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Computer Systems to Support Census Geography

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Abstract: The computer systems that support the geography of the census have grown from a single integrated system, the Geographically Referenced Data Storage and Retrieval (GRDSR) System in 1971 to a suite of systems and packages in 1986. Furthermore, a new generation of systems is now being acquired within Statistics Canada (STC), and others are being developed in similar organizations like the U.S. Bureau of the Census. At the same time, the changing role of the Area Master File (AMF), the geographic base file of GRDSR, is having an impact on the systems that create, maintain and utilize the AMF to generate products of interest to private users. In addition, the re-evaluation of the AMF and the proposed block program are tightly intertwined and will pose even greater challenges for the existing systems.

Taken together, all of these changing conditions call for a careful re-examination of our approaches to maintaining and extending the systems capacities needed to support the geographic aspects of the 1991 Census. In this paper, we present proposals for the 1991 Census that increase the level of automation, whether the geography changes or not. In addition, opportunities for change and improvement, should the geography change, are outlined. To minimize the risks involved, it is important to give these different proposals serious consideration early in the planning of a census.

Key words: Census; reference maps; thematic maps; automated mapping block program; area master file; postal codes; geographic processing; TIGER.

1. Introduction

The backbone of any modern census operation is the geography system developed to support it. This fact is noted by Gordon (1975), who says that "a census must have a spatial framework for which data are to be gathered, tabulated and reported." Marx (1985) summarizes it as follows: "The success of a census rests not only on how well we collect the data, but also on how well we link those data to geographic areas." Tomasi (1985) identifies three major geographic tools involved in the census support function. They are:

> maps, address reference files, and geographic reference files.

Maps relating to census geography include: reference maps which show the geostatistical framework (Fig. 1); collection maps which are guides to the distribution and collection of the census questionnaires (Fig. 2); and thematic maps which display specific themes or data

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variables for a given set of geographical units (Fig. 3). (Figures 1–3 are on pages 442–444.)

Address reference files contain computerized representations of street networks and associated features, along with address ranges for each side of a street between consecutive features. These files are called GBF/DIME files in the U.S. for the 1980 Census, and are referred to as Area Master Files (AMF) at Statistics Canada.

Geographic reference files contain, in computerized form, the relationships between the various components of the hierarchy of geostatistical areas. The Master Reference File (MRF) in the U.S. and the Census Geographic Master File (CGMF) in Canada are examples.

The geography and cartography components of the census are supported by computer systems that are necessary for the processing of the large and complex sets of spatial data involved in any modern census.

In this paper we shall look at the spatial systems that were put into use for the 1971 Census and the pressures that are put on these systems. The continual change in the statistics-gathering process and in statistics-users' demands indicate that significant change in these spatial systems is inevitable. We will show how these demands can often be converted into opportunities for improvement.

2. Census Geography Systems at Statistics Canada

The development of geography systems for support of the Canadian Census began in the late 1960's when spatial information system technology was still in its infancy. Ion (1969), Podehl (1971), and the GRDSR manual published by Statistics Canada (1972) document the systems that are still in use today. During the early 1970's the CGMF data files were developed to complement the urban data coverage (AMF), and to provide uniform coverage for the entire country for selected geostatistical areas.

The GRDSR system was developed for the 1971 Census as a means of retrieving census data for any user-specified area, whether or not the area is a standard geostatistical area. The retrieval process is based on a series of x-y centroids, defined at the block face level in AMF areas, and at the enumeration area (EA) level in the rest of Canada. These centroids are linked to the appropriate information in the census data base. When a user requires information for a specific set of areas, she or he outlines the areas on a map. These outlined areas are converted to digital form and GRDSR identifies all centroids. The statistics are then tabulated in a report.

An AMF records every street, address range, block face, and centroid coordinate in cities with population of 50 000 or more. Also itemized are other features such as railroad tracks, rivers and municipal boundaries. The AMFs were designed to enable data retrieval for non-standard areas and are now also being used to produce collection maps for some major urban centres for 1986. The background, content, and applications of the AMF are described by Parker et al. (1985).

The main purposes of CGMF are to provide a central computer data base of the geographic information for the census and to assure quality in the geographic data by ensuring the correct aggregation and presentation of census data. Information is coded in three data files: the geographic aggregation data file (EAMF) which contains one x-y coordinate reference for each enumeration area (EA) and a series of codes to identify all the geostatistical areas in which the EA falls; the attribute data file (ANAM) which describes the Standard Geographical Classification and official name for each area, and supplementary information such as land area and population count from the previous census; and the boundary data file (ABND) which defines the boundary polygons for certain geostatistical areas.

Since 1976, census geography systems have been operating in a mode of "minimal change," and research on new systems has been limited. Refinements and enhancements are minor relative to the initial research and development efforts, and have come about in response to specific user demands and external pressures. The demands have centered on diversified presentation formats for the geographic data with separate computer programs developed to meet these requests.

In summary, from a single system, GRDSR, we have grown to an eclectic set of systems that have been developed to overcome specific problems or to respond to specific enhancement needs. Collectively, these provide a "spatial information system" that is tied together by the AMF and CGMF data files.

3. Pressure Points

When systems are left in place for 15 years, there are many pressures put on them. These are caused in part by technological developments and in part by changes in the application itself. In order to discuss the pressures that are associated with the census geography systems, we have defined the following categories:

new products,
new clients,
new systems,
new ideas,
new data,
and new joint ventures.

These types of pressure will be examined one at a time, with a current example for each described in detail.

3.1. New products

Demand for new types of geographic products has taxed the limits of some of the existing systems, necessitating expansion of the data bases and increasing the need for changes in data structures. Some of the recent products requested include:

Forward Sortation Area (FSA)/Postal code maps,
Emergency response maps,
Tourism data modelling,
Block-face data maps,
Multiple symbol maps.

The Trillium Data Group was contracted by the Ontario Ministry of Health to produce an ambulance dispatch system for the Halton-Peel Central Ambulance Dispatch Services. Trillium subcontracted Statistics Canada to extend the AMF in Halton and Peel counties and produce reference maps (see Fig. 4 on page 445) and a street index for that area. To satisfy their needs, however, an increased number of road types had to be defined within the AMF structure.

3.2. New clients

As part of the 1986 census cost recovery effort, emphasis has been placed on developing by-products that can be sold to external clients at a profit. Within the past 18 months, a number of clients in the private sector have approached STC to obtain hardcopy products and data files that are by-products of the census geography data base. The companies include:

Gandalf Data Ltd.,
Trillium Data Group,
John Deere and Company, and
Canadian Tire Corporation.

STC has recently provided Gandalf Data Ltd. with a street index, generated from the AMF, for a taxi dispatch application in Metro Toronto. Using these data, the street address of a customer will be input into the system, which will then return the names of the intersecting streets on either side. This will allow identification of the customer's location to the nearest block.

In 1984–85, digital files of municipality boundaries for Canada (used for quality assurance in the CGMF – see Section 2), were merged and converted into a form useful for thematic mapping (see Fig. 5 on page 446)). The file currently contains only the official limits that do not respect actual shoreline (e.g., the limits go into the water and often several islands are included in a single polygon). The addition of shoreline with this file would increase the diversity of its applications, but would also substantially increase the volume of data in the CGMF data files.

3.3. *New systems*

New systems provide new opportunities for the automation of processes and for changes in existing data structures, thus overcoming the problems of excessive data and rigidity. Since GRDSR was developed for the 1971 census there have been major improvements in spatial information systems. Typical of these systems are:

ARC/INFO,
CARIS,
TIGER, and
ARIES III.

The ARC/INFO system, developed by Environmental Systems Research Institute, is a state-of-the-art geographic information and database management system. It permits various forms of input, manipulation, user query, and output of geographic data which are not possible with current STC systems. It allows for the subdivision and manipulation of geographic data by rectangular "tiles" and permits the addition of a topological structure to the AMF.

CARIS, developed by Universal Systems Limited of Fredericton, New Brunswick, is an advanced mapping system with excellent interactive response and geographic data structure. This system, which is primarily used for the production of topographic and hydrographic maps, also has geographic information and database capabilities.

The TIGER system (Marx (1985)), provides an integrated capacity based on a topological data model being developed at the U.S. Bureau of the Census to support all major geography operations for the 1990 U.S. Census. The project is revolutionary and massive in scope.

Clayton and Estes (1980) describe how image analysis systems are being used with satellite data to create land-use classification schemes, to detect land-use change on the edge of metropolitan communities, and to derive population estimates in areas undergoing substantial growth. The ARIES III system is now used by STC in the analysis of agricultural data.

New systems are praised as tools to increase productivity and decrease costs. If these systems are substituted piecemeal into the overall system process, the net result will be an increase in the number of diverse computer systems that need to be maintained.

3.4. *New ideas*

Throughout the life span of a system, new ideas for products and applications are generated. These ideas in turn can create pressure to modify the basic data structures of the system in order to improve its power and flexibility. Ideas currently being considered at STC include:

postal code integration with the data base,
addition of block topology to the AMF,
integration of AMF and CGMF data files,
EA mapping,
input, storage and output of cartographic data by standard grid units,
linkage with the Electronic Atlas project.

Currently, streets and other line features in the AMF are represented in a form that contains no information about the adjacent areas (e.g., blocks, geostatistical areas). Other geographic files represent geostatistical units in a polygon format that does not permit identification of the surrounding areas. The addition of a topological element, as in the TIGER system, would permit a boundary or street segment to be described as a "l-cell," with associated information about its junctions with other nodes ("0-cells"), and the areas ("2-cells") that lie on either side. This would make for straightforward generation and aggregation of areas, as well as other geographic, cartographic and analytical operations.

While the addition of topology would add significant value to the AMF data files, it would mean a modification of one of the basic building blocks of the spatial information system that supports census geography.

An "Electronic Atlas" is being developed by the Surveys and Mapping Branch of Energy, Mines and Resources Canada (EMR), to provide increased flexibility in the manipulation, analysis, and creative use of National Atlas information. The Electronic Atlas does not simply store existing maps, but also stores both positional and attribute data in such a way that the creation of new maps is possible through the interactive manipulation, analysis and display of the data. EMR is interested in interfacing census data and geographic boundaries with the atlas data files. The effort to develop new presentation formats for census files designed mainly for quality assurance purposes may lead to programming and other methodological problems.

3.5. *New joint ventures*

Joint ventures with other agencies lead to changes in structure, system, and processing requirements. Typical joint ventures under consideration or already agreed to are ventures with:

EMR
Cambridge
Woodstock
IST (CRAR)
Metropolitan Toronto
Burnaby
Winnipeg
Calgary.

A part of the Electronic Atlas project (sponsored by EMR and STC through the GCG subdivision) is providing programmer support for further development work. This would allow common objectives and simplified interfaces for data exchange to be achieved.

Since 1979, the city of Winnipeg has used STC's AMF as a source of street address information for dispatch of all emergency vehicles (fire, police, and ambulance). The AMF is also used to assign coordinates to each property parcel, permitting spatial analysis for planning purposes. Winnipeg now performs all updates to their files and STC uses these computerized updates. All plotting is currently performed by STC.

Exchanges such as this one with Winnipeg provide STC with improved data quality. They also limit system changes that can be accommodated without violating the joint agreements. If data and interchange formats are modified, then systems at STC and Winnipeg must be amended.

3.6. *New data*

To date most joint venture agreements have involved extension of the AMF files. One such arrangement has recently been made with the City of Woodstock and the Government of Ontario, to create an AMF for Woodstock. Bradley (1985), in an internal memo, points out that this success could be repeated in "hundreds" of other communities. This would, however, add a substantial amount of new data to an already overloaded system.

Additions to the volume of geographic data cause pressure on processing requirements, at times exceeding the limits or reducing the efficiency of some processing and plotting programs that were designed for significantly smaller data bases. This type of situation has usually been circumvented by the "quick fix" solution, that leaves much to be desired in terms of efficiency.

The following list enumerates some of the pressures that generate new data:

i) the quantity of AMF data has more than tripled since 1971;
ii) with agreements with Woodstock and other agencies it could double again;
iii) municipalities of 20 000–50 000 population want their own AMF files;
iv) increased accuracy implies more data.

Table 1 shows the growth in the number of records in the AMF data base for each of the censuses since 1971. It is anticipated that by 1991 the number of records in the data base will increase by 500 percent compared to 1971.

Table 1. Area Master Files

Year	Number of Records	Increase in percent
1971	293 000	
1976	590 000	101
1981	721 000	22
1986	1 000 000	39
1991	2 000 000	100

The National Research Council has demonstrated that the AMF is an effective data base for police departments. The GRASS system described by Arnold (1985) has been well received. Currently, a task force is recommending that GRASS be used in 120 communities across Ontario. Many of these communities have less than a population of 50 000. Thus, there will be pressure on STC to extend the AMF base to include these areas.

In 1981, the City of St. Catharines contracted with STC to upgrade the quality of the AMF so that it could be used by the Engineering Department. In the main, the upgrades were done to obtain increased node locational accuracy, which enables calculations involving street length to be used in city planning studies. The net result was to increase the size of the AMF for St. Catharines by 300 percent.

3.7. Other issues impacting on systems

There are also political or economic issues that affect the future of geography computer support systems. One example is decentralization. Regional offices would like more input in the definition of geostatistical areas, including enumeration areas (EA) and census tracts. This trend to regionalization of workload may require system changes.

The cost of software is increasing as a percentage of total system costs. This leads to an increased emphasis on sharing of software and on development of more general purpose systems.

Recent changes in technology will play a major role in shaping future geographic systems. The decreasing cost of hardware allows more automation of certain processes by the use of sophisticated equipment, e.g. scanners. The increased availability of microcomputers will mean more decentralization, i.e. more analysis of statistics by individual users, with a resultant demand for specialized micro-based geographic software, and for positional and statistical data in diskette form.

3.8. Summary of pressures

Many of the pressures we have discussed are intertwined. New clients want new products that require additional data. New ideas and products change data structures. Joint ventures result in new ideas and new data.

Clearly, the role of the files maintained for the census geography is changing. AMF data files are being used throughout the country as a base for municipal spatial information systems. CGMF files, previously used for quality assurance, are now being considered a base for thematic mapping of census data. However, the systems that support these files have failed to keep pace with the changing demands.

The increased speed and power of the current computer hardware has made it practical to consider applications, which, when GRDSR was first designed, were not economically feasible. One such application is mapping at the EA level. If this idea is accepted, it will result in the integration of data currently maintained separately in the AMF and CGMF data bases, and bring with it a new set of requirements for data structure changes.

4. Related Studies

An analysis of the literature since 1983 indicates a common ground between STC problems and those faced by other systems. Peuquet (1984) notes "the rapidly expanding range of data problems ... narrowness in the range of applications ... and unacceptable storage and speed efficiency for current and anticipated data volumes."

Data problems play a significant role. White (1983) says that "sharing data among computer-assisted cartographers is so problematic it is generally avoided." This idea is supported by Tomlinson (1984), in his keynote address to the International Symposium on Spatial Data Handling in Zurich, Switzerland, when he says that, "Of immediate concern is the ability to exchange data between bases; ... for example, to transfer data between two of the major geographical bases in Canada (CanSIS and CGIS), it is still more cost effective to plot and redigitize the data rather than to effect digital transfer." Problems with geographic data handling stem from three main causes, which Peuquet (1983) summarizes as follows:

i) "boundaries tend to be very convoluted and irregular;"
ii) "data in digital form tend to be incomplete, imprecise and error-prone;"
iii) "spatial relationships tend to be fuzzy or application-specific, and the number of possible spatial interrelationships is very large."

It is apparent that the size of the data base is also a fundamental problem. Tomlinson (1984) suggests that "few of us have any idea how large data bases will become or need to become." Currently, the U.S. Geological Survey (USGS) is in the process of digitizing approximately 1 800 map sheets for the TIGER system. In Canada, about 1 000 map sheets at 1:250 000 scale are being encoded. However, plans for the future are much more ambitious. USGS plans to digitize 55 000 sheets, a process that would derive 1.5x10»»15 pixels of information.

Since the problems are common, we should also look at the recommendations suggested for future developments to see if we all can work from a common ground. Collins et al. (1983) suggest there are three areas of improvements:

i) conversion to relational data base systems;
ii) enhancement of information content by the addition of topology data; and
iii) improvement in human interfaces with systems.

Nuttall and Korzenstein (1985) discuss the blueprint for a Geographical Referencing and Information System (GRIS) for Metropolitan Toronto initiated in 1984. They provide valuable insights based on the use made of both CANSIM and AMF data by the Metropolitan Toronto planning agency. The intention is to link five data banks, containing a total of 964 billion bytes of data, via a common spatial framework.

The GRIS is designed to serve six basic functions including:

"permit data drawn from sources with different geographical identifiers to be filed together in a single source with a common geographical identifier;"
"assist data analysis under geographical corridor or catchment area constraints;"
"produce cartographic maps at any scale."

These functions are also basic requirements for STC spatial systems. Given that the AMF data is a vital building block in the Toronto system, it is anticipated that joint discussions on problems and their resolution would provide valuable guidelines for future STC spatial systems.

5. Responses to Pressures

There are three possible responses to the pressure on the existing systems that support census geography:

freeze existing systems,
enhance existing systems, or
change to new systems.

5.1. *Freeze existing systems*

Freezing existing systems is identified as the response which authorizes only the minimum amount of work to keep current systems operational. In the view of the authors, this response is unacceptable for many reasons, including:

i) system problems in current systems;
ii) it would cancel many other geography initiatives;
iii) market pressures;
iv) excessive processing costs will result if data volumes expand;
v) credibility.

Boisvenue et al. (1983) in a review of spatial systems noted two major problems. First, many of the programs that have been created over the past twelve years have been written in different programming languages with hard coding of the options with respect to data storage and processing alternatives. The net result is that these parts of the system will have to be rewritten, if only so that the system is maintainable in production mode. Second, the report notes that our ability for producing data from current and past censuses on a stable geographic frame is not developing at the speed expected by our clients.

5.2. *Enhancement of existing systems*

Enhancement of existing systems is defined as the increased automation of processes that were formerly performed manually. This is accomplished either by the extension of existing systems or the development (or acquisition) of an additional system.

Key factors in the discussion of enhancement as a means of coping with greater pressures are:

i) some systems cannot be enhanced but must be replaced;
ii) enhancing individual systems does not readily permit an integrated approach;
iii) additional spatial relationships cannot be introduced into current systems by-way of enhancements.

Boisvenue et al. (1983) comment that "most data files were developed for a particular application with little thought to their more universal applicability." While this is a somewhat harsh criticism for a system that has endured for 15 years, it points out the difficulty of extending a system's application range.

5.3. *Change to new systems*

In changing to new systems, we authorize modifications or replacements that often exceed our current requirements based on today's estimates for needs in 1991. Change is always a calculated risk, and usually involves a dual effort. Current systems must be maintained as a fail-safe mechanism while new systems are developed and proven operational. With respect to census geography computer systems, there are ways to minimize risks. Chief among these is what might be termed the "leapfrog" approach. Table 2 identifies the various system advances that have been made by USA and Canada for the past twenty years.

As can be seen from the table, each country has gained valuable insights from the work done by its neighbour. Ideas and procedures have been adapted to the different needs of each census bureau. However, the substantial research that produced the ideas and procedures has been shared rather than duplicated. The U.S. Bureau of the Census, by its willingness to send delegates to discuss and demonstrate the TIGER system, has shown the desire to share the research that has preceded the development of the system. This knowledge, adapted to Canadian needs, will significantly reduce the risk associated with major changes in the computer systems to support the 1991 Census.

Table 2. The "Leapfrog Approach"

Census	USA	Canada
1960	FOSDIC	
1966		Street Indexes
1970	Address coding guide DIME	
1971		AMF Non-standard area retrieval
1980	GBF/DIME	
1981		computer assisted collection mapping
1990	TIGER	
1991		?????

6. Summary

Geography, cartography, and their computer support systems are the basic building blocks of the census program. The current systems have been in use since 1971 and are bursting at the seams. White (1983) talks about the aphorism, "It ain't what you don't know that hurts, it's what you know that isn't so." With respect to the census operation this is not quite true; census credibility is put at risk in either case. We should not wait until political pressures cause change, as was the case in the USA. The 1980 Census, according to Brugioni (1981), was termed "inaccurate" and "an exercise in futility" by P.M. Klutznick, then Secretary of Commerce.

Today's objectives have not changed much since they were first defined during GRDSR development. Fellegi and Weldon (1967) noted that, "It is important that developmental work get underway towards general tools to achieve economies to enable us to deal with massive volumes of data and build in important elements of standardization." In the same document he urged fiscal restraint: "We shall have to make sure that future growth will be controlled and well coordinated and that it will be achieved by efficient utilization of the financial and manpower resources."

The size and scope of systems-related problems have changed drastically since GRDSR was first developed in 1971. Data volumes will have increased 500 percent by 1991. We are now considering the inclusion of topological relationships in the reference files. In addition, a multiplicity of spatial relationships are being evaluated for inclusion in the data bases in order to extend the range of applications.

Brackstone (1983) makes two very important points when he says that "the scale of the census provides opportunities for recovering investments in automation... its crucial importance implies that technology has to be tried and proven before incorporation." The implication is that "bridge financing" required to support initial research can be recouped during production. At the same time, systems must be ready earlier than 1991 to prove their reliability before incorporation in the census production process. The proposal is therefore:

i) use the results of the TIGER research to minimize duplication of effort,
ii) use the available lead time as an opportunity for a thorough system review,
iii) let us not try to do it all at once, and
iv) begin evaluation now, to have sufficient time for program development before the 1991 Census.

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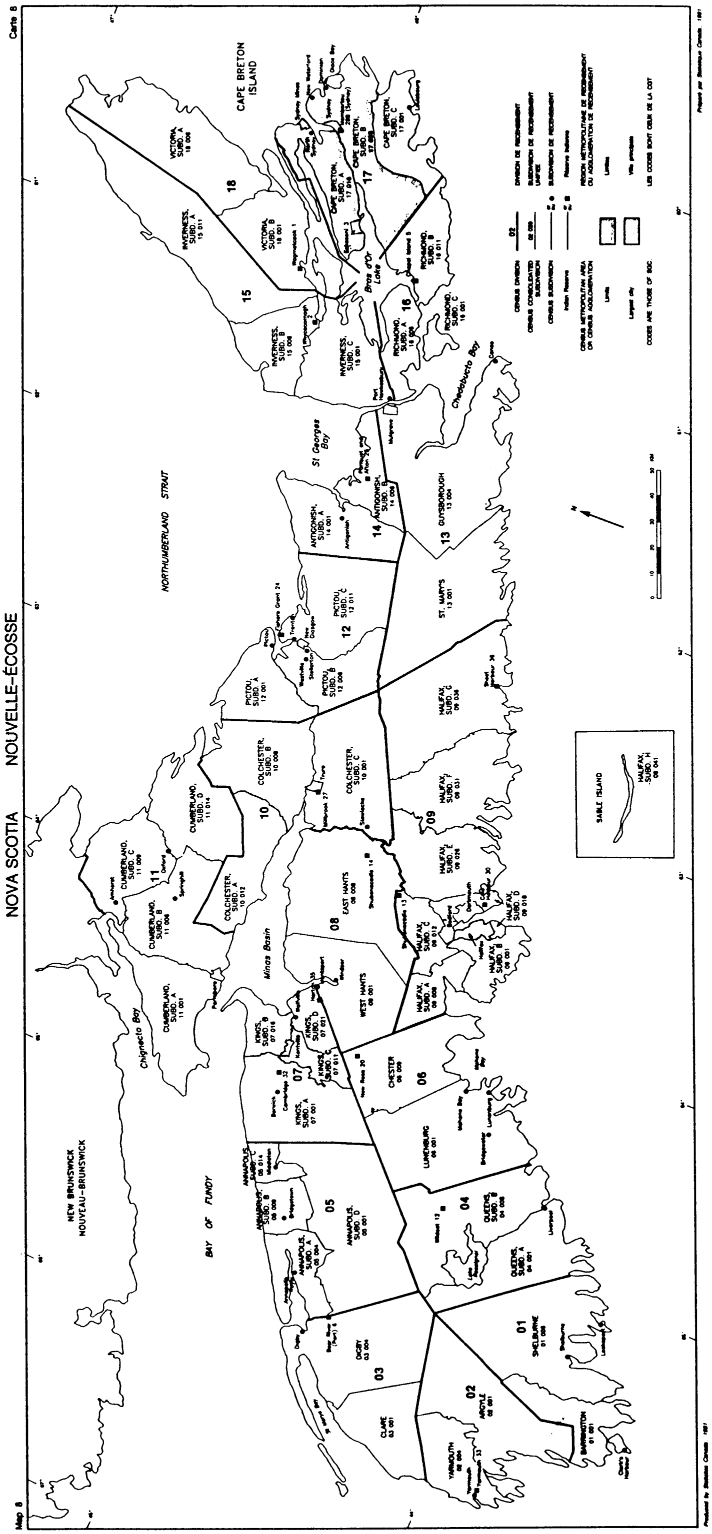

Fig. 1. Census Subdivision Reference Map

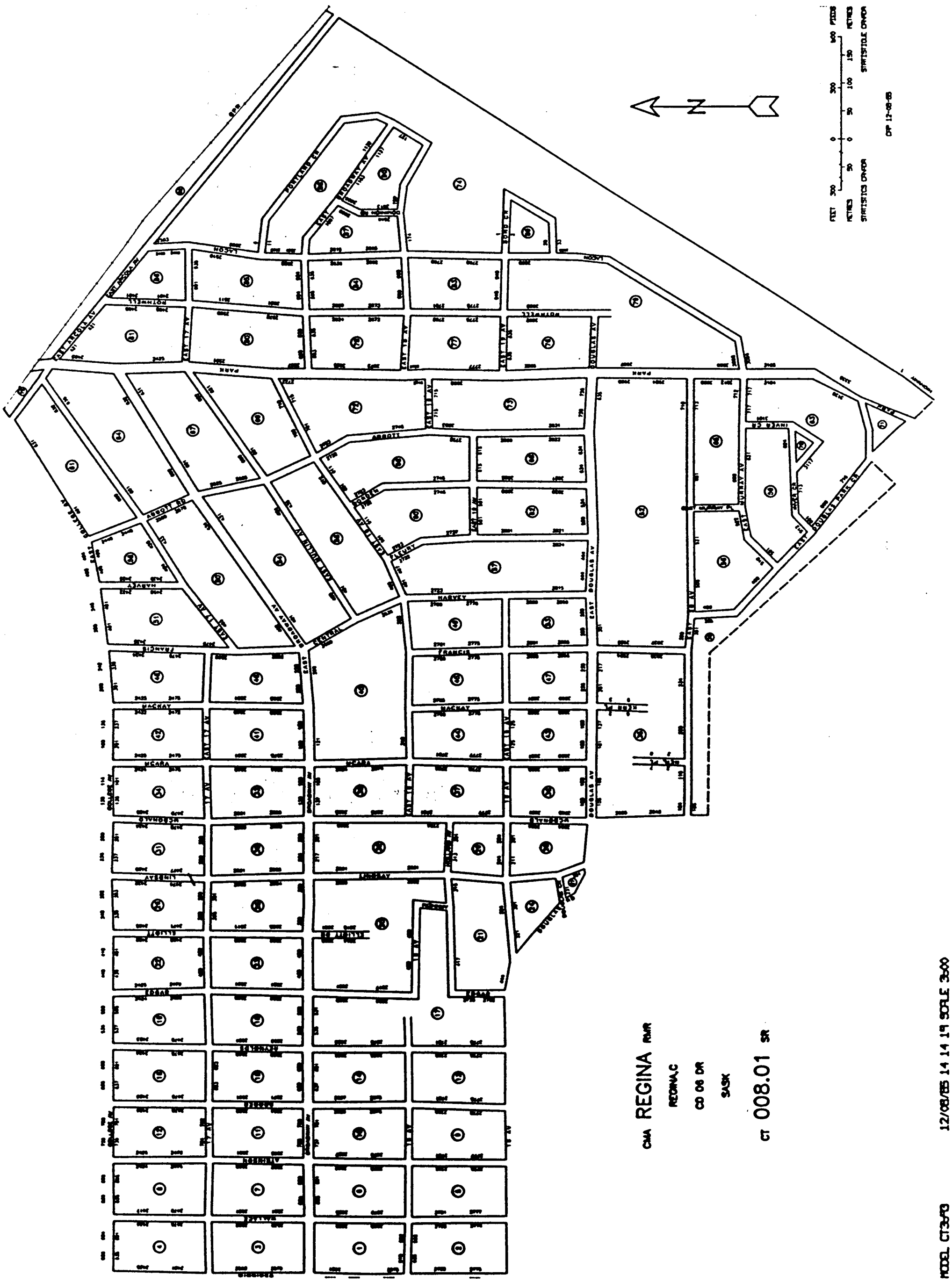

Fig. 2. Census Tract Reference Map

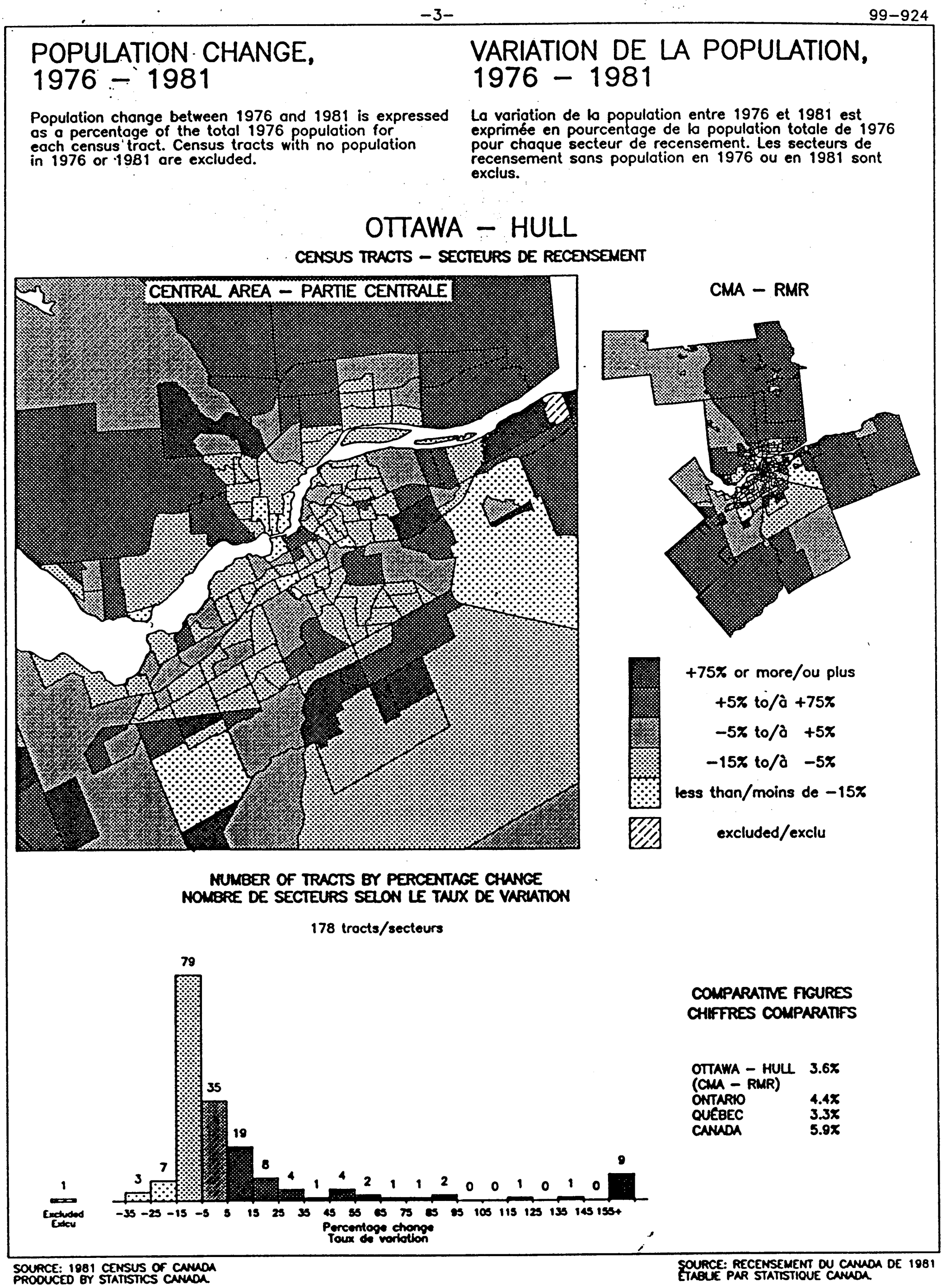

Fig. 3. Thematic Map

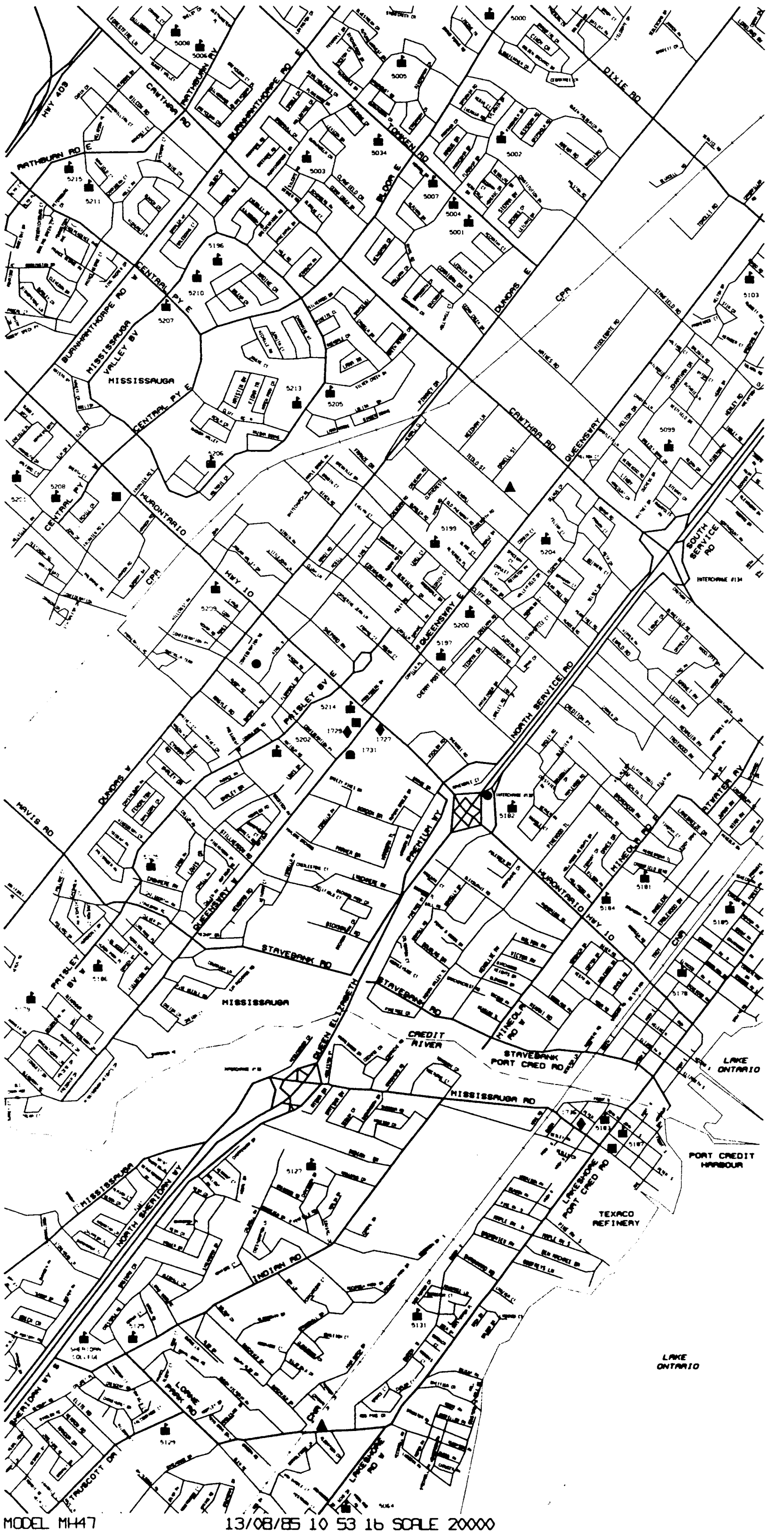

Fig. 4. Ambulance Dispatch Map

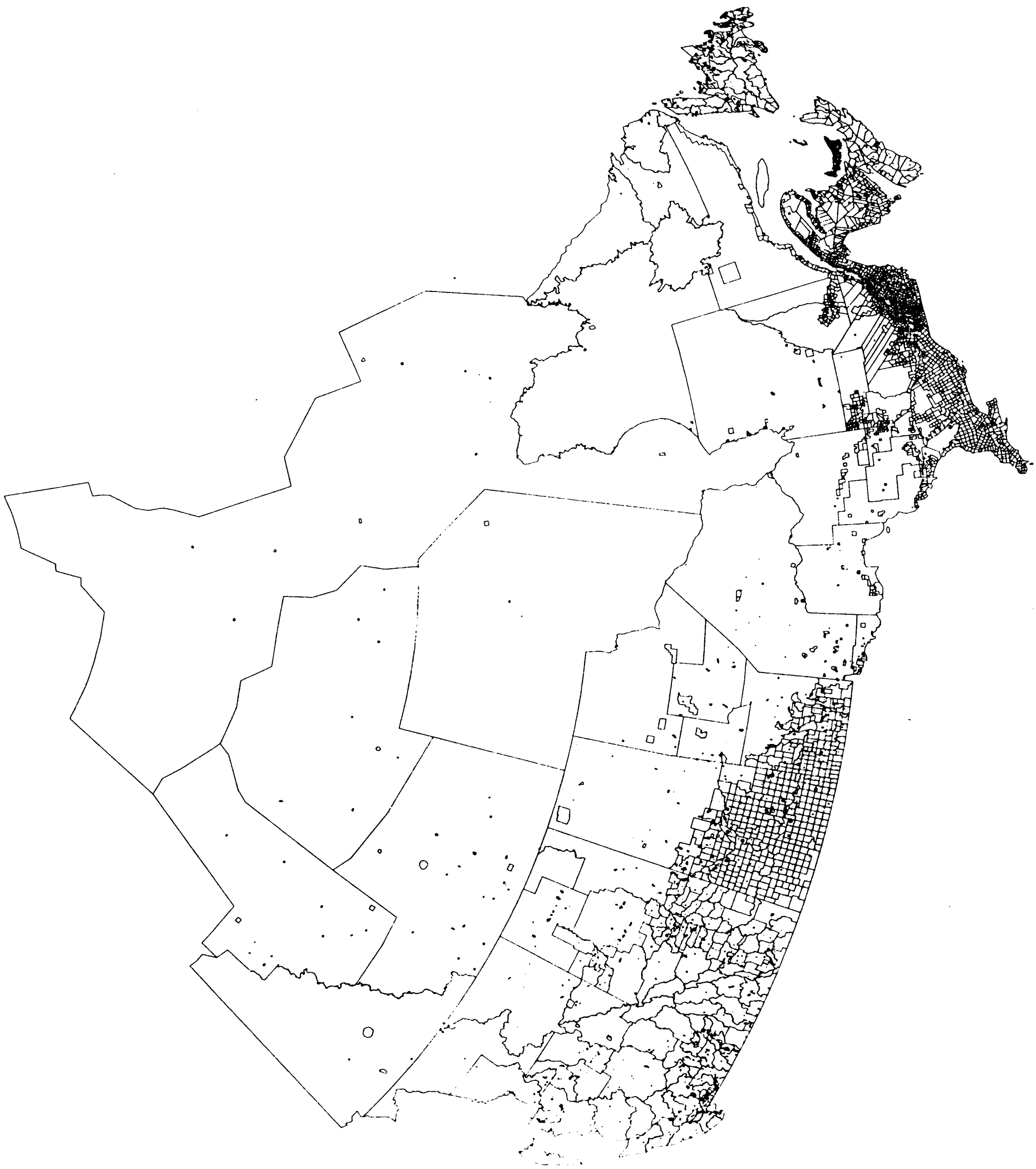

Fig. 5. Census Subdivision Boundaries