Digital map technology

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The development of smart cars and smart highways calls for the integration of highly accurate digital road maps with on-board computers and displays, GPS and RDS/TMC receivers, sensitive geomagnetic compasses and steering sensors. In common with most of the world's automakers, Volvo is committed to research and development in these important areas of intelligent vehicle information technology. Since referencing of a vehicle's position to a geographical location is a fundamental element of many these technologies, Volvo's unique expertise in digital map technology provides it with a significant competive edge for the future.

Volvo is the first automaker in the world to develop its own digital map processing technology for road transport informatics (RTI) applications. The first releases of the company's digital map databases were packaged with the Dynaguide Info System and the Mobiguide system, both of which were introduced in Europe in September 1994.

As the developer of the Dynaguide and Mobiguide systems for Volvo Car Corporation and Volvo Truck Corporation, the Traffic and Transport section of Volvo's Technological Development Department is also the operational unit responsible for the digital maps used in these systems. Dynaguide and Mobiguide provided the immediate impetus for the section to create its own mapping unit in 1993, and to acquire the necessary equipment and software for in-house map production, as well as for processing digital map data obtained from other suppliers.

These two methods of acquiring digital, geographical data - purchasing it when available in the right quality and at the right price, and developing it in-house in the absence of other options - form the cornerstones of Volvo's long-term strategy of ensuring that digital map data will be available for all intelligent vehicle information systems used in Volvo cars, trucks, and buses, as and when required.

Practical application of digital maps

The Dynaguide Info System is a traffic message receiver which processes real-time traffic incident data received via Radio Data System-Traffic Message Channel (RDS-TMC) broadcasts [Note 1]. This information is displayed on a colour LCD in the form of familiar traffic icons overlaid on a digital map. The position of the vehicle is tracked on the display unit with the aid of a Global Positioning System (GPS) receiver connected to the computer processor of the Dynaguide unit. Like the pages in an atlas, map frames are changed automatically as the driver leaves one area of coverage and enters the next, adjoining area.

The initial release of Dynaguide contains maps of Sweden, Denmark, Germany, the Netherlands, Luxembourg and Belgium. Future releases will include maps of the rest of Europe as the RDS/TMC messaging infrastructure is expanded. Other areas of the world, particularly North America, will also be added as RDS/TMC, or a similar messaging system, is adopted. The maps in Dynaguide are a combination of data licensed from the Automobile Association in Great Britain and data produced by Volvo itself.

Mobiguide is a fleet management system consisting of a driver terminal and a central office message workstation. The driver terminal consists of a cellular telephone with voice and data communication facilities, while the central worksta-

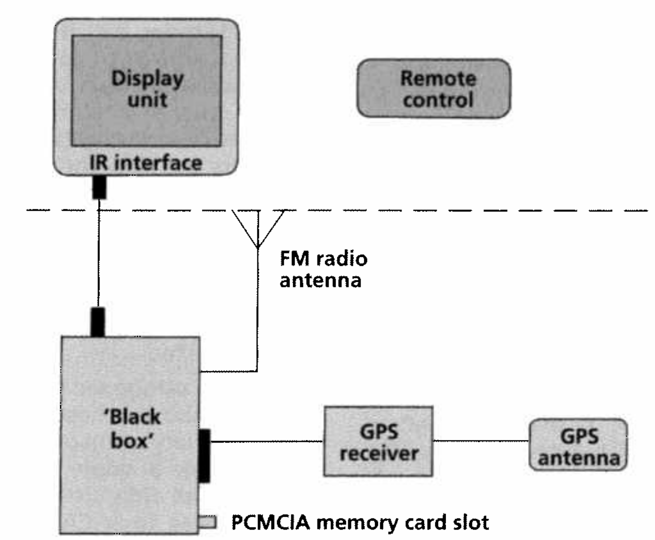

Fig. 1
Schematic diagram of Dynaguide system.

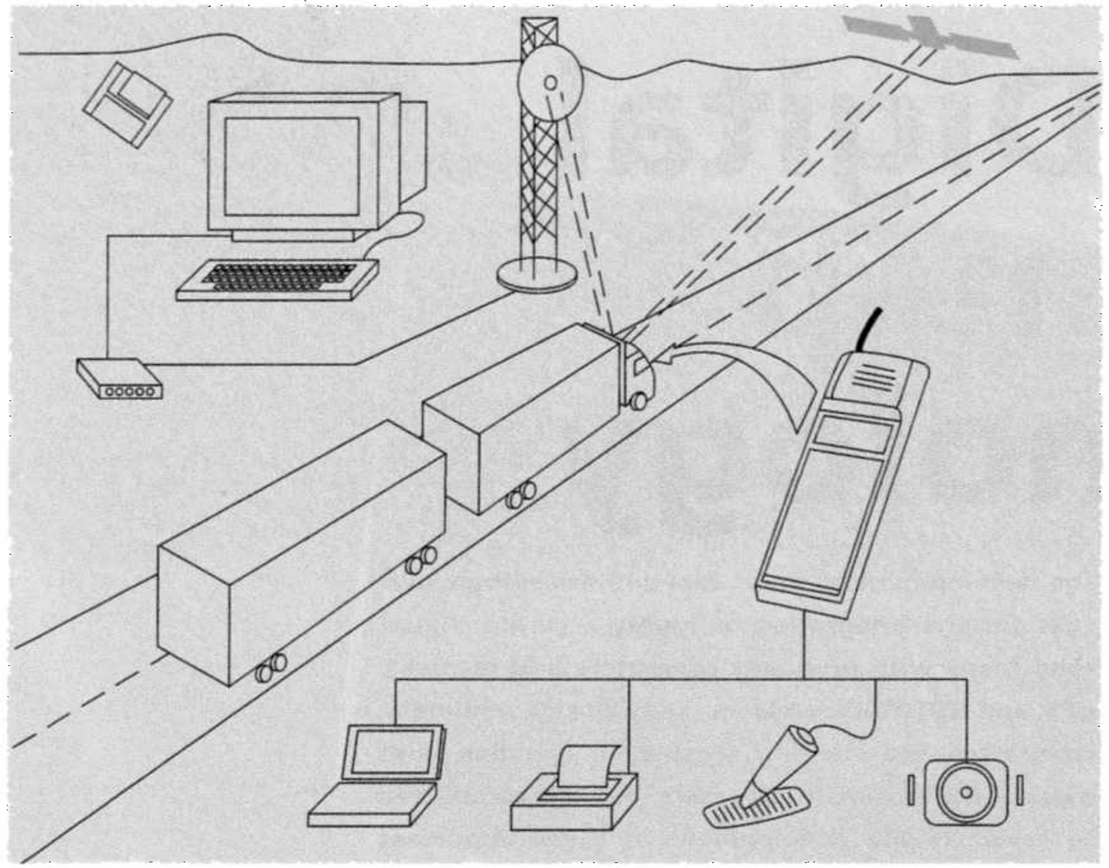

Fig. 2
Principle of Mobiguide system.

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tion is a Windows-based PC. The simplest version of Mobiguide is used to exchange messages between the central workstation and distributed cellular phone terminals.

The exact position of the terminal user can be displayed on the workstation monitor by adding a digital map to the workstation and a GPS receiver to the cellular phone terminal. The vehicle's range of communication may be lim-ited to a city or may cover a whole continent. Dynaguide data can also be used in the Mobiguide system. Licensing agreements have been signed with a number of digital map database suppliers to extend the coverage of city regions.

Conventional versus digital maps

Conventional maps - geographical and political - are two-dimensional representations of the earth's three-dimensional features, natural and man-made, and maps and atlases have been used for this purpose for over five hundred years. On a printed map, the graphical representation of the various features must convey the complete information to the reader. The map content and scale, the colour and design of the symbology, the line widths, and the style and size of the text are all carefully selected by the cartographer to project the theme of the map and to present the information - a static view of the earth at a single moment in time - in comprehensible form.

The definition of a digital map is wider, extending beyond the mere representation of a printed map in computer-readable form. On a digital map, the representation of a feature, such as a motorway or a national border, is a combination of its geometry, expressed as a set of coordinate values, and the descriptive attributes which define its particular characteristics (such as the route number or the names of the countries on either side of the border). The visual appearance of the feature is not stored with this information but is determined when a visual output is requested.

Different categories of features may also be chosen, enabling a variety of maps to be created from a single digital database. The data is stored in layers, similar to a CAD drawing; however, it is not necessary to display all of the data simultaneously. As an example, although the Mobiguide maps can display detailed street networks, these can be produced from the same data as that used in the less detailed Dynaguide system.

Creating a digital map

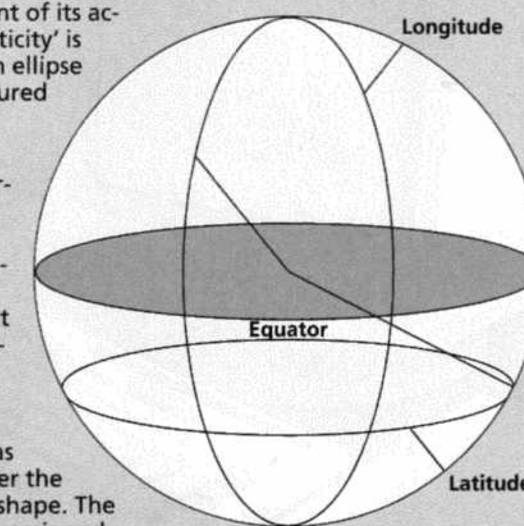
The creation of a map - analogue or digital - is based initially on the same set of design factors, the most important of which is the eventual application. The feature content and geometrical precision of the map are determined largely by the requirements which it must satisfy.

The feature content is a specification of all of the themes and categories of themes to be included in a particular map. For example, a sea chart shows mainly hydrographic features, particularly those which affect navigation, while a road map details physical and administrative land features. A national road map will display the major routes (motorways and main trunk roads), while a street-level tourist map will show all classes of roads, down to walkways and bicycle paths.

Geometrical precision, or the deviation between a measured position on the surface of the earth and the same position on a map, is a function of the map scale, the precision of the source used to prepare the map, and the resolution of the measuring device. Highly detailed, street-level digital maps for on-board navigation, such as the Philips SOCRATES system currently being tested by Volvo in Gothenburg, call for a geographical precision of between five and ten metres. This order of precision is necessary since the on-board systems employ highly sophisticated map-matching techniques calibrated with actual wheel movements and guided by compass. Databases of this type are normally created from low-level aerial photography. Since the systems measure the actual distance travelled, this must agree with the distance given by the digital map so that correctly timed guidance commands can be issued.

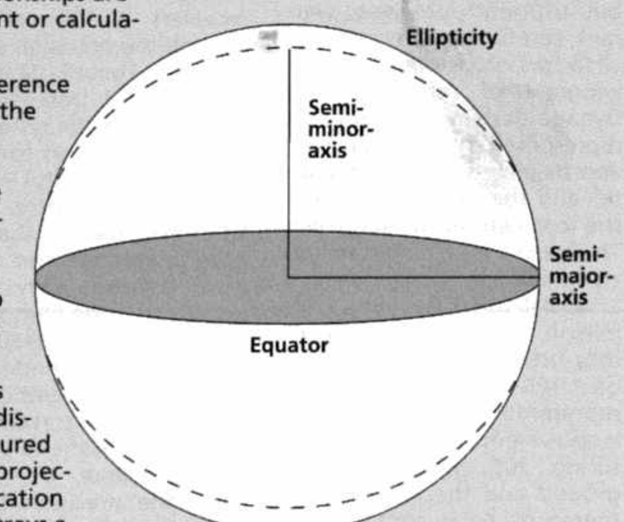
Basics of map projection

Latitude is the angular distance, in degrees, north or south of the equator, measured between the centre of the earth and a point on the earth's surface. Longitude is the angular distance, in degrees, east or west of the Greenwich Prime Meridian. The earth being an ellipsoid rather than a perfect sphere, calculation of these angles must take account of its actual ellipticity. The term 'ellipticity' is defined as the deviation of an ellipse from a true circle and is measured as 1.0 minus the ratio of the minor to the major axis.



Since the earth is almost a perfect sphere with an ellipticity of only 0.003353, the term 'spheroid' is often used in preference to 'ellipsoid'. Since precise spheroid measurement is essential to accurate measurement on the ground, and since the dimensions of the spheroid are affected by geophysical changes, the earth has been surveyed many times over the years to define its spheroidal shape. The resultant spheroids have been assigned names such as Clarke and Everest, after their principal surveyors, or WGS72 and WGS84, after the World Geodetic System surveys made in 1972 and 1984 respectively.

Whenever a new and more accurate spheroid is determined - as in the case of recent satellite measurements - the physical positions of reference points must be changed to reflect the improvement. This is known as a datum shift, a datum being a set of parameters which define a coordinate system and a set of control points whose geometric relationships are known, either by measurement or calculation (Dewhurst 1990).



A map used for positional reference purposes must be referred to the same spheroid as the system which specifies the positions (GPS in the case of Dynaguide and Mobiguide). This is necessary if the maps are to be used for precise measurement. Furthermore, both map and earth must have an identical datum.

All map projections (hundreds of which exist) are subject to distortion of shapes, areas, measured distances and directions. The projection used in a particular application may be chosen because it portrays a selected part of the earth in a visually appealing manner, or because it represents one or more of these parameters more accurately than others.

The Lambert Conformal Conic projection is the standard used for maps covering the whole of Europe.

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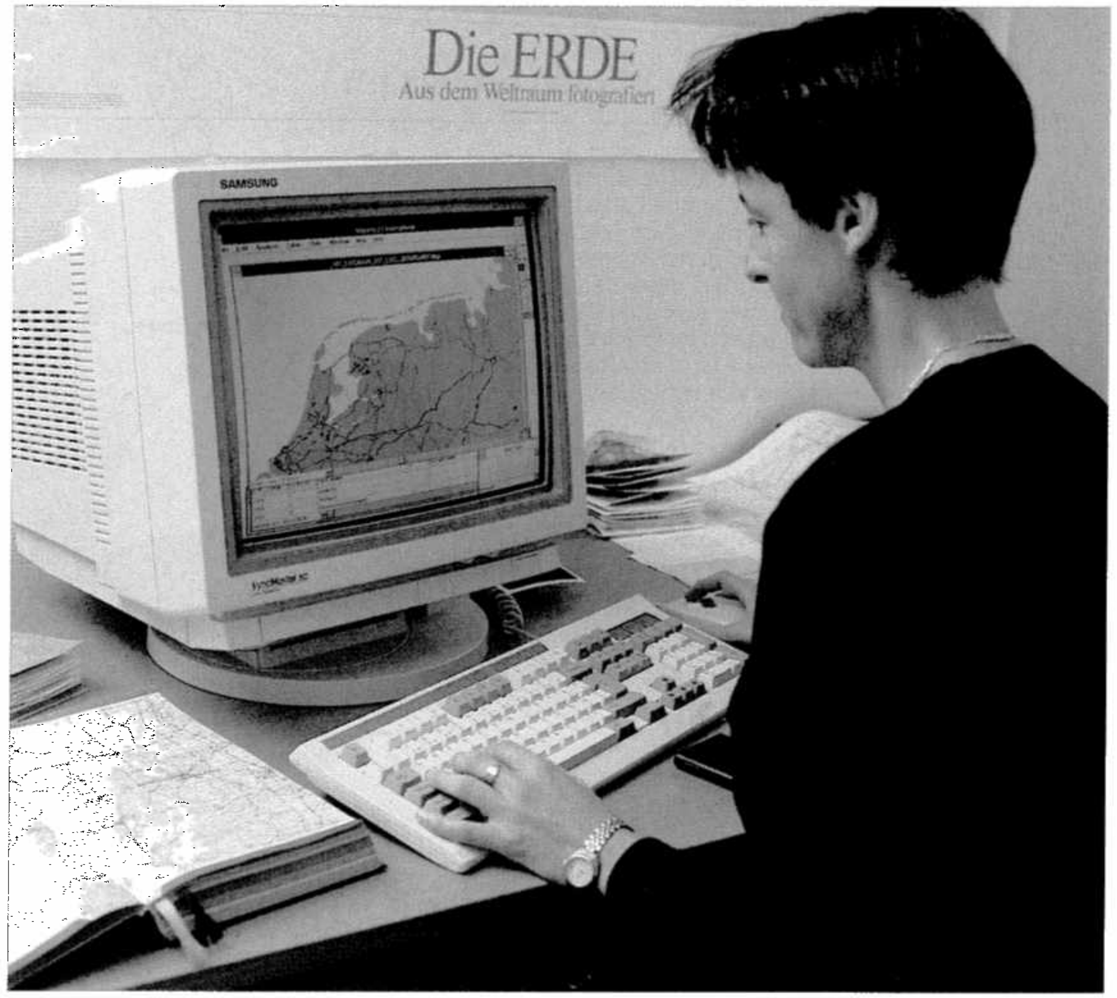


Fig. 3
Map processing is performed on a 48b Windows-based PC.

Mobiguide is a fleet management system consisting of a driver terminal and a central office message workstation.

Dynaguide requires a precision of between 100 metres and 4 kilometres, which is coarse by on-board standards but sufficiently precise to warrant careful consideration of all factors which influence exact geographical referencing. In Dynaguide, a moving vehicle is represented by a circular icon approximately 2 mm in diameter and the object is to keep the icon centred on the road. The scales of the maps displayed in Dynaguide range from 1:100 000 to 1:8.5 million, 1:3.5 million being that most generally used. At the larger scale of 1:100 000, a 2 mm icon representing a moving vehicle is equivalent to an object measuring 200 metres on the ground and the icon should, therefore, be in contact with the road if the precision of the map is within 200 metres. At 1:3.5 million, the icon will corresponding to an object roughly 7 kilometres in diameter. In this case, a precision of less than 4 kilometres will be sufficient to maintain contact between the moving icon and the mapped road.

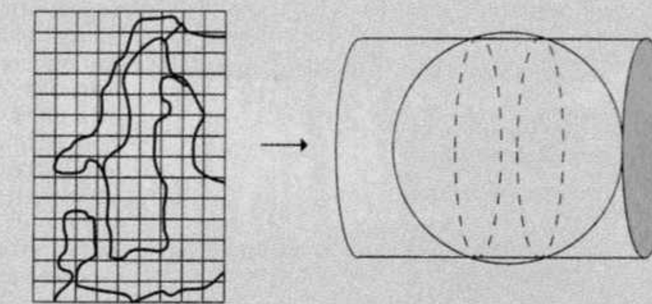
The maximum precision achievable with standard GPS receivers is 100 metres, although the precision achieved by the United States Department of Defense (which owns the satellite system and is the preferred user for reasons of national security) is actually less than one metre. In practice, this means that while other users enjoy free access to the GPS signals, they are denied access to the high precision available to the DoD. Dynaguide and Mobiguide use GPS for position referencing (the actual distance travelled is not relevant since the GPS signal is updated once per second). Since the precision of Dynaguide is well within the tolerance of GPS, and since the precision of GPS rather than that of the digital map database is the limiting factor in Mobiguide, 100 metres has been adopted as the maximum required precision [Note 2].

Map projections

Whether reality is matched with the map (as in route guidance) or the map is matched with reality (as in Dynaguide or Mobiguide), precise measurement depends on conversion of the earth's spherical shape to a flat surface. This conversion, which often involves the use of mathematical formulae, is called a map projection. In projecting a map, the spherical coordinates of latitude and longitude, which define the position of every point on the earth, are converted to planar coordinates. Since these are the positions supplied by GPS, digital maps designed for use with GPS must be referenced to spherical coordinates. However, the maps must also be planar; in other words, they must be projected to enable them to be viewed as 'normal' maps. A knowledge of the fundamentals of map projection, as well as spherical and planar coordinates, is useful in understanding how digital maps are

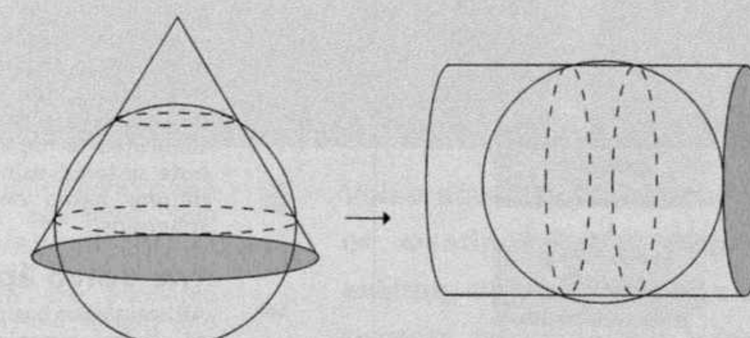
Map projection formulae

Map projection conversion for Dynaguide



Projection: Transverse Mercator Gauss Kruger
Datum: RT90
Coordinates: Metres
Spheroid: Bessel

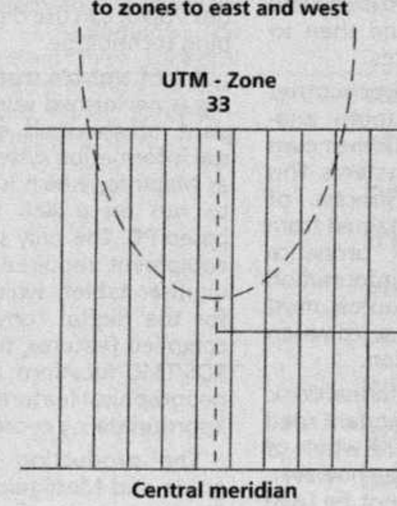
Projection: Universal Transverse Mercator Zone 33
Datum: WGS84
Coordinates: Spherical - Latitude/longitude
Spheroid: WGS84



Projection: Lambert Conformal Conic Standard parallels 42 and 56 degrees N
Datum: WGS84
Coordinates: Spherical - Latitude/longitude
Spheroid: International

Projection: Universal Transverse Mercator Zone 33
Datum: WGS84
Coordinates: Spherical - Latitude/longitude
Spheroid: WGS84

Degree of error resulting from application of UTM Zone 33 to zones to east and west



Data from different projections, datums, coordinate systems and spheroids must be converted to a single set of values to enable the GPS signals to be calibrated precisely and positions displayed accurately on the digital maps. As a further complication, scale corrections must be made so that a single map can be used in Dynaguide. The further the distance from the line of intersection between the cylinder and earth's circumference, the greater the distortion. However, this distortion is eliminated using formulae developed by Volvo.

Scale is correct for exact measurement within three degrees on either side of central meridian.

Errors in scale, resulting in incorrect distance measurement, occur with further progression to east and west.

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All of Volvo's map processing is performed using a standard, off-the-shelf, geographical information system known as MapInfo.

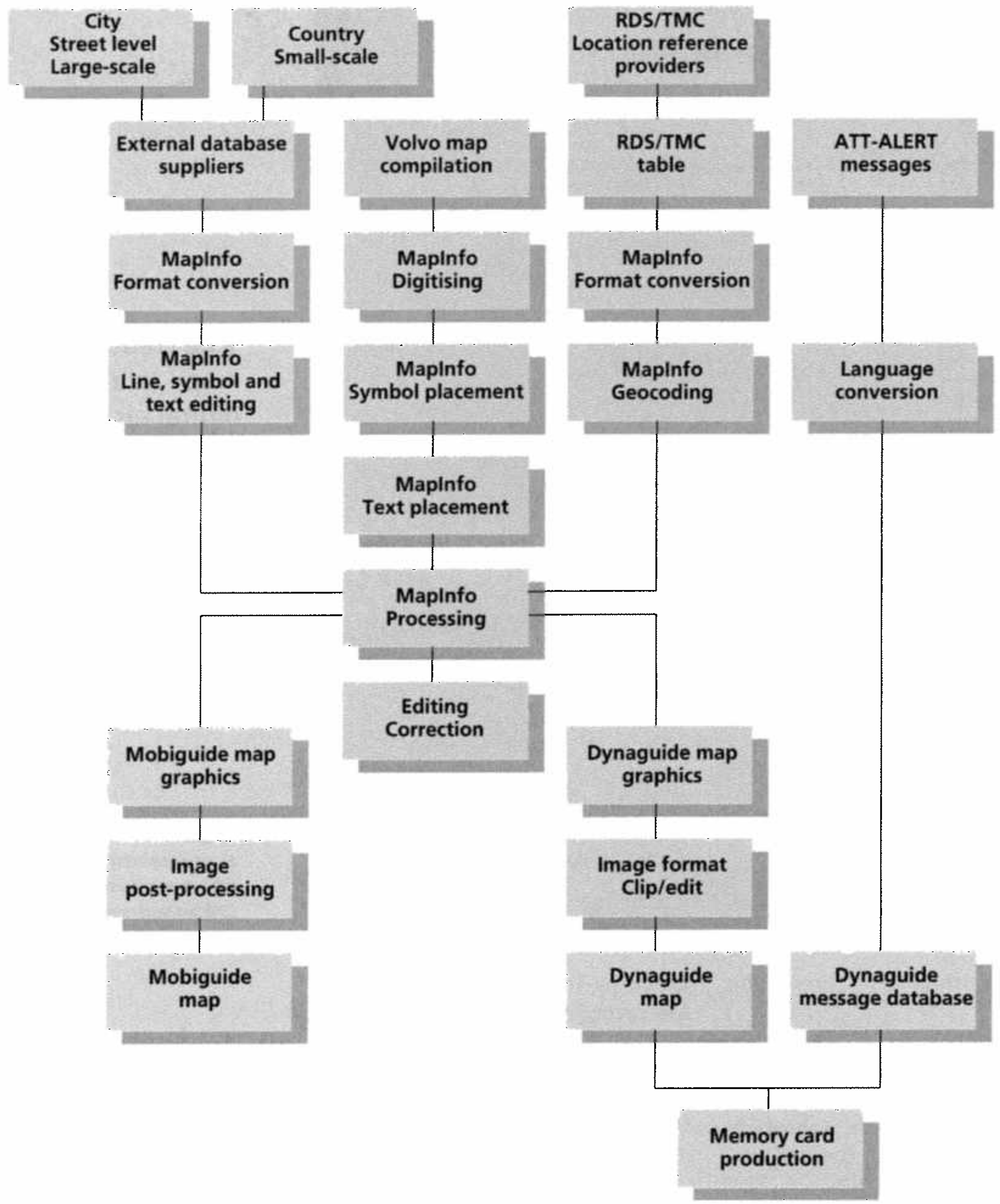

Fig. 4
Digital map production flow chart.

used in systems such as Dynaguide and Mobiguide.

Considered the best system of reproducing contours and areas across the entire country, the transverse Mercator projection known as Gauss Kruger is used by the Swedish ordnance survey authority. The planar coordinate system based on the Bessel spheroid forms the datum known as RT90 (an acronym for 'Rikets Triangulering 1990' or the 1990 Swedish National Survey), which divides the country into a metric Cartesian grid, with the horizontal origin at the equator and the vertical origin at Greenwich. Some Swedish cities also employ local datums; for example, Gothenburg's digital map files are based on its own set of coordinates. In addition, conversion formulae are available for translating local datums to the national datum, and then to spherical coordinates.

Like Sweden, most countries base their maps (both analogue and digital) on their own planar coordinate systems. This complicates the process of combining data obtained from different national ordnance surveys since the information from the various sources must be converted to a common datum and projection.

The Lambert Conformal Conic projection is the standard used for maps covering the whole of Europe. In practice, however, this projection cannot be used in the Dynaguide or Mobiguide systems since the positions cannot be referenced to a Cartesian grid, a function which is necessary to calibrate the map frames to precise reference points on the LCD and workstation screens. For this reason, map data must be reproduced in a more appropriate projection before it can be loaded into Dynaguide. Universal Transverse Mercator (UTM) is the preferred projection because of the orthogonality of its coordinates, while WGS84 is the preferred spheroid since it matches the most commonly used satellite signals.

In summary, a digital map showing the position of a moving vehicle may be represented on any scale. The larger the scale, the more precise must be the location reference. The indicated position must match the latitude and longitude signals received via GPS, while the maps must be calibrated to identical coordinate systems, using the same datums based on the same spheroids.

The Volvo approach

Although the basic techniques of digital mapping and the technologies needed to produce the maps were available twenty years ago, they have only been adopted by national ordnance survey authorities and commercial mapmakers within the last decade. In the past few years, these techniques have become much less expensive, easier to use, more powerful and more widely available. As a result, even the small, specialised mapmaker (which, in this context, includes Volvo) can use digital mapping technology.

All of Volvo's map processing is performed using a standard, off-the-shelf, geographical information system known as MapInfo, which is designed to run on a 486 Windows-based PC. The only specialised equipment required is an A0 digitiser tablet, which is used for the digital conversion of compiled features, such as the RDS/TMC locations and some geographical features, into the appropriate x,y coordinates.

The production of Dynaguide and Mobiguide maps is illustrated by the flow chart in Fig. 4. As the figure shows, map data assembled from external data suppliers or digitised from internally produced compilations are translated into a common format and projection, providing seamless coverage of the entire area to be displayed by the Dynaguide or Mobiguide systems. This vector database is independent of both projection and symbolisation [Note 3].

Symbolisation (line widths, colours, text point sizes etc.) is applied to the vector data during the image post-processing stage to create raster images [Note 4], which are stored on PCMCIA cards in the Dynaguide system and on standard diskettes in Mobiguide. The images retain their spherical coordinate references to enable the GPS signals to be displayed as moving icons. ●

CONCLUSION

Volvo now has the unique capability both of creating digital maps and utilising existing databases from a wide variety of sources, adapting this information to the special requirements of its own systems. Continued research and application development is planned to expand both the coverage and detail of the databases. Additional information, such as variations in road conditions or the availability of services, will be added to the traffic message locations to create intelligent road data-bases.

This work, combined with Volvo's active role in European and international efforts to standardise geographical databases, and with its participation in field trials of on-board navigation systems, places the company in an advantageous position to equip its cars, trucks and buses with the most advanced intelligent vehicle information technologies under development at the present time.

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ACKNOWLEDGEMENT
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NOTES

[1] RDS-TMC is a system of broadcasting traffic information, such as details of roadworks and accidents, over a standard FM radio channel. Messages are defined in coded form using the ALERT-C protocol and broadcast over the narrow FM band. At the receiver, the messages are decoded and played to the driver.

[2] The difference between standard and 'preferred user' precision is due to signal modifications introduced by the US Department of Defense to prevent unfriendly countries from using GPS in hostile ways. Although GPS with local differential correction (otherwise known as Differential GPS) is also capable of a geometrical precision of less than one metre, it requires an infrastructure of ground points in the vicinity of the GPS receiver.

[3] Vector data: The representation of real-world features in a digital graphical database by means of points, lines or surfaces (areas or shapes). The features are stored as x,y or x,y,z coordinates.

[4] Raster data: The representation of real-world features in a digital graphical database by gridded subdivision of the features into pixel form ('pixel' is an abbreviation of 'picture element').