UNITED NATIONS SECRETARIAT
Department of Economic and Social Affairs
Statistics Division

ESA/STAT/AC.115/1
May 2007
English only

United Nations Expert Group Meeting on
Contemporary Practices in Census Mapping and
Use of Geographical Information Systems
29 May-1 June 2007
United Nations, New York

Digital Census Mapping Process: conceptual framework and different approaches*

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Digital Census Mapping Process: a conceptual framework and different implementation approaches[1]

Introduction

1. Many national census agencies have already embarked on census planning activities for the 2010 round of Population and Housing censuses. Among the initial census preparatory activities, cartographic work is critical. The traditional role of cartography in a census has been to support the production of enumeration area maps and thematic maps derived from available census information. However, due to recent technological developments in Geographic Information Systems (GIS) and other geospatial technologies, the scope of census cartography has been extended to include census data analysis and dissemination. It also facilitates greater efficiency in data collection and enumeration.

2. While many countries, including developing countries, are taking advantage of the significant capabilities offered by GIS, Global Positioning Systems (GPS), Remote sensing, Surveying, Digital mapping and Internet to improve their census mapping operations, many others are still struggling to use and integrate these technologies within their census mapping operations. The long term goal is to set up a sustainable digital census mapping program, including the establishment of a Cartographic/GIS unit within their national statistical offices.

3. This paper presents a conceptual framework and different approaches to a digital census mapping strategy, with emphasis on the capabilities offered by geospatial technologies to support census mapping operations, as outlined in the United Nations *Principles and Recommendations for Population and Housing Censuses, Revision 2*[2]. It highlights the critical factors to be taken into account to integrate GIS and other geospatial technologies into the census mapping process, including institutional, organizational and capacity building aspects.

Census cartography and the mapping "revolution"

4. Until recently, many developing countries have been hesitant and slow to embrace the use of GIS and other geospatial technologies in their census mapping programs. Most of them for valid reasons such as lack of comprehensive base maps of desired scales, shortage of qualified staff, and other resource constraints limiting access to commercial

[1] This article updates the paper written in 2004 and enhances it taking into consideration the recent *Principles and Recommendations for Population and Housing Censuses, Revision 2*.

[2] *Principles and Recommendations for Population and Housing Censuses, Revision 2:* UN/DESA/Statistics Division, October 2006.

software, computers, digital base maps, satellite imagery, aerial photography, GPS receivers, etc.

5. However, it should be underscored that with recent technological developments, spatial data can now be collected and exchanged more rapidly, duplicated without alteration, and easily disseminated to end-users. Moreover, spatial data, in its digital form, is increasingly combined with a variety of statistical data (demographic, socio-economic, environmental, etc.) in order to create relevant information for geographic information analysis and decision support (Goodchild, 2000; Martin, 1996). GIS has evolved into a mainstream IT technology that operates and functions at home on the web (Google Earth, MapQuest, etc.), on portable devices, on servers, and is embedded in many applications (environment, utilities, geo-marketing, location-based services, etc).

6. The census data users in developing countries are increasingly aware of the potential offered by these technologies and demand for their use and integration within census mapping operations. The census mapping field is experiencing a paradigm shift from the traditional cartographic approach, which is paper-based and repeated for every census (i.e. delineating and updating enumeration areas), to a digital census mapping approach, which is an up-to-date approach and a continuous and dynamic process. As a consequence of this shift, the question that is being addressed by national census agencies in many developing countries is no more "whether" geospatial technologies should be utilized, but rather "how" to use them to better support census cartographic work.

The Census Mapping Process: a conceptual framework

7. In order to understand how better we can integrate geospatial technologies with census mapping operations with an optimal solution, it is useful to outline the framework that underpins the census mapping process. This will assist in identifying the cartographic tasks that can be supported by the use of geospatial technologies. As illustrated in Fig.1, mapping operations support the census process at its three stages: pre-enumeration, enumeration and post-enumeration. Thus, at each stage, maps have specific functions with regard to census operations and various combinations of geospatial tools provide an added value to the mapping tasks at each stage.

8. In the pre-enumeration stage, the national census agency prepares the enumeration area maps as a basis for counting, as accurately as possible, every household and person in a well-defined area during the enumeration period. The use of available large-scale maps (including high-resolution satellite imagery and aerial photos) is therefore ubiquitous: first, to estimate the number of persons living in an area and their geographic distribution, and then to support the delineation of enumeration areas (EA) and other census area units, and ultimately to produce enumeration maps, in digital or hardcopy format, in order to be used by the enumerators during the data collection operations as part of the field work.

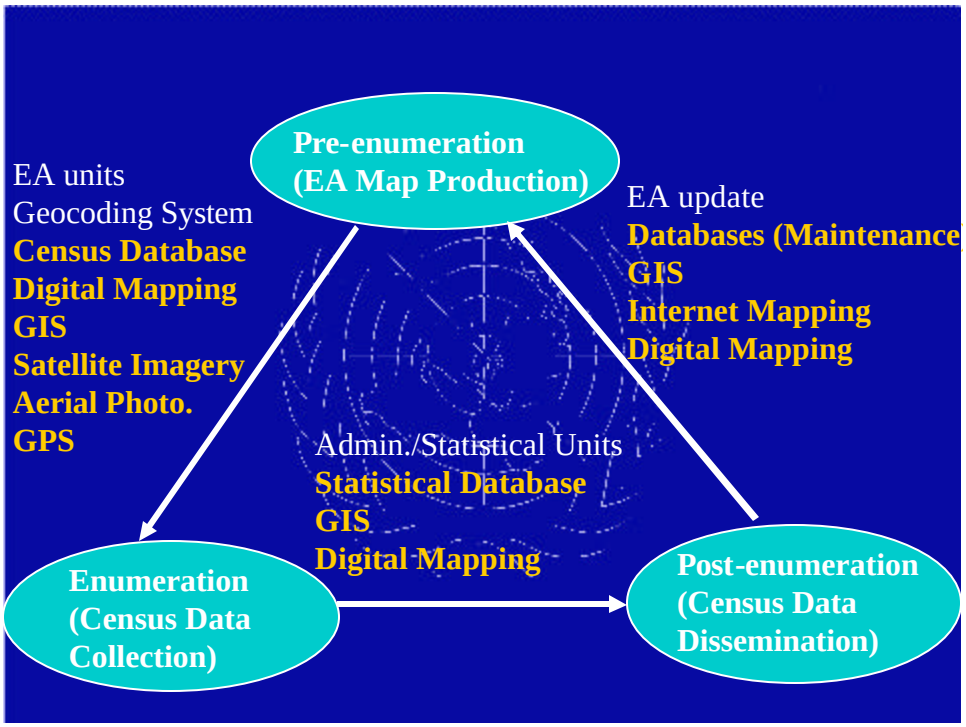

Fig. 1: Census Mapping Process

9. For this purpose, census cartographers, in consultation with census planners and major census data users, have to undertake a complete and consistent partitioning of the national territory into hierarchical geographic units, with the enumeration area as the lowest level. The delineation of the boundaries of enumeration areas should be, to the extent possible, consistent with the boundaries of administrative divisions and other existing natural or built reference features like roads, rivers, landmarks, etc., and undertaken in consideration of the administrative and statistical reporting units to be produced for dissemination purposes. Ultimately, the purpose is that they can be recognized without ambiguity by the enumerators.

10. The development of a coding scheme is necessary assigning a unique code to each enumeration area. The code scheme, reflecting the administrative hierarchy, should be flexible enough and well structured to incorporate new and future administrative divisions. If we assign geographic identifiers, such as latitude-longitude coordinates, to the boundaries or the centroid location of the enumeration areas, the resulting codes, referred to as "geocodes", permit data to be linked geographically and displayed on a map, and therefore establish a link between GIS boundaries and tabular census data. Some countries go even further by geocoding street intersections, landmarks, buildings, and dwelling units. For many data users, geocoding refers more specifically to this latter operation.

11. At the enumeration stage, large-scale maps guide enumerators in identifying their assigned dwelling units and other places where people are expected to be during the enumeration period of the census. In addition to their fundamental support during the census data collection, large and mid-scale maps help census supervisors coordinate the

work of their enumerators and enable them react swiftly to any problems they may face. Mid- and small-scale maps help census managers monitor progress of their overall census operations across the country.

12. The quality of maps is very crucial at this stage; it impacts the quality of census data collection and the results. The enumeration phase offers the opportunity to verify, correct and validate enumeration maps that have been produced at the earlier stage. However, in many cases, maps may not have sufficient information on human settlements and other specific populated places. During the enumeration phase, the national census agency may need to refer to existing gazetteers or, in conjunction with the national mapping agency or national names authority, update or create a new national gazetteer, to provide a place-names list of populated places of larger than 5000 or 10000 inhabitants, other places of cultural or touristic significance, lakes, streams, mountains and regions of major importance. Information given in the gazetteer includes the standardized forms of the names of the places, the administrative division in which each is located and the geographic co-ordinates of the location of such places.

13. In the post-enumeration stage, maps make it easier to spatially analyze, present and disseminate census results to various users with specific needs. The development of a geographic statistical database, for administrative and aggregated statistical units, is very useful to carry out spatial analysis and to disseminate census results. Furthermore, the development of an internet-based map viewer (map server) is more and more being created by national statistical offices to enable a significant number of users, including the general public, to easily access and query GIS-enabled statistical data.

14. Also after completion of the census, during the intercensal period, digital maps and imagery provide a solid basis for the development and maintenance of administrative/jurisdictional boundaries. There is a possible use to aggregate small areas (as enumeration areas) to disseminate data and avoid confidentiality problems. The maintenance of the geographic databases is carried out between censuses, reflecting the up-to-date census mapping process. In addition to the development of socio-economic and environmental indicators and other indicator maps and atlases, key components to providing information on education, health, poverty, and community services across the country, are generally undertaken at this stage.

Digital Census Mapping Strategy: different implementation approaches

15. As shown in the framework above, maps are useful at the three stages of the census mapping process and geospatial technologies can be integrated in the process as an optimal solution. Therefore, initial efforts at the planning stage should focus on the selection of the appropriate method for successfully accomplishing the integration of geospatial technologies. Many would ask the following legitimate question: is there any uniform approach for a digital census mapping program that is appropriate for all countries? The short answer is that there is no unique solution. Each country has to consider its own needs taking into account available resources.

16. Indeed, the national census mapping strategy needs to be determined on a country-by-country basis and requires a tailor-made approach that considers the

following factors: size of the country; existing base maps; available financial resources; existing technical capabilities and trained staff; and a timeframe available to plan and carry out the census mapping process[3]. There is a range of options in meeting these criteria: for example, a large country may have base maps and some technical capabilities but does not opt for a full census mapping strategy because of the extensive work needed and the short timeframe available. On the contrary, a small country largely rural may opt for a full census mapping program, despite having limited resources, because it may have received extensive technical support to acquire the required digital aerial photography to produce its base maps and had sufficient time before undertaking the census.

17. In any case, the easiest way for countries with limited resources and available base maps to start the process of using GIS is with a post-census digital mapping strategy: it is an approach that does not need extensive work under pressure and can only use mid- or small scale maps with administrative and statistical units. It focuses on developing mapping tools and GIS applications to increase the dissemination of census data and to spatially display information. More importantly, it is a learning process, initiating the building of technical capacities, and an early planning exercise for the next round of census.

18. At the other extreme, countries with significant resources and having carefully planned ahead of time its census mapping activities, may choose a full digital census mapping program. The precursor of this strategy is the development of a complete digital database of enumeration areas. This is a daunting task, but necessary, for a sustainable digital census mapping project. A fully digital map database allows multiple options covering the whole census spectrum: from census data collection, to census data management and analysis, up to census data dissemination. Even for a complete digital database of enumeration areas, there are many available options with an increasing order of complexity, starting with digitizing existing sketch maps, to producing an EA map database, up to creating a full database of dwelling units, geo-referenced by GPS data collection[4].

19. Many other countries would opt for a mixed approach that can use existing sketch maps along with newly created digital maps that cover only some urban areas (or regions) with the aim of extending the coverage in the next round of censuses to other urban and rural areas across the whole country. A gradual GIS-based solution, taking into account the current situation of cartographic work and focussing first on a well-defined goal, is more realistic and achievable in a reasonable period of time. For example, a country may

[3] For details, see the Handbook on geographic Information systems and digital mapping, UN Publication, 2000, (ST/ESA/STAT/SER.F/79).

[4] The *Handbook on geographic information systems and digital mapping* indicates the following five phases: (i) Production of rudimentary digital maps created on the basis of existing sketch maps; (ii) Geo-referenced enumeration area maps that can be properly integrated with other digital geographic databases; (iii) Inclusion of geographic reference layers, showing, for instance, roads, rivers, and other features; these can be included as simple images from scanned maps or designed as a structured vector database; (iv) A digital postal address registry where addresses are matched automatically or semi-automatically to digital road databases; (v) A digital database of precisely located dwelling units, created with the aid of geographic positioning systems.

decide to use a combination of existing maps with high-resolution satellite images and digital aerial photographs to provide a detailed, up-to-date map of some major cities of the country and to define EA boundaries, while traditional manual techniques continue to be used for other cities and rural areas. In addition, instead of embarking on the development of a geographic database project for the whole country, the country may choose to conduct a prototype in a city or a small area of the country that can evolve and be extended over time to other areas.

More integration of GIS, GPS, Image Processing, and Internet

20. As stated earlier in this article, GIS, GPS, Remote sensing, including aerial photography, and Internet are increasingly used in the field of census data collection and dissemination. Aerial photography has been playing a major role in geographic data acquisition in urban areas, and the use of satellite imagery, due to its low resolution, was limited to rural areas and aerial phenomena. However, satellite imagery is extending its application to urban areas with the increase of its spatial resolution to 0.6-meter (e.g. QuickBird satellite) and the nascent digital aerial photography (using digital camera) is extending its scope to small urban areas.

21. GPS receivers continue to be popular and widespread, offering greater accuracy and reduced cost, and their use for location-based applications is expected to widen with the new European navigation system, Galileo, under construction. GIS applications have been tailored to the needs of field operations, allowing GIS to move from the office to the field (ArcUser, 2004). The Web-based GIS applications trend continues to grow, and Internet mapping, with map viewers like Map-Quest, Yahoo! Maps and particularly Google Earth Maps is a popular phenomenon in recent years. An important Internet mapping application of interest for statistical offices is the Statistical Map Server: a web mapping application which allows users to represent statistical data and indicators through interactive thematic maps in both an Intranet and external environment, and to perform their own query and data analysis by country and by region. Some web-based mapping applications such as National Geographic Society's Map Machine, the World Bank's Map Server, FAO's Key Indicators Mapping System (KIMS) and, at the national level, the US Census Bureau FactFinder, are good examples of Map Servers (UN, 2004).

22. However, the most significant development lies with better integration of GPS, image processing, Internet and GIS systems for an optimal data utilisation. Indeed, most current GIS data collection software can link digital photos to mapped features and integrate them directly into an attribute file, adding value to Mobile GIS data collection (i.e. photos of landmarks). GPS coordinates (waypoints) can be displayed real-time in GIS software (i.e. ArcPad), and when connected to the Internet offer the ability, for example, to search Yahoo! and find people, places, products and services while on the move. Today, most photogrammetric flights are equipped with digital cameras connected to on-board GPS, improving the precision of the data that has been gathered. Furthermore, the combination of digital video (DV), satellite imagery and GPS for the capture and the input of data into GIS for manipulation, analysis and display, is empowering data collection and integration.

Institutional and Organizational issues

23. Many national statistical offices have put forward much effort to tackle the enormous potential of geographic information technologies and to build a sustainable mapping program. However, it is becoming clear that the major barriers and constraints to harnessing geographic information and integrating geospatial technologies are not necessarily technical but rather institutional and organizational. One of the most important challenges for many statistical offices in developing countries is the ability to maintain a specialized in-house Cartography/GIS unit, dedicated to the census mapping program, that can establish relationships with other governmental agencies and other organizations involved in geographic information activities, particularly with the national mapping agency. To enforce a basic principle stating that geospatial information should be collected once and shared by many, the national statistical office should establish agreements and mechanisms allowing purchasing of existing maps or sharing the cost of creating new ones, suited for census taking.

24. Building spatial databases, at national and local levels, is increasing and the concept of spatial data infrastructure, as part of the national infrastructure, is emerging. Furthermore, a National Spatial Data Infrastructure (NSDI)[5] is becoming to be regarded as a fundamental asset of a society, equal to its roads, communications networks, and other public utilities. It is now widely accepted that developing national spatial data infrastructure will better facilitate the availability and access to spatial data for governmental organizations, the private sector, universities and citizens in general. National statistical offices should participate actively in building the NSDI since population datasets and geocoding systems, for which they are custodians, are considered basic components of the NSDI.

25. With current technologies, geospatial data users within government should be able to access and use data from consistent datasets which meet their requirements, no matter where the data is collected and maintained. A One-Stop geospatial information portal is a method for making government's geospatial information accessible to and shared by agencies and the user community. The one-stop portal approach, reflecting the interoperability of systems and data, is a mechanism that considers datasets to be held on different systems by different custodians, but linked by common standards and policies. National statistical offices gain to use this one-stop portal to disseminate their census information and extend their outreach to a larger user community.

Critical Success Factors

26. The shift to a digital census mapping approach is a reality which is no more under question, requiring national statistical offices to embark sooner rather than later on

[5] NSDI is a combination of technology, policies, standards and human resources necessary to acquire, process, store, distribute, and improve utilization of geospatial data. Conceptual parts of NSDI: 1. Institutional framework defines the policies, legal and administrative support to create, maintain and apply the standards to fundamental data sets; 2. Standards define technical characteristics to fundamental data sets; 3. Fundamental data sets require geodetic framework, topographic and cadastre data bases; 4. Technological framework allows the users to identify and receive the access to fundamental data sets (GSDI Cookbook, 2000).

building a sustainable census mapping infrastructure. There is, however, a mixed feeling on the success and failure of GIS-based census mapping projects that have been carried out by national census agencies. Indeed, in order to avoid failure and succeed in a full digital census mapping program, we have to consider the following critical factors[6], before embarking on its implementation: (i) Ensuring commitment from senior management level for building a long-term digital census mapping program; (ii) Conducting a comprehensive needs assessment with a need-driven approach rather than a technology-driven approach; (iii) Choosing the appropriate methodology of integration of the new geospatial technologies with the census mapping operations; (iv) Setting up a permanent unit for Cartography/GIS activities within the National Statistical Office; (v) Developing a partnership for cooperation with the National Mapping Agency and other organizations involved in geographic information activities; (vi) Building technical and human capacities required for sustaining the census mapping program.

27. It is of critical importance to consider the census mapping program as a long-term programme that benefits not only the national census agency, but also the other national organizations and census data users. Approaching census mapping as a process, knowing that it requires an important initial investment, can better help a return on investment in the long term (Tripathi, 2000). In addition, conducting a comprehensive needs assessment helps define adequately the user needs, particularly at the three stages of the census process, and helps identify the available resources within the national statistical office and in the country, in terms of maps suitable for the census operations (with an inventory), existing software packages and related equipment, qualified staff in cartography and GIS, and funding for census mapping. The evaluation of user needs and available resources would help select the appropriate methodology to build a staged census mapping program with optimal use and adequate integration of geospatial technologies.

28. A census mapping program carried out as a continuous process requires an independent geographic information unit within the National Statistical Office, with a permanent staff that can carry out the census mapping tasks that span the census stages and also the time between censuses. A permanent unit should be able to develop a partnership for data standards and interoperability, for agreements and contracts for data collection and sharing, and cooperate with the other major actors in building the National Spatial Data Infrastructure of the country. Building the required capacities to run a census mapping program is a challenging issue, since digital census mapping necessitates a combination of specific skills, rarely offered through an academic program. Most important are questions of incentives to be provided in order to retain the qualified staff that has been trained, and of the ability to ensure a continuous training to keep them abreast of advances in technology.

Concluding remarks

[6] More details in the Handbook on geographic information systems and digital mapping, UN Publication, 2000.

29. The United Nations Statistics Division (UNSD) is organizing this Expert Group Meeting on "Contemporary Practices in Census Mapping and Use of Geographical Information Systems" to critically review contemporary frameworks and different approaches to census mapping and the capabilities offered by advanced technologies to support census mapping operations, with an ultimate goal of producing a technical report on best practices in digital census mapping. It is one of the priority activities of the 2010 World Programme on Population and Housing Censuses for this year, 2007, that will provide background material to support regional workshops that the UNSD is planning to organize and conduct, starting in September 2007.

30. In addition, the results of the meeting will be an input into the revision and updating of the current Handbook on Geographic Information Systems and Digital mapping. In this context, this paper aims to stimulate discussion on the optimal use and integration of geospatial technologies (GIS, GPS, and Remote Sensing, etc.) within the whole census mapping process, with an emphasis on the critical factors a national statistical office should consider in order to succeed in the implementation of a full digital census mapping program. It underscores the strategic use of digital census mapping methods for the 2010 Round of censuses.

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