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Applying geospatial imagery technology in transport planning

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Abstract:

Recent advances of geospatial imagery technology, geographic information systems, and computer software and hardware technologies have changed the way geographic analyses are done. Geospatial imagery technology has provided a new basis for urban planning, infrastructure development, environmental assessment, land use evaluation, and detailed design of engineering projects. A new remote sensing satellite system now can offer spatial, spectral and temporal resolutions never before available to the public. With ever-increasing computing power, remotely sensed geospatial imagery data can be easily integrated into GIS or applications which are capable of incorporating satellite data and aerial photography into their data layers. However, to use these technologies effectively, it is important to know the strengths and limitations of remotely sensed data, and to understand which types of imagery and which imagery resolution are suited to particular projects. This paper discusses the recent development and the future trend in geospatial imagery technology and GIS, including remote sensing satellite system, aerial photography and airborne spectrographic imaging, and how best to use them in the transport planning process.

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Introduction

Transport planning projects, such as route planning for new roads or railways, require comprehensive and accurate maps. Often maps are out of date, and resurvey is required combined with aerial photography. In addition, most projects require detailed attribute and position data to be measured and input into geographic databases or integrated with map products. Traditional measurement and identification of attribute data are often carried out by expansive detailed ground survey, or difficult and time-consuming analysis of aerial photographic images. The key elements of the transport planning process are its accuracy and reliability of the data, and its ability to be rapidly collected and delivered. Transport route planning, for example, requires integrated topographic and attribute data, for input to a route optimisation model such as Align3D (Gipps 1992; Gipps and Gu 1997) or GIS-based data models.

Recent development in geospatial imagery technologies provides a solution for an integrated geospatial database. The term 'geospatial imagery technology' best describes technologies including remote sensing satellite systems, aerial photography, airborne spectrographic imaging and softcopy photogrammetry. The geospatial imagery technology has not only reduced the cost of data acquisition dramatically, but also offered high quality of the data to the spatial problems. However, to use these technologies effectively, it is important to know the strengths and limitations of remotely sensed data, and to understand which types of imagery and which imagery resolution are suited to particular projects.

This paper discusses the recent development and the future trend in geospatial imagery technology and GIS, including remote sensing satellite system, aerial photography, airborne spectrographic imaging, and interactive online Internet geospatial images, and how best to use them in the transport planning process.

Geospatial imagery technology

The geospatial imagery technology is emerging into a new era. The next decade promises an explosion in the quantity and quality of global land data available from remote sensing satellite systems, aerial photography and photogrammetry technologies. Some geospatial imagery systems such as the US Mapping Alliance Program (MAP 1998) and The Hyperspectral Environmental Mapping and Applications Paradigm (THEMAP 1998), offer a one-stop shop for customers to browse a wide range of geospatial products and services such as high resolution satellite images, digital terrain models and 3D terrain modelling. Others provide interactive online Internet services for access to archived geospatial images.

Satellite imaging

Satellite imaging has been available on a commercial basis for 10–20 years and the quality and resolution of the images has been steadily improving. The standard 'model' sold currently by SPOT IMAGE, operators of the French satellite, covers an area 60 km square. The digital panchromatic (grey scale) images used to construct digital terrain models (DTMs) are based on a 10-metre mesh (Figure 1), while the multispectral images used for the colour displays are based on a 20-metre mesh.

Figure 1 SPOT satellite image with 20-metre resolution

The new generation of imaging satellites provides spatial, spectral and temporal resolutions that have never before been available to the public (Carlson 1997). Satellites such as IKONOS 1 from Space Imaging EOSAT is expected to produce 1-metre resolution panchromatic images and 4-metre resolution multispectral images in 1998. Other systems are also about to enter service – EarthWatch is building a constellation of four satellites consisting of two 3-metre resolution EarlyBird satellites and two 0.82-metre resolution QuickBird satellites. The EarthWatch constellation will provide complete global coverage, frequent revisit times, a reliable, redundant source of images at different times of day, and a selection of spatial and spectral resolutions. The EarlyBird satellites will be deployed in near-polar, sun-synchronous orbits, which are essential for global coverage, while the QuickBird satellites will be deployed in medium-inclination, non-polar orbits, focussing their highest resolution capabilities on the more densely populated latitudes. Table 1 lists some of the new generation of land imaging satellites.

Many of the new generation of satellites will be able to provide images with a resolution of 1 metre. High resolution images allow the user to identify relatively small objects. For example, in a 3-metre resolution image, cars and trucks can be distinguished. However, there is a trade-off between the area of a data model and its resolution. The quantity of data which has to be handled means that a compromise has to be found between the range and detail. The 10-metre mesh over an area of 60 km square employed by SPOT IMAGE is a compromise that was developed for looking at geological and other resources over a wide area; it offers a broad perspective and is suitable for concept planning. However, higher resolutions over this area, say 1-metre mesh, would produce

Table 1 New generation of land imaging satellites

Country	Satellite system	Launch	Sensor type*	Resolution (m)			Color bands
				P	M	R	
US	Space Imaging IKONOS 1,2	'98, 99	P&M	1	4		4
US	EarthWatch EarlyBird 1,2	'97, 98	P&M	3	15		3
US	EarthWatch QuickBird	'98, 99	P&M	1	4		4
US	NASA Landsat 7	'98	P&M	15	30		7
US	TRW Lewis	'97	P&M	5	30		384
US	Orbimage OrbView-3,4	'98,99	P&M	1	8		4
France	Spot 4	'97	P&M	10	20		4
France	Spot 5 A,B	'99, 04	P&M	5	10		4
India	IRS-1 C,D	'95, 97	P&M	6	23		4
India	IRS-P6 (CARTOSAT-1)	'99	P	2 5			1
India	CARTOSAT 2	'02	P	<1			1
Russia	SPIN-2	'96	P	2			
Russia	Almaz 1B	'98	P&M&R	2 5	4 1	5.4	
Canada	Radarsat	'95	R			9	
Korea	KOMPSAT	'98	P&M	10	20		3
Japan	ADEOS	'96	P&M	8	16		4

* Sensor type: P = panchromatic, M = multispectral, R = radar.

an image 100 times bigger than the 10-metre mesh one. As the resolution of an image increases, the area on the ground represented by each pixel decreases, and the number of pixels increases. In the case of transport route planning, higher resolution should be reserved for more detailed planning once corridors have been identified more precisely. Figure 2 shows a satellite image with 2-metre resolution from the Russian SPIN-2 satellite. Although SPIN-2 failed to make orbit last year, the archived database contains more than a terabyte of satellite and aerial images of most urban areas. A new Russian satellite called Almaz 1B and scheduled for launch in 1998, will operate with 2 5-metre and 4 1-metre resolution

Figure 2 SPIN-2 satellite image with 2-metres resolution

Aerial photography

Generally satellite imaging covers a larger area with lower resolution, while aerial photography provides very high resolution but over limited areas. Unlike maps, with their generalised symbols and colours representing the physical and cultural landscape, aerial photography reveals the terrain as it exists in nature. All buildings, bridges, roads, railways, urban and rural areas, are shown with detail that no map can depict. Aerial photography is, therefore, extremely useful for urban planning, specific site evaluation, regional analysis, land-use surveys, and environmental impact assessment

Advantages of aerial photography over ground-based observation are:

- Aerial photography has better spatial resolution and geometric fidelity than many ground-based sensing methods.
- It offers an improved vantage point and provides a permanent recording
- It has broader spectral sensitivity than the human eye.

SPOT Image Corporation is now offering very high resolution raster aerial imagery for US urban areas (SweetSPOT 1998). This imagery is derived from aerial film sources, which are scanned and ortho-rectified with 0.5, 1.0 and 2.5 metre resolutions. The imagery can be loaded and displayed in accurate position and scale as a backdrop layer in the GIS, allowing the user to trace roads, footpaths, fencelines, buildings and other features from the imagery. Figure 4 shows an aerial photography with 0.5-metre resolution. At this level of resolution, locations of cars and trucks on particular lanes are easily viewed, as are many other small features in the urban landscape.

Figure 3 Aerial photography with 2-metre resolution

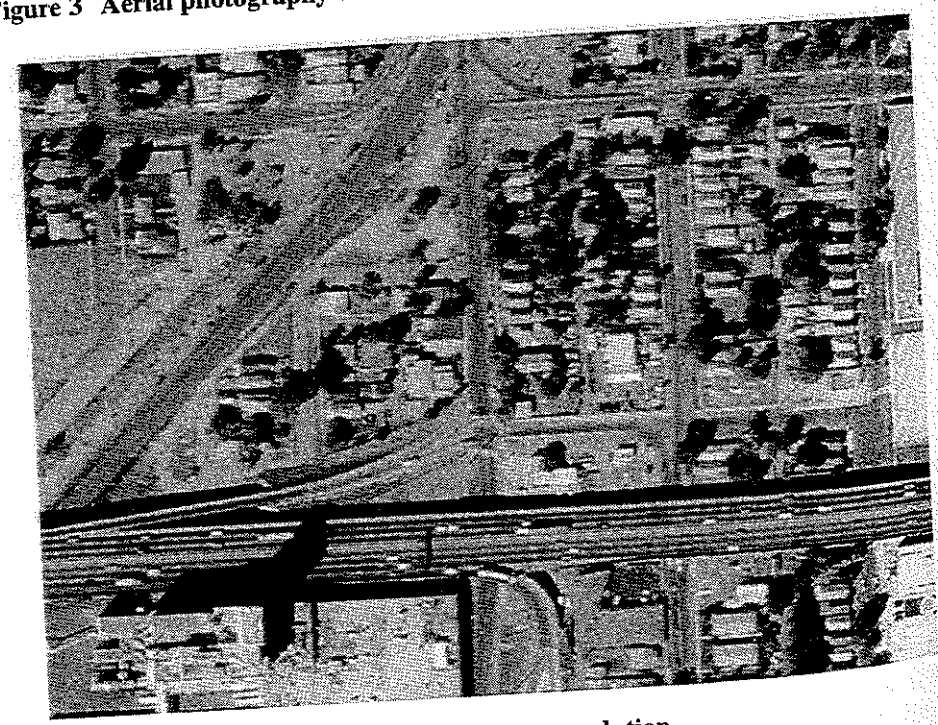


Figure 4 Aerial photography with 0.5-metre resolution

Airborne spectrographic imaging

Satellites and even aerial photography are limited in the nature of data that can be collected and the conditions under which it can be collected. Cloud or haze can be a major problem in the tropics, delaying data collection for months. An alternative or complementary data source is from CASI (Compact Airborne Spectrographic Imager). CASI is an airborne image acquisition system. It is essentially a digital camera, which acquires imagery data at high spatial and spectral resolutions, in the visible and near infra-red region from 400–920 nm, in up to 288 spectral bands. One of the CASI systems is THEMAP which is particular useful in route planning processes. THEMAP is a geomatic system, integrating precision digital imaging spectrometer sensors, soft photogrammetric technology and geographic information systems that replaces:

- Aerial photography, digital camera and airborne video data collection, as well as extensive ground survey, in order to produce accurate base maps (typically two ground control points for THEMAP compared to around 60 for equivalent products per 30,000 ha surveyed to meet high accuracy mapping requirements)
- Extensive ground sampling to measure communities, species, locations, water quality and environmental parameters (compare traditional 1% and 5% forest sampling over say 4 months for 200,000 ha with 4 hours for a 100% survey with THEMAP).

THEMAP produces high resolution engineering, urban planning and management maps which can be used for:

- Residential planning and development, including existing land use
- Urban and regional highway route selection, planning, environmental impact and detailed design.
- Transmigration settlement design and construction management.

THEMAP can process and integrate data from all current and planned satellite sensors, radar-based, visible and near infra-red spectra. However, in order to provide products with a dramatic reduction in ground sampling and survey and at the same time measure environment and resources, the THEMAP system incorporates the CASI airborne imaging spectrometer sensor, developed by ITRES Research Canada. The CASI is a fully calibrated and programmable pushbroom imaging spectrometer that measures radiation from 400–1000 nanometres of the electromagnetic spectrum. The system operates in spatial mode where it collects data in up to 19 bands, and the spectrometer mode which provides up to 288 continuous spectral measurements at 1.8 nanometre intervals.

In order to eliminate extensive ground survey THEMAP integrates a kinematic positioning system on the survey aircraft, using differential global positioning system (DGPS) technology received in real time from regional satellite rebroadcast of the GPS correction signals. The DGPS information is recorded together with accurate pitch, roll and yaw information derived from a digital Inertial Navigation Sensor (INS) and an accurate time reference.

Further, the effects of the atmosphere are taken into account in order to filter out all light except that reflected by the target in question. For the calculation of reflectance, the amount and spectral characteristics of incident light reaching the target are established

through atmospheric transfer modelling. This results in an accurate measurement of true reflectance at the target, allowing further spectral processing. The effect of these corrections is to provide a spectrographic signature which assists identification of the nature of the target.

Softcopy photogrammetry

Softcopy photogrammetry takes a stereo pair of images and uses computer algorithms to identify corresponding points on the two images. By measuring relative changes in position, it can estimate the altitude of different points to produce contour maps, or by draping an ortho-image over the 3D model it can produce views of the terrain viewed from other perspectives. It can be applied to either satellite images or aerial photography.

As a guide, the vertical accuracy of the DTM obtainable from softcopy photogrammetry is approximately the same as the horizontal resolution. Thus satellite images with a 10-metre resolution will produce a DTM with a vertical accuracy of ±10 m. While this may seem coarse to someone with a background in surveying or design, it is important to remember that the DTM is being used to identify low-cost alignments and corridors, not to undertake design. The aim is to locate a road that, in the case of a freeway, will have a minimum radii of curvature of more than 1000 m horizontally and 10,000 m vertically, through hills that may stand hundreds of metres above the surrounding land. In this context the 10 m accuracy represents an additional texture imposed on the general shape of the terrain, and while it may affect the final location of the alignment it will not change the location of the low-cost alignments by more than a few metres.

Softcopy photogrammetry can also be a very cheap approach to the problem of producing DTMs. The low cost means that it may be more cost efficient to create several DTMs for the one study. The first, based on satellite data, is used for concept planning. The second, from more accurate satellite images or aerial photography, can be limited to the area of interest that was determined from a global perspective of the first model. The introduction of a second more accurate model then raises the question of how accurate the first model needs to be. At the moment the number of firms (worldwide) with an established record in creating accurate DTMs from satellite images is very limited, and they have been able to charge high prices for the services. However, if the first model based on the satellite image is not going to be the last model, it may make more sense to compromise on accuracy and cost in the first phase and concentrate on the accuracy in the second phase when higher resolution images provide better data.

Software-based photogrammetry systems such as ERDAS IMAGINE (1998) or VirtuoZo (1997) can rapidly derive a digital elevation model (DEM) and orthorectified imagery from airborne and satellite visible spectrum sensors. The dominant use of VirtuoZo is to create DTMs and Contoured Orthoimages for mapping purposes, or as a data source for proprietary Geographic Information Systems. These packages and many others (US ATEC 1996; Land Form 1997), can integrate a DEM and image data to create a physically accurate, highly informative perspective view. Satellite or aerial images can be superimposed on three-dimensional terrain representations.

Geosptial imagery technology and GIS

A geographic information system (GIS) is a computer-based tool for mapping and analysing things that exist and events that happen on Earth (ESRI 1998). Many GIS software packages have been published over the last few years and many more are expected to be commercially available. GIS technology integrates common database operations such as query and statistical analysis with the unique visualisation and geographic analysis benefits offered by maps and geospatial images. Geospatial imagery technology has been closely related to GIS and it has been provided unique GIS data sources. It collects data in the form of images and provides added power to GIS for manipulating, analysing and visualising those images. Remotely sensed geospatial imagery data can also be easily integrated into GIS software packages such as ARC/INFO, ArcView and TransCAD, or applications that are capable of incorporating satellite data and aerial photography into their data layers. ArcView's new extension Image Analysis (ESRI 1998) is designed to deal with image data from geospatial imagery technology. It provides the tools necessary for ArcView GIS users to take advantage of the wide range of digital image data including aerial photography, digital ortho-imagery and satellite data, perform image visualisation and enhancement, map registration, feature extraction and image categorisation, and simple change detection.

Many features of remotely sensed images make them unique GIS data sources, viz :

- Remote sensing provides a repetitive look over a regional area or a samll area
- Remote sensors can focus in on a specific band width or look at multiple bandwidths simultaneously.
- Remote sensors often record signals electronically and provide geo-referenced, digital data.
- Remote sensing satellites operate in all seasons, cover whole range of the earth image data

Interactive geospatial images on the internet

The recent trend in geospatial imagery technology, GIS and other IT industries has been toward a client/server architecture. Internet-based online service hosted by powerful servers has been the norm. Table 2 shows currently commercial geospatial images available on the Internet.

The online central SPOT catalogue named DALI (1997), from SPOT Image, contains meta-data for all the scenes since the launch of SPOT 1 in 1986, and by most of the 15 direct receiving stations all around the world. In addition, it holds Quick Looks, available for browsing purpose, of all the SPOT scenes received at the Toulouse and Kiruna stations since 1991. In 1995, some of the direct receiving stations started delivering Quick Looks to the central catalogue, on top of meta-data.

Space Imaging EOSAT announced the availability of its Interactive CARTERRA Archive (1997) online browsing system in 1997, which enables customers to view samples of the company's satellite and aerial image products via the World Wide Web, and place product orders. The CARTERRA Archive provides a wealth of Earth imagery and inform-

Table 2 Geospatial images available on the Internet

Satellite systems	Internet server	Images available	Resolution (m)	
			P*	M
Spot Image, SPOT1,2,4	Catalogue DALI http://www.spot com/anglaise/offer/catalo/oc_consu htm	More than 4,000,000 SPOT images and more than 1,000,000 with Quick Looks	10	20
Space Imaging EOSAT CARTERRA	CARTERRA Archive www spaceimage com/browse	300,000 images from satellites and aerial mapping systems	<1–180	<1–180
Landsat and SPOT	ACRES Digital Catalogue http://acs auslig gov au/intro html	Covers images collected from SPOT1,2,3 and Landsat 5	10	20
SPIN-2	TerraServer http://www terraserver com/	2 million sq km of the SPIN-2 imagery 40 km by 160 km 200 km by 300 km	2, 10	

*P = panchromatic; M = multispectral

ation products for a wide variety of uses such as agricultural assessments, environmental monitoring, forestry, land-use mapping, urban planning, transportation management, and disaster management. CARTERRA Archive contains approximately 300,000 images from satellites and aerial mapping systems. Images are available in both black and white and colour and have resolutions ranging from sub-metre to 180 m. New images will continuously be added to the archive as Space Imaging EOSAT's constellation of satellites and aerial mapping systems replenish it with newly collected imagery from Indian Remote Sensing satellites and Landsat satellites and the latest 1 m satellite, IKONOS 1.

The ACRES (Australian Centre for Remote Sensing) digital catalogue system (ACRES, 1997) is a database of archived satellite data acquisitions over Australia from the Landsat and SPOT earth observation satellites. New acquisitions are routinely added to the catalogue within four working days of data reception at Alice Springs and within ten days of reception at Hobart.

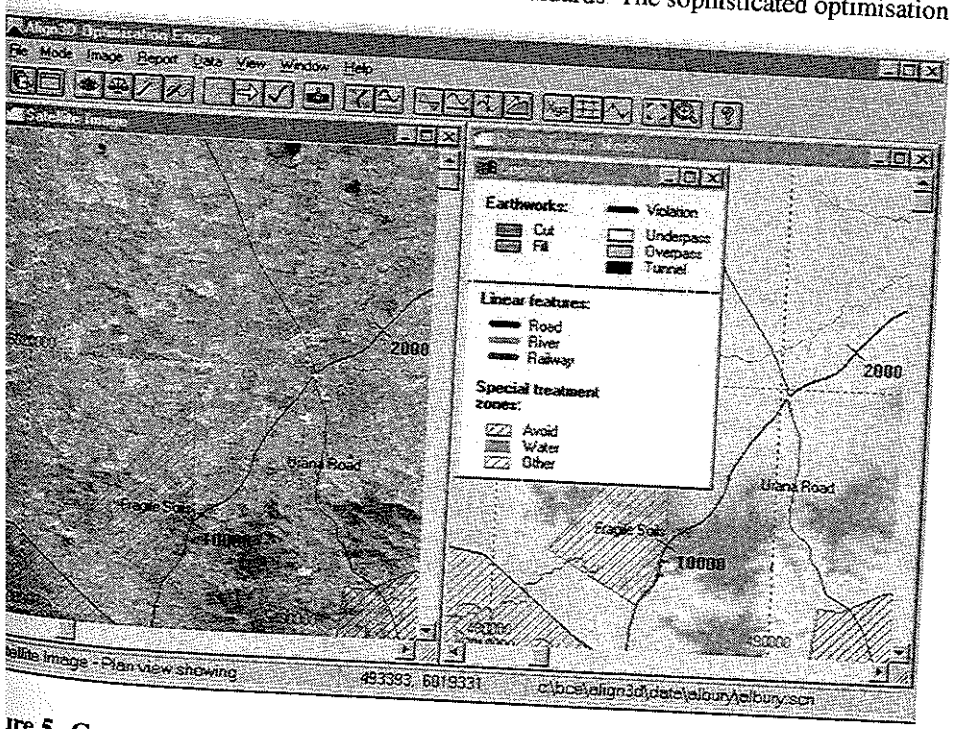
The TerraServer (1997) is the first and largest database of full resolution satellite imagery available on the Internet. The server will contain more than a terabyte of satellite and aerial images of most urban areas of the world from the Russian satellite SPIN-2. The availability of these images gives anyone access to and the ability to purchase images via the Internet. The TerraServer site will allow people to preview the images at full resolution and detail prior to purchasing, which has been a limitation of all previous methods used in purchasing satellite imagery. The Web site allows free online viewing of the images and downloading of the images for a small fee.

Application of geospatial imagery technology

The resolution, quality and computer analysis of geospatial images is offering increased opportunities for transport planners to take a strategic perspective of the transport systems One of the applications is transport route planning. Align3D, for example, a route optimisation package, blends the state-of-the-art geospatial imagery technology and computer techniques. Align3D can substantially improve route planning because it can accurately determine ground topography and optimise the 'fit' of road or rail to landscape. Figure 5 shows a generated route superimposed onto a satellite image or digital terrain model

Interaction with satellite imagery or aerial photography significantly reduces the time to develop terrain plans and minimises community disruption at the investigative stage of a project. New ultra-wideband radar technology is capable of penetrating foliage and allows the terrain to be located beneath dense tree cover, something that could not previously be achieved without expensive land survey

Align3D automatically generates low-cost road alignments that satisfy defined constraints. It generates sets of alternatives, rather than a single least-cost solution, to allow planners the freedom to balance environmental and social impacts against costs for routes using different parts of the corridor. It considers many factors during the optimisation: terrain, geotechnical, linear features (such as roads, rivers, railways and pipelines), zones that require special treatment for social or environmental reasons (such as parks, towns or flood plains), and geometric standards. The sophisticated optimisation



ıre 5 Generated route superimposed on satellite image or digital terrain model

algorithm makes it easy to handle complicated cost functions Optimisation is fast, and once the initial data files are prepared, the entire operation is automatic A single alignment of 100 km of freeway with hundreds of constraints may take only 15 minutes. It consistently produces lower cost alignments than is possible with conventional techniques The potential for savings increases with the complexity of the transport corridor and can exceed 30% in rough terrain

The relationship between these technologies is more complex than a simple one-way flow, and the cycle should be repeated at least once with more accurate and focussed data Data based on 10 m resolution available over 60 km square areas from current generation of satellites, suffices for concept planning, where the aim is to identify the most suitable corridors Provided the images are not intended to be the final source of data it is not important if they are file copies that are a few years old This can mean saving months of project time in tropical areas where persistent cloud cover or haze can delay data collection for months Once the corridors are identified, the cycle should be repeated using more accurate sources of data, such as THEMAP The large-scale satellite images used in the first stage allow the problem to be viewed in context (Figure 5), and provide a relatively cheap means for identifying the most likely transport corridors The more expensive and detailed data gathering techniques employed in the second stage can then be confined to limited areas (Figure 6) In addition to providing the raw material for softcopy photogrammetry, the images can provide the data for the constraints employed in Align3D (Align3D has the tools to enter data by tracing linear features or zone

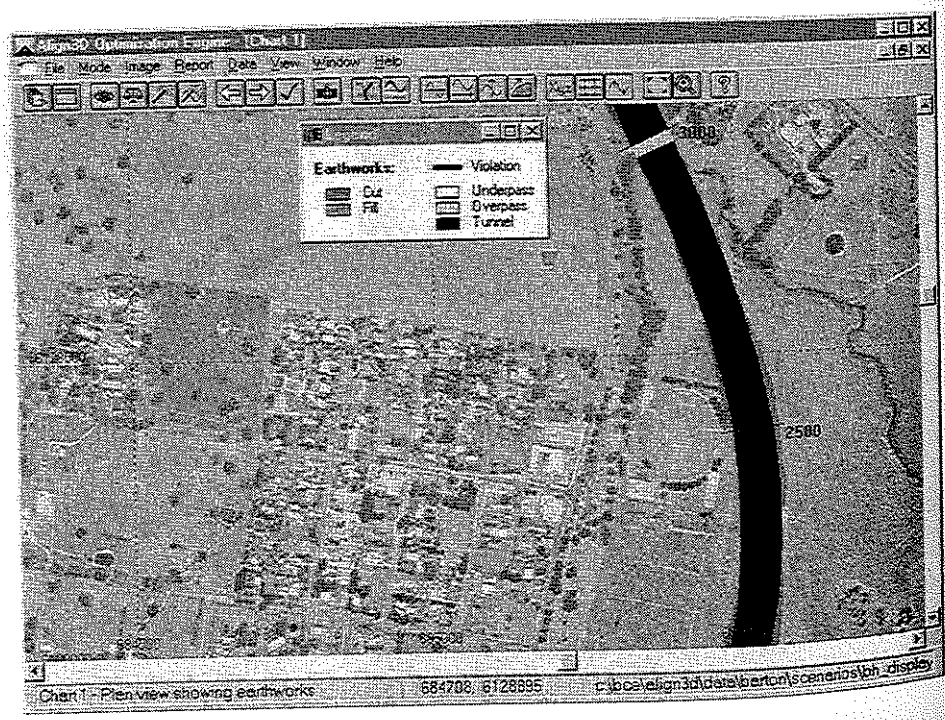


Figure 6 Detailed view of an alignment on aerial photography

boundaries and filling in data dialog boxes) The flows can also be reversed The alignments produced by Align3D can be used to edit the DTM and the image, and the resulting data is used by the softcopy photogrammetry package to create 3D perspective views and flythroughs of the proposed alignment It is also likely that remote sensing techniques will allow the collection of preliminary information about the boundaries of geological areas

Conclusions

Geospatial imagery technology offers spatial resolution, spectral coverage and temporal frequency that have never before been available The advances of geospatial imagery technology, geographic information systems and computer power have changed the paradigm of conventional transport planning New technologies are also bringing the cost of data acquisition within reach of more users The new technologies have enabled transport professionals not only to visually analyse and review transport projects, or make public presentation, but also to use the data for urban planning, infrastructure development and environmental assessment

The Internet technology provides a perfect environment to distribute data Today Internet-based online land image services provide images in both black and white and colour and have resolutions ranging from sub-metre to a few hundred metres This provides a great opportunity for transport planners to preview and purchase the images according to their specific needs An integrated system of geospatial imagery technology, GIS, GPS and Internet technology may become one of the most necessary information management tools of the next century

The application of geospatial imagery technology in transport route planning has shown great benefits in terms of savings of both planning time and cost Transport route optimisation tools such as Align3D integrate geospatial imagery technology and sophisticated optimisation techniques, to automatically generate low-cost route alignments that satisfy defined constraints By using geospatial imagery and Internet technology to gather initial data, Align3D significantly reduces the time, cost and effort of data acquisition Interaction with satellite imagery or aerial photography also allows planners to review, compare and refine the optimised alignment to balance the environmental and social impacts against route costs, and also allows a 'virtual' drive-through of a chosen route for 3D visualisation and public presentation

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