Estimating Five-year Averages*

For the non-time-series methods in the previous section, the obvious way to get a five-year average is to estimate $\overline{Y}(k, i)$ for i = 1, ...,60 and average the estimated values. Some corrections for the passage of time, such as inflation adjustments or using month-of-interview as an independent variable, could be considered.

An alternative "non-time-series" approach would be to use the modeled five-year average $\overline{Y}(k)$ directly, rather than modelling each month. Intermediate options, such as modelling individual years and averaging these estimates, could be considered.

Since the ultimate product of the Continuous Measurement system will in fact produce a time series, it seems appropriate to model the time-series aspect of the problem. The two references cited in the previous section concentrate on using the time series model to improve the estimate of the most recent characteristics of the area. Some modifications would be needed to adapt the methods to the problem of estimating a five-year moving average.

With all these methods that pool data for several months, regardless of whether the time-series aspect is explicitly incorporated in the model, there will be a practical issue of dealing with revised estimates for previous time periods, as new data change the best estimate for the earlier periods.

C. *Estimates for Different Geographical Levels*

It is extremely desirable for estimates for different geographic levels to be consistent, i.e., estimates of totals for small areas should sum to the estimates for larger areas which they comprise. Not all estimation methods preserve this additivity.

The simplest way to ensure additivity is to start by making estimates for the smallest areas and sum them to get the estimates for the higher-level area. The problem with this is that the ILF sample size in individual small areas is quite small; in many of the methods, relatively little weight might be put on the direct sample estimates from each area. Summing the small-area estimates may give too little weight to the direct estimate for the larger area, and too much to the general relationships of X and Y.

A better approach may be to start with the large-area estimate and modify the original small-area estimates for sub-areas to agree with it. One simple way to do this would be to determine the percentage each small area contributes to the total of the original small-area estimates (either direct or indirect) and then partition the large-area estimate accordingly. Specific models may prescribe better ways of "partitioning" the large-area estimate.

D. *Indirect Estimates Preserving Joint Distributions*

The best way to make small-area estimates while preserving the joint distribution of variables is an open research issue. There are some obvious methods which may or may not provide good practical solutions:

i) for categorical variables, it is possible to define all the cross-categories, estimate the total number of persons or household in each cross-category, and then sum these estimates to get the larger categories;

ii) for variables which are normally distributed, estimates could be made not only for the means $E(Y_1)$ and $E(Y_2)$, but for the variances $Var(y_1)$ and $Var(Y_2)$ and $Cov(Y_1,Y_2)$ for each small area, conditional on all the available data. (See Little and Rubin, 1987). A pair of random numbers (Y_1,Y_2) could be generated from the joint normal distribution with the estimated parameters for the particular small area. These estimates would each differ from the best predictive estimate of the mean of the small area. However, they would preserve the joint distribution when relationships of variables were examined for a set of small areas.

E. *Indirect Estimates Involving Household Survey Data*

Starting in about 2003, we hope to have data from household surveys such as SIPP and CPS linked to the MAF, so that variables, such as income, poverty, or labor force characteristics, measured by these surveys could be included in the model. Because the questionnaires and interview modes for these surveys are specifically designed for measuring these characteristics, they are generally thought to give better, i.e., less biased, measures than the census long form or the ILF would give.

However, the relatively small number of households in sample for those surveys is not sufficient for estimates below the national or state level. Further, not all counties are in sample for these surveys. For this small-area estimation problem, "small" means county or MSA, not tract or other small sub-county area as in the previous discussion.

A long-term objective of PIE is to be able to use data from these surveys to reduce the biases from the ILF. One approach would be to use regression models such as those in Section X.A, with the dependent variable $\hat{\hat{Y}}(k, i)$ standing for the survey estimate, say for mean income or poverty rate in the k^th^ "medium-size" area, such as a county or group of counties. The ILF direct estimates would be included among the independent variables in the model. The goal would be to predict the expected value of the survey estimate for the small area.

An alternative approach would be to formulate a measurement error model, and use the CPS or SIPP data along with the ILF data to estimate the terms of that model, then to use the model to adjust the ILF estimates. Example of such models are given in Groves (1989).

XI. SOME IDEAS FOR INDIRECT METHODS — HOUSING UNIT LEVEL (METHODS FOR 2003 AND BEYOND)

Rather than predicting an aggregate value for each small area, several methods model the characteristic Y(k,j,i) for the j^{th} unit in the k^{th} small area. (For example, Dempster, Rubin and Tsutakowa (1981)).

For our purposes, the obvious choice is the housing unit, or possibly the MAF address (see Section VIII for the distinction). The address-level MAF is the starting place for organizing and linking CM data. Also, housing units are easier to geocode than persons, which is important for estimates for very small areas.

Administrative records, such as IRS or Medicare information, may lend themselves more naturally to a person-level approach. There may be some point to considering a dual approach involving a linking of housing-unit-level and person-level estimation problems. However, for now, we assume that person-level information will be translated to variables at the housing unit level, as described in Section VII.A.

Some potential independent variables may not be available for all individual units in the population, but may be available at higher geographical levels, such as county, or lower levels such as the individual small area. These could be included as unit-level variables which happen to be the same for all units in the area. Alternatively, a hierarchy of geographical levels could be represented in the specification of the model.

For applications to the PIE where the household survey collects the dependent variable, the limited availability of the auxiliary ILF data is a more serious problem. There will be relatively few housing units for which we have both an ILF observation and a household survey observation at more or less the same time.

For administrative data such as IRS records, the auxiliary variable would be available more frequently, but the missingness of the data is probably "nonignorable", i.e., availability of IRS records is related to income in ways not explained by the other auxiliary variables. This complicates the modelling. Also, extensive use of administrative records for individual units may raise more privacy concerns than using aggregated data.

A useful unifying approach may be to view the estimation problem as one of imputing missing values at the unit level. This would make it easier to solve the problems of correctly reproducing joint distributions and ensuring additivity across areas.

A wide variety of imputation methods are used in practice. Some general and computationally efficient methods for imputing missing data are described in Little and Rubin (1987). The "ignorable" methods of their Chapter 10 and 11 would seem to be appropriate for dealing with the ILF and household survey data, since the major source of missing data is failure of a unit to be in the ILF random sample. If imputation for item nonresponse is handled at the same time as the "imputation" of data for nonsample units, then the nonresponse part of the missing data measure is not obviously ignorable. Our inclination is to treat that as a separate problem from "imputation" for nonsample units. The likely nonignorable missingness of some administrative records data is a more serious obstacle.

The problem has some nonstandard aspects:

1. the "partially deterministic" variables and unpredictably available data mentioned in Section VIII.E;
2. the time series aspects of the data, especially the possible importance of models for transition probabilities, based either on changes since the previous census or on questions about changes in person or household characteristics;
3. the nesting of some variables; for example, person characteristics would not be measured for vacant units;
4. the availability of higher-level demographic controls which should be incorporated into the estimation.

The housing-unit-level imputation methods are likely to be more computer-intensive than the aggregate methods of the previous Section. This may be a significant disadvantage at present, given the number of cases and number of variables we are considering, but will be much less important by the next decade, as computer speed and storage capability increases.

XII. SUMMARY AND CONCLUSION

Our purpose in writing this paper has been to alert statisticians and demographers who work on methods for small-area estimation of the possible opportunities and challenges of Continuous Measurement. Even a partial implementation of CM would make unprecedented amounts of new data, and coordination of existing data, available for making such estimates.

New methods will be needed to make good use of all these data. The CM objectives will add new requirements to the small-area estimation problem, as we have described. There is plenty of time to work on this; the more challenging PIE estimates will not be needed until 2003 or later. However, research needs to start soon, for there is plenty of development work to do.

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ATTACHMENT A

TOPICS ON 1990 SHORT AND LONG FORM

100-PERCENT DATA (Short Form)

HOUSEHOLD RELATIONSHIP
SEX
RACE
AGE
HISPANIC ORIGIN
NUMBER OF UNITS IN STRUCTURE
NUMBER OF ROOMS
TENURE STATUS
ACREAGE AND WHETHER BUSINESS ON PROPERTY
VALUE OF PROPERTY (OWNED)
RENT (RENTED)

SAMPLE DATA (Long Form)

MARITAL STATUS
SCHOOL ENROLLMENT
YEARS OF SCHOOL ATTAINED
LANGUAGE SPOKEN AT HOME—ABILITY TO SPEAK ENGLISH
PLACE OF BIRTH
CITIZENSHIP
YEAR OF ENTRY
VETERAN STATUS
DISABILITY STATUS
PLACE OF WORK
JOURNEY TO WORK
ANCESTRY
RESIDENCE 5 YEARS AGO
CHILDREN EVER BORN
LABOR FORCE-EMPLOYMENT STATUS
HOURS WORKED LAST WEEK
YEAR LAST WORKED
INDUSTRY
OCCUPATION
CLASS OF WORKER
WEEKS WORKED LAST YEAR
INCOME
YEAR MOVED IN
NUMBER OF BEDROOMS
COMPLETE PLUMBING
COMPLETE KITCHEN FACILITIES
HAVE A TELEPHONE
HOW MANY AUTOMOBILES
FUEL USED FOR HEATING
SOURCE OF WATER
CONNECTION TO PUBLIC SEWER
YEAR BUILT
CONDOMINIUM STATUS
AGRICULTURE SALES FROM PROPERTY
UTILITY COSTS
SELECTED MONTHLY OWNER COSTS

A PROTOTYPE CONTINUOUS MEASUREMENT SYSTEM FOR THE U.S. CENSUS OF POPULATION AND HOUSING

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INTRODUCTION

The Census Bureau is considering a proposal which might replace the traditional long form content sample in the 2000 census with a "Continuous Measurement" (CM) program which would collect the same information throughout the decade. The Continuous Measurement system would consist of:

i) an ongoing field operation to locate and update a sample of addresses from the Census Bureau's Master Address File (MAF), which is linked to the TIGER geographic database;

ii) a large Intercensal Long Form (ILF) survey;

iii) a Program of Integrated Estimates (PIE) to combine data from the ILF, other household surveys such as the Current Population Survey (CPS) and the Survey of Income and Program Participation (SIPP), the previous census short form, and demographic estimates derived from administrative sources, to make small-area estimates.

Although the idea of "spreading out the census" has been suggested at least since Eckler (1972), it began to be given more serious attention after the 1990 census as discussed in Melnick (1991), Subcommittee on Census and Population (1992), Sawyer (1993).

The proposal draws heavily on ideas of Kish (1981, 1990) and a previous Census Bureau proposal by Herriot, Bateman, and McCarthy (1989), as well as estimation ideas suggested by Herriot and Schneider (1990). The major development since these earlier proposals is the availability of the MAF, which is already being developed as a source of addresses for the 2000 Census.

This paper describes the prototype design being considered for the CM system, the reasons for selecting it, and plans for testing and evaluation of CM. Additional details of the design are given in Alexander (1993), which includes additional references.

COMPONENTS OF THE CONTINUOUS MEASUREMENT DESIGN

A Sampling Frame Based on MAF/TIGER

The Census Bureau is currently developing a system to build and keep up to date a national MAF. This will largely be in place by 1996, constructed by an ongoing computer match of U.S. Postal Service mail delivery files with the 1990 census Address Control File. These addresses will be linked to the TIGER geographical data base. Addresses not geocoded by the computer match will be resolved clerically when possible, using resources such as commercial maps, assistance of local governmental officials, and additional information from the Postal Service and its letter carriers.

The CM prototype would add to these plans an ongoing field operation to locate MAF addresses that are in the ILF sample, and check out any situations that cannot be resolved by the computer and clerical operations. The MAF/TIGER files would be updated to correct any errors or duplications found in using the frame for the ILF and other current surveys, or by special Quality Assurance samples. Additional updating would be conducted by ILF interviewers when a block which needs updating is near a housing unit being visited for the ILF. This new operation, called the Sampling and Address-Correction Feedback Operation (SACFO) is separate from the MAF/TIGER system, but interfaces with it.

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* This paper reports the general results of research undertaken by the Census Bureau staff. The views expressed are attributable to the author and do not necessarily reflect those of the Census Bureau. This is document CM-17 in the Continuous Measurement Research Series.

The main uncertainty about this SACFO operation is the handling of "rural-style" addresses, usually post office boxes or general delivery. We hope that by 1999 most of these addresses can be linked to a "city-style" address (house number, street name, apartment designation) used for Emergency 911 service, even when this address is not used for mail delivery. Respondents would be asked to write this geocodable physical address on the ILF questionnaire sent to their mailing address. The 2000 census form would also collect both addresses whenever possible.

The updated MAF/TIGER will be linked to a file containing data from the ILF, other household surveys, and the 2000 census. This will be used for the Program of Integrated Estimates described below.

The Intercensal Long Form (ILF) Survey

The ILF will mail questionnaires to about 250,000 addresses per month. The sample will be spread evenly across the MAF each month; i.e., the sample housing units will be spread evenly across the country. Each month's sample will be a separate set of housing units. Over five years the cumulative mailout sample size will be about 15,000,000 housing units.

Units that do not respond by mail, after several reminders, will be interviewed by telephone whenever the telephone number can be obtained from sources such as commercial lists or the previous census. Units that cannot be interviewed by mail or telephone will be designated for possible personal visit. Only a sample of these units will be sent out to be interviewed. The subsampling rate for personal visit units, including vacant units, will be 1 in 3 in most areas. A rate of about 1 in 5 will be used in remote areas. The total monthly interviewed sample size is expected to be about 200,000 units, including vacant units for which information is collected. This comes to about 12,000,000 interviews over a five-year period. (See Attachment A) This compares to about 14,500,000 interviews for the 1990 long form.

For the years 1999-2001, the monthly mailout will be about 400,000 per month, so that CM can start with small-area estimates based on three years of data.

In interpreting these sample sizes, it is necessary to take into account the weighting of the survey. The personal-visit cases will each be given a weight of 3 or 5 times the basic weight, according to their subsampling rate. The weighted nonresponse rate for occupied units, corresponding to the portion of the population not represented by the survey because of nonresponse, is 7.5%. (See Attachment A)

The ILF will have larger standard errors than the 1990 long form for comparable estimates. Partly this is due to the small sample size and partly to the need to use weighted estimates with some units having much higher weights than others. Differential weights increase the survey's variance compared to an equally weighted sample of the same size. The overall effect is that typical ILF standard errors will be 1.25 times as large as the comparable 1990 long form standard error. Attachment B illustrates this effect for estimates of the number of children in poverty for various small areas.

This 25% increase in standard errors affects confidence intervals about the same as going from a 95% to 90% level of confidence for a given interval. This loss of precision would be worthwhile if there are sufficient gains in data quality due to use of more recent data, collected by better-trained interviewers.

The loss of precision would be greater for estimates of the characteristics of vacant units or group quarters, which are sampled at 1/3 the regular rate, or 1/5 in remote areas.

There also may be a loss of precision compared to the 1990 census for places of under 2,500 population with their own governmental units. The 1990 census sampled such places, containing about 7.5% of the population, at a rate of 1 in 2. To make up for this, the sample in large areas—tracts of over 4,000 population—had their sampling rate reduced to 1 in 8 rather than the usual 1 in 6. The CM proposal currently assumes a uniform sampling rate everywhere. If the 2000 census content determination process establishes a need for extra sample in certain areas, the CM design will be modified to meet the same need. The legislative requirements for the oversampling have not yet been well documented; certainly the sudden cutoff at 2,500 needs to be evaluated.

The ILF sample size for individual tracts or other small areas would be evaluated periodically. Areas with poor response rates, or low rates of completion by mail and telephone, would have a higher-than-average mailout sample size or personal-visit followup rate. This would avoid some of the historical problems with insufficient long-form data in some "hard-to-enumerate" areas.

Compared to a one-time census, the smaller, permanent ILF interviewer staff would be more selectively recruited, more experienced, and more extensively trained and observed. This seems likely to produce data of better quality, although experimental evidence quantifying the effect is lacking.

The Program of Integrated Estimates

The first CM estimates will be derived solely from the ILF, using conventional weighting and tabulation methods along the lines of those of the 1990 long form sample or CPS. The estimate for a specific block or tract will be based almost exclusively on ILF sample data from that block or tract, although some adjustments will be made based on comparisons of the sample units to the entire MAF. There will also be some form of adjustment of the estimates to agree with independently derived demographic estimates for states or counties. For more details, see Alexander and Wetrogan (1994).

After the 2000 census, the samples for the Census Bureau's current household surveys, CPS, SIPP, the National Health Interview Survey (NHIS), the National Crime Victimization Survey (NCVS), the American Housing Survey (AHS), and the Consumer Expenditure Surveys (CES) would use the MAF as a sampling frame. At this point, the linking of these data and ILF data to the previous census short form will make it much easier to get good synthetic estimates for characteristics measured by these surveys for medium-sized areas such as cities and groups of counties.

This methodology is particularly promising for estimates of income, poverty, and housing quality. For these characteristics the ILF questionnaire gives a crude measure of the phenomenon, which would be highly correlated with the more valid measure given by the other, smaller surveys. Information from the ILF could also be used to improve substate labor force estimates from the CPS; here the CPS information would dominate the estimates, and ILF data would be used to adjust for differences between the CPS sample and the complete population.

The ILF would also serve as a useful screening sample for rare subpopulations; this is especially important for NHIS. Using ILF this way depends on legislative changes which would permit some sharing of addresses between the MAF system and other Federal activities.

The methods for publishing or releasing the CM estimates still need to be worked out; this is a top priority for the Census Bureau's new CM Development Staff. The general strategy will be to make available very detailed general-purpose files, so that users can tabulate these to make whatever estimates they need. The files will be compatible with one or more standard statistical packages. Likely possibilities are 1) tallies by block or block group for each month, that can be summed to give estimates for any geographic area and any time period; 2) a file of individual household data, with identifying information and detailed geography suppressed to preserve confidentiality. These data files would be updated quarterly; we hope to have each quarter's processing complete six months after the end of the quarter.

Although users can examine annual data for small areas, estimates for areas as small as census tracts will be very imprecise unless at least five years worth of sample (three years for 1999-2001) are used in the estimates. For block groups, even five-year estimates will have large standard errors; traditional long-form estimates for these areas also have high standard errors (see Attachment B).

For larger areas, annual estimates would be of interest. For areas of 250,000 persons or more, sample sizes would be large enough to support analysis of annual data. Annual National estimates could be made with considerable demographic detail. However, annual estimates for the total population may not agree with estimates from special-purpose surveys like CPS Supplements or SIPP, because of differences in the questionnaires and interview mode.

RATIONALE FOR THE DESIGN

Our objective in selecting a CM design was to produce small-area (or small domain) estimates that are better overall than the corresponding small-area estimates from the traditional long-form design. The proposed CM design would produce an estimate corresponding to any estimate which can be produced from the traditional design, including estimates for small areas such as tracts, block groups, school districts, traffic analysis zones, etc., and small domains such as demographic subgroups comprising 0.1% of the population or less. The fundamental differences are:

i) the CM estimate will be an average over a five-year period (three years for 1999-2001);

ii) the five-year average will be updated annually;

iii) the CM estimates will typically have a 25% higher standard error.

The overall quality of these small-domain estimates is the major uncertainty we must address in our research on CM. For large domains where annual estimates have adequate standard errors for analysis, the quality advantages of the CM design are much easier to demonstrate.

The case we intend to build for the overall better quality of CM small-domain estimates depends on three main hypotheses:

A) an annually updated five-year moving average is better for almost all purposes than a once-a-decade point-in-time measurement;

B) for the important uses of small-area data, the advantage in A is sufficient to outweigh CM's increased standard errors;

C) other differences in measurement error between CM and the long form have relatively small impact and have an overall neutral effect on the comparison.

Our proposed research is intended to support or refute these hypotheses. The next few sections will discuss what we now know about these quality issues, and present our general plans for tests, research, and consultation with users about the research results.

Besides quality, the second major issue is cost. In addition to direct savings from eliminating the long form, CM has the potential for savings in other Federal data collection programs. These will be discussed in a later section. Also, the improvements in MAF quality due to regular use of the list for the ILF throughout the decade may lead to savings in the address list operations prior to the 2010 census, beyond what MAF could save without SACFO.

We need further research to estimate the magnitude of these costs and savings with any degree of confidence. Some preliminary calculations for design purposes did suggest that, for the prototype sample size, there is some chance that the savings produced by CM over the entire Federal system could equal or exceed the cost of the CM operation. This was taken into account in proposing the design.

MEASUREMENT ERROR ISSUES

There are a whole range of detailed measurement error comparisons between a continuous "Intercensal Long Form" and a traditional once-a-decade long form. Each system has advantages and disadvantages for small-area estimates. Right now there is not enough information to draw a conclusion about the net impact on "total error"; we hope to shed light on some components of the error through research and testing over the next few years.

Probable Measurement Error Advantages of the ILF Compared to a Traditional Long Form:

1. Better training, observation, and evaluation of interviewers.
2. Ability to conduct ongoing experiments to evaluate and improve questions and procedures.
3. More uniform actual interviewed sample sizes for small areas, since problems in specific areas can be identified and corrected by increasing sample sizes or assigning more effective interviewers.
4. Greater opportunity to investigate and correct for errors in estimates identified by independent local sources.
5. More uniform treatment of seasonal effects. This is especially important for places like seasonal resort areas. CM would be better for areas where April characteristics are not representative of the whole year, for example agricultural employment. However, it would be worse for characteristics where April is "representative" and some other months are not, such as educational activity.
6. Use of variable reference period, eliminating the recall lag for long-form units interviewed long after census day.

Probable Measurement Error Disadvantages of the ILF Compared to a Traditional Long Form:

1. Less complete coverage of housing units, compared to a survey done at census time.
2. Possible problems of within-household undercoverage of persons compared to the number collected on census forms. Undercoverage relative to the census is observed in CPS and other surveys. However, this problem may not be as serious for the ILF, which will be a census-like survey using census-like roster rules and interview modes.
3. Lack of exact short-form counts for the same time period as the survey, for use in controlling tract level sample estimates to agree with the full population.
4. Worse measurement of income, for interviews which take place late in the year.
5. Greater confusion about variable reference periods for questions, compared to a census with a fixed census day.

6. Greater confusion about residence rules.

Most likely there will not be a single conclusion about the measurement quality that applies to all characteristics. We expect that CM will give more uniform quality, eliminating very bad estimates for a few small areas. However, for some important characteristics, such as income or numbers of people by age-race-sex, the long form would give a more exact estimate as of census day than the ILF does for any given time period.

DISCUSSION OF FIVE-YEAR MOVING AVERAGES

The critical uncertainty about the adequacy of CM small-area estimates for small areas such as census tracts (or "Block Numbering Areas" where tracts are not defined) is whether rolling five-year cumulated estimates will meet the needs of data users. Our research and consultations with users are at a very early stage, but some preliminary conclusions can be drawn.

Our initial discussions with data users suggest that the idea of cumulative estimates takes some getting used to. The first reaction is inevitably to compare the five-year average to good annual estimates; clearly good annual estimates would be ideal. However, when the comparison is made to a once-a-decade snapshot, we have so far not found many situations that obviously favor once-a-decade.

At a very simplest level, the situation is this. When small areas are very stable over time, a five-year average is as good a single number to describe a small area as an estimate at a single arbitrary point in time. When the characteristics of the area are changing dramatically, an estimate at a single point in time is very misleading. In this case, a single five-year average can also be misleading, but a time series of moving averages gives some information about the change.

The five-year average estimate needs to be supplemented by:

i) some numerical measure of variability within the five years, which will signal that the estimate should not be accepted at face value;

ii) the ability to display the five single-year estimates, with their standard errors, so that the nature of any extreme variation can be noted;

iii) the ability to display seasonal patterns so that these can be noted.

Example 1:

(Assume constant population size for simplicity)

	Poverty Rate	
	Tract #1	Tract #2
Year 1	25	5
Year 2	20	10
Year 3	15	15
Year 4	10	20
Year 5	5	25
Average	15	15

This kind of example has been cited by several critics as an unfavorable example for the five-year cumulation. The five-year average says the two tracts have equal poverty rates, but tract #2 currently has a much higher poverty rate. A supplemental display of annual estimates might reveal the trend, but the individual annual estimates are based on too small a sample to be trustworthy. The official measures, used for such purposes as allocating funds according to need, would be the five-year averages.

However, a one-time snapshot would give worse results overall. If year 1 were the census year, then Tract #2 would be identified as having a very low poverty rate, with no indication that any change has occurred. If year 3 were the census year, the results would be the same as the five-year average, but with no indication of uncertainty. If year 4 or 5 were the census year, the data would not yet be published since it takes about two years to complete processing for the large one-time long form sample attached to the census. We expect the smaller, ongoing ILF to have about a six months processing lag; this expectation does need to be tested.

The big advantage of the moving average is that after year 6 there will be an update that will gradually reveal the high poverty rate in Tract #2, if it persists.

Example 1 (Continued)

	Poverty Rate	
	Tract #1	Tract #2
Year 2	20	10
Year 3	15	15
Year 4	10	20
Year 5	5	25
Year 6	5	25
Average	11	19

There are technical problems with cumulations that must be solved, and at best will have only imperfect solutions. How are dollar amounts to be adjusted for inflation? How do we handle situations where blocks are split and it is hard to determine the correct block for units interviewed before the split? Changes in the boundaries of cities are simpler; past years' values for the current city boundaries can be calculated retroactively, but this is still a complication.

Another issue is whether the five-year averages would be population-weighted. For CM, population-weighted averages will be much more convenient computationally. For a rate, the population-weighted average would be

$$R^w = \bar{X} / \bar{N} = \sum_{i=1}^{60} R_i \, (N_i / 60\bar{N})$$

where R_i = rate in month i

N_i = population in month i

X_i = numerator of rate in month i, and

$$\bar{X} = \sum_{i=1}^{60} X_i / 60 \text{ and } \bar{N} = \sum_{i=1}^{60} N_i / 60$$

The alternative unweighted rate is

$$R^u = \bar{R} = \sum_{i=1}^{60} R_i / 60$$

To illustrate the difference, consider a small area where a large increase in population (families) in the middle of the five-year period dramatically increases the poverty rate

Example 2:

	N_i	R_i
months i = 1 . . ,30	100	0
months i = 31, . . . ,60	1000	.90
R^u = .45	and R^w = .818	

The larger rate R^w in effect looks at the total number of "family-months" and determines what proportion were spent in poverty.

PLANS FOR CM RESEARCH AND TESTING

The timing and objectives of proposed testing and development are described in Attachment C. Our plan is to use the test results to address the research issues as follows.

The 1994-95 Cumulative Estimates Simulation Project

For a few test areas we plan to create a simulated population on the computer for the years 1980-1992. Housing units for the 1980 and 1990 census will be linked when possible. Simulated values for intermediate years, and non-long-form households, will be generated using probability distributions consistent with the observed values. Transition probabilities for intermediate years can be estimated from American Housing Survey sample households, for which 1980 long form data are also available. For blocks with large numbers of new units, we will try to determine when the actual units were built.

With the simulated population, the sampling and estimation for the ILF can be implemented. Also the 1980 and 1990 long form sampling and weighting can be implemented and checked against actual census estimates. It will then be possible to examine various uses of long form estimates, see how these uses would be affected by using CM estimates instead, and compare the results to the "actual" population values at the time the data are used.

If funding permits, the simulation files will be made available to interested users who wish to compare the CM and long form estimates.

This part of the research will address the utility of five-year moving averages, and the impact on estimates of not having tract-level controls from the short form. We do not expect to address measurement bias with this study, although some information may be collected on the variability of small-area nonresponse rates in the long form.

The simulated CM estimates give us a good opportunity to illustrate the CM data delivery system. Some mock output files will be produced and distributed to interested data users for comments on their utility. This will not be a realistic test of our ability to produce real data from the system quickly. The data delivery system for the 1995 Questionnaire Test will be more complete and realistic.

The 1995 Questionnaire Test

We plan to collect ILF information by telephone from November 1994 through December 1995, using a variable reference period. We have not yet decided whether the test will be National or be conducted in only a few test sites. The test will use a questionnaire based on the 1990 long form, with any changes needed because of the moving reference period. The questionnaire would be revised once the 2000 census content determination is complete.

A control group will be interviewed around April 1995 using a fixed reference day. This will address our most serious questionnaire concern, possible recall error in the reporting of income late in the year. To help interpret any differences, a comparative study is being considered of income estimates from various existing household surveys using different reference periods and interview times (CPS March Supplement, 1990 long form, SIPP, CES, NCVS, etc., as well as some non-Census-Bureau surveys).

This test will also be used as a trial of the data processing and data delivery system. An initial version of the public data files is tentatively scheduled for August 1995. Depending on funding and staffing of the CM Development Staff, the initial files may be fairly complete, or may be restricted to an illustrative set of variables. These files will be made widely available to interested data users; the mechanism for distributing the files has not been worked out. The data delivery system will be revised based on user comments, and improved versions will be released during 1995 and 1996 as necessary as response to the comments.

Additional test components to get at the effects of alternative reference periods and seasonal variability will be considered. This test will not address coverage. Some experience with cumulative estimates as compared to a March or April long form might be gained if some test areas overlap with the 1995 Census Test areas; the merits of this are being discussed.

Some cost information relevant to the telephone interviewing and data processing activities of the full CM system would be collected.

The 1996 CM Operational Test

Starting in FY 1996, there will be a full-scale implementation of CM in a few test areas, including at least one site with many non-city-style addresses. The test sample will probably use a sampling rate at least as large as the proposed 1999 system. We are considering a larger sample rate to get more precise estimates quickly. This test will give us more information on cost parameters, by monitoring the work flow and cost of the test.

The test will also be used to evaluate CM's coverage of households and persons within households. Our likely approach to this is to apply coverage measurement procedures being developed for the 1995 census test. We might actually be able to use 1995 census test final address lists to evaluate the CM list, if the CM test uses some of the same sites.

The CM estimates will be studied to try to evaluate some measurement errors, to confirm or further investigate findings of the 1995 Questionnaire Test. This will involve looking at variations in the CM monthly estimates, and comparing estimates with other data sources.

USES OF CM TO ENHANCE OTHER PARTS OF THE FEDERAL STATISTICAL SYSTEM

Even without any ILF, SACFO's coordination of address sampling and updating activities and PIE's linking of census data for use in estimation would have important benefits for the operations of Current Household Surveys conducted by the Census Bureau. A sampling operation based on MAF would be more flexible than the current system based on listing building permits throughout the decade in sample areas. Linking survey data to census data and information from administrative records systems holds great promise for small-area estimation and intercensal demographic estimates. A small "mini-ILF", aimed only at collecting information on areas which would be "outliers" in small-area estimation models could dramatically improve the performance of the estimation methods at relatively low cost.

The full-scale ILF would increase these benefits by providing a larger number of address corrections and more direct information for small-area modelling.

The ILF could also be used to screen for rare subpopulations or characteristics, allowing programs that need to collect data for small groups to reach these groups affordably. The ILF sample is sufficiently large that the screening sample could be confined to the same areas as the other surveys and still yield plenty of cases.

For CM to be used as a screening survey for other Federal programs, some changes in legislation are needed to allow sharing of addresses among agencies. Most of the cost advantages of screening for rare subpopulations could be obtained if the Census Bureau could supply other statistical programs with a list of addresses containing an oversample of units in the rare subpopulation, even without supplying any data on the units.

We have just begun to contact Federal agencies to see how CM might help them to achieve their mission more efficiently. Some ideas, that at first glance seem technically realistic, are listed below as examples of applications of CM besides direct updating of long-form data.

Uses of Small-Area Estimation Methods

1. Use ILF or PIE data as covariates in ratio estimates to reduce the variance of CPS state or substate (large counties or cities) labor force estimates.
2. Use ILF or PIE small area data in combination with global income and poverty data from SIPP or the CPS March Supplement to produce synthetic estimates for small areas such as school districts.
3. Share sample units with the American Housing Survey, which has many questions in common with the long form housing questions.

Uses of ILF or MAF as a Screening Sample

1. Use ILF to screen for rare populations needed by NHIS to provide the detail needed to understand the causes of health patterns seen in aggregate data.
2. Use brief ILF supplemental questions to screen for units likely to have rare characteristics such as health conditions, residential alterations or, for NCVS, rare crimes such as abduction of children. Further information would be collected by followup interviews.
3. The MAF could be used to supply addresses of newly constructed units, for surveys of energy use or expenditures.

Besides benefits for existing programs, the full CM system provides the opportunity to meet new needs for data quickly and efficiently.

Uses for New Topics

1. The MAF provides a ready sample to concentrate interviewing in any local area. With ILF in place, there would always be a current baseline of long form "background variables" for any geographical area defined in terms of whole blocks. This would allow a focused local survey to measure needs and rate of recovery for areas affected by natural disasters, such as floods, earthquakes, or hurricanes, or unusual economic or environmental events.
2. The ILF supplement could be used to provide National and subnational information on a variety of topics within the planned limits of 5-10 minutes worth of supplemental questions.
3. There may be efficiencies or opportunities to improve quality by coordinating MAF/TIGER and SACFO with the Census Bureau's systems for collecting information on building permits. Information on permits is used as a Leading Economic Indicator.

CONCLUSION: PROSPECTS FOR CONTINUOUS MEASUREMENT

The testing plan outlined above has two purposes:

i) begin the implementation of SACFO and PIE;

ii) provide the users of Federal statistics with the information to determine whether the benefits of the CM system are sufficiently compelling to justify a change from the time-tested long form design starting in 2000.

Some amount of work to develop SACFO and PIE is clearly worthwhile. Census Bureau staff currently devote considerable effort on disjoint systems for i) maintaining an address frame for household surveys, ii) constructing a list of addresses for the decennial census, iii) using administrative records for demographic estimates. Using MAF for all three programs in a coordinated way requires planning and coordination, but so far seems to require very few additional operations. Instead, there is an opportunity to eliminate redundant operations.

It is an ambitions research task to prove the feasibility and value of CM in time for a decision about the 2000 census. If users of long form data strongly prefer updated cumulative estimates for the ILF system, this would be a reason to pursue replacing the long form with the ILF in 2000. This is by no means a foregone conclusion. Alternatively, if this comparison is about even, but new uses of ILF as a source of screening sample or modelling covariates are sufficiently compelling, that would give us reason to go forward. Once the research has determined the benefits of CM relative to a long form, the cost of the system and the additional response burden of collecting the additional information must be weighed against the benefits. An important goal of our research is to develop the details of the CM operation and, through testing, to measure the cost.

Our general research timing would be to provide evidence about whether CM is a superior source of data by the end of 1995. If the results are positive, this would justify a tentative decision to proceed with the system for 2000. Evidence on cost and feasibility would be available by the end of 1996, at which time a final decision on "census" content is needed.

The remaining argument in favor of an early implementation of ILF is that eliminating the long form would simplify decennial census operations. However, there is no evidence that the long form is a distraction that interferes with the census count operation, so simplification by itself does not seem to justify a 2000 implementation of CM unless we can demonstrate benefits for data users. Our immediate goal is therefore to contact data users and professional organizations familiar with uses of census data, to obtain their assistance in evaluating our research plans and research results.

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ATTACHMENT A

ANTICIPATED BREAKDOWN OF MONTHLY ILF SAMPLE SIZE

Occupied Units:	225,000			
Completed by mail		135,000		
Completed by telephone		50,400		
Eligible for personal visit (P.V.)		39,600		
Subsampled out			27,600	
Designated for P.V.			12,000	
P.V. Interview			6,886	
P.V. Noninterview			5,114	
Vacant Units:	25,000			
Subsampled out		17,424		
Data collected by P.V.		7,576		
Total Mailouts:	250,000			

Total Interviews: Occupied = 135,000 + 50,400 + 6,886 = 192,286

Vacant = 7,576

Total = 199,862

Average subsampling rate = .85 x 3 + .15 x 5 = 3.3
(assumes "remote areas" have 15% of population)

Weighted noninterview rate for occupied units =

$$\frac{5{,}114 \ x \ 3.3}{135{,}000 + 50{,}400 + 6{,}886 \ x \ 3.3 + 5{,}114 \ x \ 3.3} = .075$$

ATTACHMENT B

ILLUSTRATIVE COMPARISON OF RELIABILITY BETWEEN DECENNIAL CENSUS AND CONTINUOUS MEASUREMENT DATA COLLECTION SYSTEMS FOR AREAS IN MARYLAND: PERCENT OF CHILDREN 5-17 IN POVERTY

Areas	Decennial Census			Intercensal Long Form (ILF)*	
	Population Size	Estimate	CV**	CV 12-month***	CV 60-month****
Maryland					
State Total	4,781,468	10.5	1.1%	3.2%	1.45%
Baltimore City	736,014	31.3	1.5%	4.1%	1.8%
Anne Arundel County	427,239	5.3	5.6%	15.7%	7.0%
Carroll County	123,372	3.6	10.0%	32.3%	14.7%
St. Mary's County	75,974	9.4	9.2%	NA	11.9%
Gaithersburg	39,542	7.4	16.2%	NA	21.2%
Somerset County	23,440	15.6	14.0%	NA	18.3%
Kent County	17,842	12.9	14.9%	NA	22.4%
Hyattsville	13,864	5.6	25.8%	NA	35.1%
Havre de Grace	8,952	23.5	14.2%	NA	19.6%
Capitol Heights	3,633	7.2	46.5%	NA	61.7%
Cottage City Town	1,236	5.0	46.0%	NA	103.8%
Congressional Districts					
Distnct 1	597,684	10.2	3.2%	9.1%	4.1%
District 2	597,683	6.3	4.2%	11.8%	5.3%
District 3	597,680	11.9	3.0%	8.4%	3.7%
Distnct 4	597,690	8.0	3.6%	10.4%	4.6%
District 5	597,681	4.7	4.7%	13.9%	6.2%
District 6	597,688	8.3	3.5%	10.2%	4.6%
District 7	597,680	30.2	1.6%	4.7%	2.1%
Distnct 8	597,682	4.1	5.2%	14.8%	6.6%

NA - Not Applicable

* Calculations of reliability for ILF estimates are based on: 1) a sample size 64% of that needed to provide reliability comparable with that from the decennial census and 2) no oversampling of governmental units under 2,500.

** The CV or coefficient of variation is a measure of sampling variability. The CV is the ratio of the standard error of a sample estimate to its expected value. There is no specific rule to determine if a given CV is good or not. This determination is based on considerations, such as use of the data, consequences of making the wrong decision, and so forth. In practice, a CV of 10% less is often considered to be adequate, between 10 and 50% to be acceptable, and 50% or more to be undesirable.

*** Estimates are based on weighted observations from 12 months of interviews.

**** Estimates are based on weighted observations from 60 months of interviews.

ATTACHMENT C

ACCELERATED MAF-BASED CONTINUOUS MEASUREMENT DATA COLLECTION ACTIVITIES

FY	Data Collection Activity	Objectives
1994	Cumulative Estimates Simulation Project	• Demonstrate properties of Cumulative estimates • Measure effect of population controls on estimates • Illustrate data delivery system
1995	RDD Test with 2000/month total in 3-4 sites, starting November 1994. Convert to split-sample questionnaire test in July 1995. Small mail pretest.	• Test alternative versions of questionnaire • Measure effect on time of year and moving reference period on income data, etc. • Demonstrate ability to deliver timely data • Tentative decision regarding 2000 long form
1996	MAF-based test with at least 4000/month total in 4 sites, starting October 1995.	• Develop/test field procedures • Measure coverage of MAF/SACFO • Decision regarding 2000 long form
1997	MAF-based "development survey" for Congressional-District-level estimates, full speed in January 1997. Rural sample clustered in PSUs.	• Refine actual procedures • Produce annual estimates for areas of 500,000 or more • Final content determination
1998	Expand MAF-based sample size; change procedures and questionnaire to fix problems found in FY 1997. Better rural spread.	• Further evaluation of quality • More annual estimates for areas of 500,000 or more • Phase-in full system
1999	Full MAF-based system. Complete rural spread.	• Collect small-area data to replace 2000 long form

The Implications of Continuous Measurement for the Uses of Census Data in Transportation Planning presents the findings and recommendations of a panel of transportation planning experts on a possible replacement data-collection system for the decennial census.

Created under the Intermodal Surface Transportation Efficiency Act of 1991, the Bureau of Transportation Statistics (BTS) is an operating administration of the U.S. Department of Transportation.

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Information on *The Implications of Continuous Measurement for the Uses of Census Data in Transportation Planning* and other publications is available by writing BTS Product Information, U.S. Department of Transportation, Room 3430, Washington, DC 20950, faxing 202-366-3640, or calling 202-366-DATA. This report and other BTS products are also available on Internet at WWW.BTS.GOV.

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