Eurocarto 7, Enschede, The Netherlands, 1988

REMARKS ON THE ECONOMICS OF COMPUTER-ASSISTED CARTOGRAPHY AND GEOGRAPHICAL INFORMATION SYSTEMS

Wolf-Dieter Rase
Bundesforschungsanstalt für
Landeskunde und Raumordnung
Postfach 20 01 30
D-5300 Bonn 2
Federal Republic of Germany

Abstract

The introduction of computer-assisted techniques for mapmaking resembles the transition from handicraft to industrial production. The cost of labour force is substituted by investment costs for machinery. The economics of computer-assistance in cartography depends on four main cost factors: hardware, software, data base acquisition and personnel. To justify the investment a certain "critical mass" of production requirements - overall number of maps and graphics, number of maps of the same type and from the same geometric base files - must be present. The discussion of economics cannot be restricted to the purely pecuniary issues. The application of data processing in mapping improves the message transfer by providing cartographic techniques not feasible with manual methods. Although these effects do not cause an immediate financial kickback, they have a long-range impact on the quality and acceptance of spatial planning.

1. Necessity of economic analysis

Until some years ago it was taken for granted that the introduction of data processing techniques will generally lead to an overall reduction of cost, independent of the application area. That picture has changed in recent years: the economic aspects of computer application in mapping and GIS gained more attention. The discussion was stimulated by different causes, among others:

- spectacular pitfalls with the introduction of information systems in pubblic agencies,
- lower budgets in local, state and federal government,
- a more sober approach to EDP,
- awareness of the social implications of rationalization.

To allocate funds for data processing (hardware, software, brainware) the economic advantages of the innovation must be clearly proved in advance. The controlling bodies might also take the freedom to check the promises after a while. Thus it is certainly useful to have a closer look at the economics of computer-assisted map production and geographical information systems. Although each case is different, dependent on application area, status and financing of the organization, equipment and staff (to name only a few), there are some rules and objectives generally applicable.

In this context the terms "computer-assisted cartography" and "geographical information system" should be taken as synonyms. In a production environment (not necessarily in academic research) the two items are so closely intertwined that a clear-cut separation is not reasonable, and, in most cases, not possible. A GIS without mapping facilities misses the most efficient presentation technique for spatial data. Mapmaking on a larger scale has to be backed by a system for data management and analysis.

2. The main cost factors

The application of EDP in mapmaking is comparable to the change from handicraft to industrial production. The high personnel cost for producing a unit is substituted by investment cost for machines. To recover the investments the cost must be distributed over a large number of units. High volume production leads to a reduction of the proportional cost per unit. In cartographic applications of EDP four main cost factors should be taken into account:

- Hardware: computers and graphical input/output devices.
- Software: operating systems, basic graphics software, application programs.
- Data base: statistical and geometrical data.
- Personnel: systems designers, programmers, users.

The aforementioned factors affect the economics of a GIS in different ways.

2.1 Hardware

To recover the investment in hardware the number of maps and other graphic output should be maximized. To improve the economics the computer system is used for other tasks as well to fill the unavoidable holes. Mapmaking is seldom a continuous production because the flow of requirements cannot be smoothed out all the time. It is the rule, not the exception, that the computer system serves many other functions besides mapmaking, for example data base management, statistical analysis, documentational tasks in numerous forms, simulation and forecasting, administrative work, or textprocessing.

The outlook for the future of hardware costs is quite bright. The trend in the miniaturization of electronic circuits will last for the next few years until the physical limits are reached. Faster processors with more capabilities, memory chips and external storage devices
with more capacity will become available at lower costs. This has also some impact on computer graphics:

- mechanical plotters are replaced progressively by raster devices on several levels of resolution, number of colors, speed, format and cost;

- faster and more intelligent devices and workstations relieve the main computer from basic graphic functions, such as area fill, segmentation, zoom and pan;

- smaller and less expensive computers provide more computing power and storage capacity at lower costs.

The less expensive hardware will enable individuals and institutions to use data processing systems and apply GIS and computer-assisted mapping where it was not feasible until now for economic reasons.

2.2 Software

The investment in software depends on the actual requirements of the institution. The costs are recovered best if as many maps as possible are produced with the same software option or package. It is not advisable to buy or create software to cover all possible requirements. It is more economical to restrict the functionality to the most common cases. The unusual cases are done in the conventional way or with the help of friendly neighbours in public authorities or firms.

The absolute cost of software development will increase because qualified personnel will remain a very scarce, well-paid resource. Besides applying modern software design methods and techniques to facilitate program design, test and maintenance the software cost per map (relative cost) can be decreased, for example by

- extending the life cycle of cartographic programs,
- getting users outside the own shop and distributing the cost over a larger number of users,
- using existing programs, program modules, and subroutine libraries.

The main prerequisite is the portability of the cartographic software. In case of migration to another computer system or the acquisition of a new graphic device the number of necessary modifications to the source code should be minimized, or better avoided at all. The only way to meet this objective is to follow established standards in several respects:

- programming language: The cartographic program should compile on a different computer system and/or a different operating system with out problems, and the results of a computation should not differ. Of the various programming languages Fortran still remains the "lingua franca" of computer graphics, despite its age and obvious deficiencies. The language C became quite popular among system designers, but is not a standard (yet). Modula-2 and ADA will gain more popularity, the first for its elegance and ease of use, the second for the economic strength of its originator.
- device-independent graphic interface: The output to and the input from graphic devices should be organized in a standardized way. If a graphic device is exchanged or added, or the program is ported to another system with different graphic devices, no changes to the program should be necessary. The Graphical Kernel System (GKS) is the first graphic standard adopted by the major standards organizations. Although GKS has its shortcomings, it serves cartographic purposes quite well. Other standards, such as CGI

(Computer Graphics Interface) and CGM (Computer Graphics Metafile) are already in the standardization pipeline and will find their applications in mapping. PHIGS (Programmer's Hierarchical Interactive Graphics System), another standard comparable to GKS, is intended to serve a different constituency, such as highly interactive CAD applications with hierarchical geometric elements.

- database access: Thematic and geometric data are integrated on a thematic map. The access to the thematic and geometric databases should be standardized to avoid program modifications. Unlike the graphic interface there is no standard for data base access. The query language SQL is supported by most databank systems, but SQL is not a standard. It is at least questionable if the relational databank model is adequate for geometric data. Applications of relational databank systems for storage and retrieval of geometric data suffer from severe performance problems (Schek 1986). To be on the safe side an application-specific implementation of the database access is advisable at the moment.
- operating systems functions: Application programs must communicate with the operating system, for example for file access, getting date and time, inquiries about the system environment, and other functions. The programming languages provide a limited assortment of system functions, in most cases only for opening and closing files, or for inquiring file parameters. For sophisticated graphic systems more functions than available on the language level must be provided, such as dynamic memory allocation, timing, support for asynchroneous events and parallelism, and so on. The operating systems provide the functions by subroutine or function calls, but they are system-specific. They have to be modified or eliminated in case of migration. The UNIX operating system seems to be the solution. But contrary to folk wisdom UNIX is not a standard. Neither the command shells nor the system calls nor the utilities including compilers are unified throughout the different UNIX versions and their derivatives and clones. A committee of the IEEE has developed an operating system interface named POSIX to define a set of system calls (Toth 1988). If the standard should be generally adopted, it will take a few years until enough operating systems will provide the appropriate hooks for the system programmer. When POSIX is finally implemented the name of the operating system, the underlying computer and the originator will be meaningless for the programmer and user.

Standards do not come for free. Because they are a general solution by definition they impose more overhead on the individual programmer, the computer system and the organization than a solution specially fitted to the application and the environment. The savings of increased maintainability and portability, together with the faster and less expensive hardware, however, compensate quite well for the increased overhead.

2.3 Geometric Database

The cost for creating and maintaining the database, especially the geometric database, is underestimated in most cases. Experts account 90 % of the overall cost of a GIS for the acquisition and maintenance of the geometric information (Goodchild 1982). Digitizing requires a considerable amount of human labour, even with the help of expensive equipment for automatic line following or raster-to-vector conversion. Although some plausibility tests can be applied visual inspection of the digitized data for completeness and integrity cannot be avoided. Thus the number of maps from the same basic data should be maximized to distribute the cost over as many maps as possible.

The exchange of geometric base files is hampered by the specific requirements of each authority in terms of map scale, resolution, content and regional coverage. Two developments in the Federal Republic of Germany towards a general geometric data base should be mentioned here:

- ALK (Automatisiertes Liegenschaftskataster): the State Geodetic Surveys are converting the cadastral records into digitial form, including the cadastral maps. The parcel geometry (coordinates and topo logy) can serve as the base for a hierarchy of digital boundary networks used in spatial information systems (Haag, Köpper 1987).
- ATKIS (Automatisiertes Topographisch-Kartographisches Informationssystem): the topographical maps (scale 1 : 5000 to 1: 200 000) will be based on a digital terrain model. The DTM as well as the data for non-topographical map features can be used for other purposes than making topographical maps (AdV 1988).

It will take at least another ten years until boundary networks are available from the ALK project. In face of the immense amount of work necessary to get ATKIS going, for example for converting the base maps, it is presumptuous to expect results before the turn of the century. In the meantime the requirements must be fulfilled by application-specific ad-hoc digitization. To facilitate the exchange of base files, some basic rules should be observed, for example careful documentation of the base map parameters, proper transformation procedures for the coordinates, or the recording of registration marks.

2.4 Personnel

The lack of qualified personnel on all levels, from system designer to operator, from decision maker to user, is the main reason for failures and inefficient operations. The qualification of the personnel has to be brought on the same level with the capabilities of the hardware and software. Educational programs must be established to improve the qualification of the available manpower. Hiring additional personnel with special knowledge might be necessary.

Personnel is the factor where the analogy with classic rationalization - replacement of labour force by machines - is not longer valid. I am not aware of any case where the overall number of cartographers has been reduced due the introduction of computer assistance for mapmaking. The impact of data processing on the structure of the cartographic department as well as on the qualification of the individual, however, cannot be denied. The number of persons doing clerical work, such as drafting or mounting, decreases in favour of map designers and DP specialists. It is mandatory nowadays for a professional cartographer to obtain a certain amount of training and experience in data processing. The computer is a tool exactly in the same sense as a ruler, a compass, or an ink pen. The use of the cartographic software available at the own institution is the minimum requirement. The fluent command of a programming language may not be necessary, but it certainly helps. In any case the cartographer should be able to assess the economic advantages and disadvantages of data processing in a specific situation to select the appropriate solution.

It should be always kept in mind that the innovation cycles of hardware, software and personnel differ considerably in time. Processor speeds and memory capacities, constant cost assumed, double every two years. Approximately every five years a novel hardware concept emerges. It takes five to ten years until the hardware improvements are reflected by the improvements in software. But ten to twenty years are necessary until our educational system is able to provide the adequate qualifications.

Related with personnel is the problem of uncritical and erroneous application of mapping programs. Because cartographic software is generally available (each statistical package has mapping options) persons without training and knowledge of cartographic principles are able to produce thematic maps. Thus the environment is polluted with bad, meaningless, misleading and unusable graphic output, which hardly deserves the name "map". If the rule-based, knowledge-based or expert systems now in development for cartographic applications will be a cure to this disease is uncertain. Nevertheless it is beneficiary to take a closer look at AI applications in cartography.

3. Non-pecuniary factors

Strict pecuniary economics are only one side of the coin, besides the fact that not all financial implications can be foreseen. It is a good rule-of-thumb to think twice about the introduction of computer-assisted techniques if a straight back-of-the-envelope calculation does not reveal an economic advantage of at least an order of magnitude. Experience shows that in reality many additional problems may occur, for example late delivery of software products, technical problems with devices and media, lack of user acceptance or even sabotage, or more trivial things such as missing documentation or manuals in a foreign language. Such unexpected events can turn projects without sufficient safety margins into failures.

Another facet is the improvement of administrative services without any immediate financial kickback, but long-range consequences. Inadequate information of the political decision-makers or the general public, for example, may lead to counteractive initiatives. Because these initiatives are located outside the usual political and administrative channels and procedures, they cannot be controlled in the established fashion. Maps play an important role in the information about regional planning on all levels. If maps can be produced with lower costs, they will be used more often to prevent such obstacles.

Non-pecuniary benefits of computer-assisted techniques consist also in the possibility to improve the transfer of the cartographic message. The map designer is able to optimize the visual image for a specific target group at marginal costs, for example by

- varying the class intervals for a choropleth map, or the scale factor for proportional symbols,
- selecting alternative thematic or visual variables, or different cartographic representations,
- using "difficult" map designs.

The latter point illuminates quite well the new perspectives opened by computer assistance in cartography beyond the pure pecuniary aspect. Many mapping techniques can be found in cartographic handbooks and trade journals, which are used very rarely, even though they have an outstanding capability to get the message through. Examples are

- multivariate maps: choropleth maps with two or three variables represented by different base colors or shadings; proportional symbol maps with different graphic variables (size, color/shading, form/orientation).

- "speaking" proportional symbols, such as human-shaped polygons to represent population figures,

- cartographic anagrams (cartograms): the two dimensions of the map are used as graphic variables; the deviation from Euclidean space has a surprise effect which can be utilized to transmit the message;

- set operations on geometric data (map overlay): intersection of line and boundary networks, calculation of geometric sets; the new spatial units based on Boolean operations serve for extending the data base or the evaluation of planning alternatives;
- perspective drawings: bird's-eye views of the topography or buildings; 3D representations are especially useful for an audience not used to read 2D maps;
- computer-generated animation to depict spatial processes over time, to simulate a walk through a planned urban quarter or a flight over an imaginary landscape.

The techniques could not be applied on a large scale, because their realization by conventional methods was too expensive. The computer provides the necessary improvement in economics to make them feasible for routine use.

4. Conclusion

Computer assistance improves the economics of thematic map production if the "critical masses" for economic utilization of hardware, software and the geometric data base are present. The economics can be further improved by multiple use in several respects. The main bottleneck for DP applications in mapping seems to be the qualification of personnel, not only in the DP center and software development, but also in the cartography lab and the research department. The educational system begins to provide the necessary qualifications. Educational programs and on-the-job training have to be established for the staff members who have already gone through the system. On the other hand software developers should improve the user interfaces and the manuals in a manner that the familiarization with a system can be kept as short as possible. Finally it is hoped that the improvement of economics of GIS and mapping has a positive effect on both the quality and the acceptance of spatial planning.

References

AdV (1988), Amtliches Topographisch-Kartographisches Informationssystem (ATKIS). Das Vorhaben der Landesvermessungsverwaltungen zum Aufbau Digitaler Landschaftsmodelle und Digitaler Kartographischer Modelle. Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland.

Haag, K., Köpper, B. (1987), Die ALK-Grundrißdatei als zentrale Datei eines bodenbezogenen Informationsssystems. Zeitschrift für Vermessungswesen, H. 9, September 1987

Goodchild, M. (1982), Accuracy and spatial resolution: critical dimensions for geoprocessing. Douglas and Boyle (ed.), Computer Aided Cartography and Geographic Information Processing: Hope and Realism. University of Ottawa.

Schek, H.-J. (1986), Datenbanksysteme für die Verwaltung geometrischer Objekte. 16. Jahrestagung der Gesellschaft für Informatik, Berlin 1986. Informatik-Fachberichte 127, Springer-Verlag

Toth, B. (1988), POSIX compliance. Computer Technology Review, Vol. VII, No. 4, April 1988

Rase, W.-D. (1986), Rechnergestützte Zeichnung von Karten für die Raumplanung. Symposium "Digitale Technologie in der Kartographie", Universität Wien 1986.