ESTIMATING PRODUCTION PARAMETERS FOR LARGE VOLUME AUTOMATED MAPPING ON A RASTER PLOTTER

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ABSTRACT

The Bureau of the Census will be producing hundreds of thousands of individual maps in support of the 1990 Census of Population and Housing. The map production system will be fully automated, therefore, great dependence is placed on new technology and operating procedures. Vendor specifications on equipment capabilities alone can neither provide a true measure of how much equipment and staff are required to meet the production schedule, nor determine which procedures to follow in order to maximize production flow and minimize administrative control. Since an automated cartographic production environment of this magnitude was not available from which to extract production parameters, it was necessary to develop a means of estimating them. This paper describes the content and results of the 1986 Electrostatic Plotter Production Test conducted by the Census Bureau.

Although production demands such as those in support of a census operation are somewhat unique, the results of the test reveal numerous general parameters about map production using an electrostatic plotter and provide a benchmark from which to measure performance.

NEED FOR THE CARTOGRAPHIC PRODUCT

The nature of field work requires (1) the production of multiple copies of a very large number of individual maps at many different scales, (2) the correction of features and boundaries in the data base from which those maps were made within a relatively short time frame, and (3) the generation and distribution of updated versions of those maps. This presents a formidable challenge considering the small amount of production time and the great number of maps to be produced. There will be approximately 400,000 enumerator assignment areas defined for the 1990 Census of Population and Housing. For field collection activities, each enumeration area is represented on a separate map and all maps must be delivered to their respective locations within weeks of each other. Public Law 94-171 requires that the Census Bureau provide population counts together with appropriate maps to each state for the purpose of redistricting in a matter of months after the 1990 Census is taken. Maps also are provided to state and local governments for use in reviewing the completeness of the count in operations scheduled before and after census day. Given the volume of maps to be produced, timeliness of production and delivery become the greatest consideration in the design of a map production system.

SELECTION OF EQUIPMENT

The least efficient functions of an automated cartographic system are the input and output of data. Census Bureau operations require an output device that will convert a stored digital cartographic image into a printed map sheet as quickly and inexpensively as possible. These requirements immediately exclude some categories of plotting devices. Pen plotters, while providing a range of options from monochrome to multiple colors and a variable quality of line work, are far too slow. Large format laser plotters have great potential for use but their present formats are restrictive. In addition, large format laser plotters generally create images on photographic film. To create a usable map product, the image must be transferred photographically to paper. This extra step requires unacceptably large amounts of additional time and expense. Large raster format electrostatic plotters possess the attributes best suited for production needs.

Formerly strictly a monochrome device with coarse resolution, electrostatic plotters now have color capability and increasing resolution. They produce maps that can be used in the field with no further processing other than trimming the sheet. When switching from production of one map to production of another, there is a minimum of changeover time. Often the changeover from production of one map to the next is only a matter of reading the next file from a tape, and rasterizing the map image. Most importantly, raster plotters are orders of magnitude faster than pen plotters and the operations involved in processing maps photographically. The sacrifice is in map design options. Maps had to be designed to fit the limitations of the plotter in use at the time: a monochromatic electrostatic plotter with 200 dots-per-inch resolution and an image area limit of 35.25 inches in one direction.

PRODUCTION AND PLANNING

In the early stages of planning the production and distribution of computer-generated cartographic products for field work there were a number of unknown factors. Basic parameters were difficult to estimate since there was no precedent operation. The most imperative question was the overall rate of production: how many maps could be produced during each shift?

Rate of production affects planning in many area of geographic support for the 1990 decennial census. Most directly affected by production rate are the number of plotters to be purchased, the amount of staff to be hired, and the scheduling of resources. In order for planning and purchasing to progress on schedule, valid estimates of production capacity are needed.

The rate of map production is a combination of three factors: equipment, procedures, and map design. To determine a valid estimate of production rate, both equipment and procedures require testing and evaluation. The testing should be done while producing maps similar to those to be produced in future operations. The equipment to be used had not been tested under full load conditions over a significant period so a simple "load" portion of the test would provide initial estimates of hardware reliability and productivity. The ratio of hardware "up-time" to "down time" would provide a reasonable estimate of hardware reliability. The rate that maps were read from tape, rasterized, and plotted would result in a measure of hardware productivity.

Rate of production is equally affected by the procedures used to control incoming requests, generation of an image, quality assurance, and delivery. Introducing new technology into map production requires redesign of the entire map production and distribution system. The ability to store maps as digital images on tape and create paper maps on demand precludes the need for warehousing large numbers of maps. Maps are created if and when there is a need, thereby eliminating wasted time and materials. The "on-demand" creation of a map requires a job control system that routes a request from the user, to the plotter, and back to the user quickly and accurately.

Map design is also factor influencing production rate. The number of lines on a map affect the time to read and rasterize the map from tape. The maps used in the test were from current census operations: the 1986 Censuses of East Central Mississippi and Central Los Angeles County, and the 1987 Census of North Central North Dakota. The design of these maps is similar to what is planned for future operations.

TEST OBJECTIVES

Accurate estimates of total production require testing of both equipment and procedures simultaneously. In order to gather all the facts needed for effective planning, a set of objectives were formulated:

- Operate an electrostatic plotter for a specified period under production conditions.
- Determine a realistic map production rate to validate assumed production rates used in planning.
- Develop and test a map request system.
- Develop and test operator, control, and quality assurance procedures.
- Provide experience to help refine staffing requirements for future production units.

TEST BACKGROUND

To produce maps for field work during the 1990 decennial census there will be twelve regional map plotting sites around the country, along with facilities at Census Bureau headquarters and the Data Preparation Division in Jeffersonville, Indiana. These fourteen sites will produce maps requested by over four hundred district offices. The electrostatic plotter production test simulated a regional plotting site in full production with the responsibility of providing maps for a number of district offices. The test was designed primarily to test the production capacity of an electrostatic plotter, and secondarily to test the control of work flow in a production setting. By simulating the work flow at a regional plot site in addition to a simple "load test" on the hardware, it was possible to gather valuable information for improving training procedures, production procedures, and quality control procedures, and for determining the space and equipment requirements of future operations. The site and staff for the test were chosen to approximate as closely as possible the conditions that would be present during an actual census operation. The site chosen was the Laguna Niguel Processing Office in Laguna Niguel, California. The Laguna Niguel Processing Office had been established to process the data collected during the 1986 Census of Central Los Angeles County. The site was selected because it best met the combined requirements of equipment, staff, and space necessary to simulate a production environment. Sufficient staff was available at the processing office to participate in the test since the processing of the 1986 Census of Central Los Angeles County was nearly completed. The majority of the staff there had very minimal knowledge of census geography, cartography, and computer operations. Using an inexperienced staff would more closely simulate a 1990 census production operation. The total staff for the plotter test consisted of fourteen people, who were divided into two groups of seven each. The first group worked the day shift (7:30 am, to 4:00 pm) and the second group worked the night shift (4:00 pm to midnight). Each shift included one supervisor, one assignment clerk, one plotter operator, two quality control technicians, one multi-purpose staff member, and one geotechnician. The multi-purpose staff member aided or substituted for the plotter operator, assignment clerk or Q.C. technician. The geotechnician was a Geography Division staff member from headquarters who performed both active and evaluative roles.

The major equipment requirement was an electrostatic plotter with a controller. This equipment was in place and operational at the Laguna Niguel Processing Office before the test. The controller read a 1600 bpi magnetic tape that was created on the Census Bureau's Sperry mainframe computers with a combination of software written in house and provided by the plotter manufacturer. The digital map stored on the magnetic tape was in a vector format and had to be rasterized. Conversion to raster format was done by the controller, vector by vector, as the tape was read. The number of files on each tape was limited by the complexity of the map images stored. In this test, the number of map images per tape ranged from three to sixty-two.. All tapes were generated at the Census Bureau's headquarters in Suitland, Maryland and shipped to the Laguna Niguel Processing Office along with lists of files contained on the tapes.

The procedures were written to function both in the test situation and eventually in an actual production environment in the regional plotting sites. Because there were several ways map requests were completed, a special management system was designed to maintain up-to-date information about all requests in the system. The management system comprised a set of control logs held by the assignment clerk. The control logs were organized by district office, one for each district office requesting maps. The control logs were used to record the progress and disposition of each map requested. The request form itself became a transmittal slip with information continually added to the form as it progressed through the process. At certain points in the process the assignment clerk made a photocopy of the request form and inserted it into the appropriate control log, replacing the previous version. Control log updates were made following the plotting of maps, assurance of quality, application of correction procedures, and disposition of the request. Using this method, the control logs provided an audit trail of every request passing through the system.

The most difficult procedures to write were those for the quality control technicians. These technicians were temporary employees for whom judging cartographic products was, for the most part, a new experience. In written procedures and in training, the emphasis was on usability of the map. If the map had a small error, but was still usable in the technicians' opinion, the map was accepted. If there were one or more errors that made the map unusable, it was rejected. If a map was rejected, the quality control technicians were to make a basic judgement concerning the source of the error in order to aid in correcting the map. Maps with errors made at the plotting stage could be replotted almost immediately; however, maps with errors introduced at the tape generation stage had to be recreated. In the latter case, a request was sent to headquarters for a new tape to be made and sent to the plot site. The tape replacement process was simulated by the geotechnician supplying a replacement tape after an appropriate delay.

TEST EXECUTION

The test spanned ten working days, each comprising two shifts, for a total of one-hundred sixty hours of potential production time. Training for the test staff took place on a Friday afternoon and the test began on the following Monday morning. Requests for maps were generated by the geotechnician who supplied them to the assignment clerk on a flow basis, simulating incoming orders from several district offices. After receiving a map request, the assignment clerk determined the location of the map by tape number and file position. The information was recorded on the request form and the form delivered to the plotter operator. The plotter operator plotted the maps as they appeared on the map request form by mounting the appropriate tape on the controller, advancing the tape to the proper file, and plotting the requested number of copies.

For purposes of the test, some files with known errors had been included without the operators' knowledge. If a tape could not be read by the controller, a request for a new tape was sent to headquarters. The plotter operator recorded the time required to read the tape file and plot the map. Time also was recorded for non-production time such as start-up and shut-down, routine maintenance, problem resolution, and staff breaks. When all the maps on a request were plotted, the operator removed the roll of maps from the plotter, attached the request form, and delivered the roll to the assignment clerk. The assignment clerk updated the control log to show the maps were plotted and transmitted the roll of maps to the quality control technicians. Once in the quality control area the technicians unrolled the maps, cut them into individual sheets, and checked each sheet for image quality and for the presence of major content errors. If all maps were accepted, they were packed and placed in a bin for shipping to the appropriate district office. If maps were rejected during the quality check, the quality control technician made a judgement as to whether the problems were introduced at the plotting stage or the tape generation stage. The control log was updated with results of the quality check. The quality control technicians also recorded starting and ending times for processing each map.

RESULTS

Table one shows the numeric results of the test. The overall rate of production was 80 maps per eight hour shift. It is difficult to make any estimates of a time unit lower than the shift level because of the relationship between maps plotted, sheets plotted, and tape reads. A map may be divided into multiple sheets. In this test, the number of sheets per map ranged between one and six. Each map was created after the controller performed a tape read. With a single tape read the controller read in the entire digital map from the tape, rasterized it, and plotted it on one or more sheets. If more than one copy of a map was needed, the duplicate copies did not require the tape to be read again because the information was already in the controller memory. For example: assume that the plotter operator received a request for four copies of a particular map and the map was divided into six sheets. The tape would have been mounted, and the digital map read into the controller and rasterized, taking approximately ten minutes. When all the information had been read from the tape, the plotter would have created the first map by plotting the six individual sheets. The plotting taking approximately two minutes. The plotter operator would have then programed the controller via a small keyboard to plot three additional copies of the map. Eighteen sheets (three copies of a six-sheet map) would have been plotted taking six minutes. Total elasped time would have been eighteen minutes, resulting in four maps and twenty-four sheets plotted. The most time consuming step is the tape read, therefore, the rate of production is dependent on how many copies of each map are plotted per tape read.

TABLE 1

	District Office			
	Mississippi	North Dakota	Los Angeles	Total
Number of maps plotted	373	894	340	1607
Number of sheets plotted	373	3570	340	4283
Amount of time for tape reading, rasterizing, and plotting (in minutes)	1899	4125	1480	7504
Quality control (minutes)	292	2107	250	2649
Total number of tape reads	196	293	168	657

Average maps per shift:	80	maps
Average sheets per shift:	214	sheets
Average Q.C. time per shift	132	minutes

The Mississippi maps had the greatest density of linework; the North Dakota maps had the largest number of multi-sheet maps and the Los

Angeles maps the smallest. The data show that the number of sheets used to display a map is a lesser factor affecting the reading and plotting time than is the number of features displayed on the map, since the Mississippi maps took more time to plot (per map) than the North Dakota maps.

Approximately 75% of the total test period was in production time; the remainder was non-production time, which consisted of meal breaks, staff meetings, routine plotter maintenance, and problem resolution.

Routine plotter maintenance included changing paper, adding toner & replenisher, and cleaning the rollers inside the plotter. During the test, the paper was changed 38 times with an average of 10.5 minutes per change for a total of 399 minutes of non-production time. Not every paper change was a result of the plotter running out of paper. A small number of rolls were damaged or creased and were changed before they were completely used.

During the entire test, 45 hours were spent in quality control. This is about a 1:3.5 ratio between quality control time and plotting time. This ratio shows that one quality control clerk should be able to quality check the output from three plotters.

RECOMMENDATIONS FOR FUTURE OPERATIONS

In an actual production setting, the rate of production is expected to increase as the staff gains familiarity and as improvements are made in equipment, procedures, and map design. Recommendations for future operations are for the most part based on problems encountered during the execution of the test. The majority of difficulties were with the hardware. A significant increase in production can only be achieved by obtaining hardware with some additional features. Features suggested by the plotter test staff along with the evaluation team from headquarters have been incorporated in plans to purchase plotters for production operations. The Bureau of the Census has issued a Request for Information on purchasing plotters built with desirable options not currently available.

Possibly the most important feature needed is the ability of the controller to read a raster format tape. The controller currently in use reads only vector format files and rasterizes the single map file being plotted. The raster image is lost as soon as the next file is read. The ability to save the raster image on tape and load it back into the the controller would save the rasterization time on subsequent requests for the map. Direct reading of a raster image also would allow cartographers to rasterize the map image using a mainframe computer, and use run-length encoding to write the image to a tape. This process would be far more efficient than rasterizing at plot time.

Other suggested features are the inclusion of a header record preceding each map file on the tape, and a programmable controller. A header record would contain the geographic identifier of the map such as MINNESOTA or TRACT 101. The operator would be able to enter the geographic identifier directly into the controller rather than be required to enter a relative position of the file on the tape. The assignment clerk would no longer have to determine and record the position of the file on the tape, saving time and eliminating a potential source of errors. The present controller allows commands to be entered only after the preceding command has been completed. The Census Bureau has suggested that the controller accept up to ten instructions at once and execute them in sequence. This would allow a single plotter operator to operate several plotters at once.

The possibility of using color plotters is also being investigated. Large format electrostatic plotters have been developed with full color capability. These plotters have slightly faster rasterization time because of improvements in processor design; however, the actual plotting time is increased. Most color electrostatic plotters use a multi-pass method. The paper passes over the charging head through the first toner for the first color, the paper then is rewound into the machine for a second pass over the charging head and through the second toner. This process is repeated for colors three and four. Plotting a two-color map results in the map making two passes through the machine, and therefore takes approximately twice as long as a single color plot. A full four-color plot takes approximately four times as long as a monochromatic plot. Because of the time constraints associated with the production of maps for field use, many maps would still be plotted in a single color, with multiple colors used only for special use or very complex maps.

CONCLUSION

All the objectives of the electrostatic plotter production test were achieved. An electrostatic plotter was operated for two shifts each day for a two-week period. This time span was sufficient to simulate production conditions. Over the two-week period, an average map production rate of 80 maps per shift was achieved. A 100 map-per-shift rate is realistic with improved equipment and procedures. A map request system was developed and used. Including a number of modifications, the system is usable for future operations. Plotter operator, control, and quality assurance procedures were developed. Recommendations from the test staff helped refine these procedures. Experience with staffing levels was obtained and have resulted in staffing recommendations. Recommendations were made for plotting sites with a number of different configurations.

The 1986 Electrostatic Plotter Production Test provided a basis from which to make (1) a reasonable estimate of the production rate of a large format electrostatic plotter, and (2) recommendations for future procedures, equipment, and staff. Although the rate of map production will change with the introduction of new demands on the system, improved equipment, and changes in procedures and staff, the results of the test have provided a reference point from which system evaluation may be judged.