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New technologies for transport route selection

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Abstract

Planning a new road or railway can be an expensive and time-consuming process. There are numerous environmental issues that need to be addressed, and the problem is exacerbated where the alignment is also influenced by the location of services, existing roads and buildings, and the financial, social and political costs of land resumption.

A comprehensive approach to the problem is available through the recent convergence of: geospatial imaging, softcopy photogrammetry, regional significance analysis and alignment optimisation. The first technology is concerned with obtaining low cost data containing far more information than was available in the past. The second two are concerned with extracting from that data, information essential to the planning process. The final technology is about automating the way alignments are generated to produce low cost, high quality routes.

The convergence of these enabling technologies can have a major impact on the way that various jobs are performed – or whether they are done at all. Separately, they can have a major influence on a large number of disciplines, but taken in combination they can change the paradigm of alignment planning completely. By taking tasks that were previously difficult, time-consuming and expensive, and making them easy, fast and cheap, they can change completely the way alignments are planned. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Transport planning; Remote sensing; Geospatial imaging; Geographical information systems; Softcopy photogrammetry; Alignment optimisation

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1. Introduction

Constructing a new road or railway, or realigning an old one can be very expensive, with costs depending on the alignment selected. Costs are increased by long structures, by large volumes of cut and fill, and by unbalanced cut and fill where the discrepancy has to be dumped or borrowed. The cheapest solution would be to follow the natural surface of the land, but this is frequently impossible as the alignment is subject to many constraints such as geometric standards and trying to avoid or negotiate in a particular fashion various features and areas en route. There are numerous environmental issues that need to be addressed to ensure that the alignment does not reduce biodiversity or degrade the environment. The problem is exacerbated in urban or semi-urban environs where the construction of a bypass or the reconstruction of an existing road is also influenced by the location of services, existing roads and buildings, and the financial, social and political costs of land resumption. These complexities make the planning of acceptable high quality, low cost alignments a difficult art.

The first step in producing high quality alignments depends on obtaining suitable data on the terrain, geology, rivers, flood plains, existing roads and town boundaries. In addition, there are issues such as land use and ownership, social and economic impact, and identifying environmentally sensitive areas. Depending on the length of the alignment and the complexity of the physical and social environment, it can take many months to collect the data. The impact of the data-gathering on the local community can be unsettling as local inhabitants attempt to find out whether they will be adversely affected, or to protect themselves against adverse impacts long before the road authority has had an opportunity to develop plans.

1.1. Converging technologies

A comprehensive approach to the problem is available through the recent convergence of a number of technology areas, viz.:

- geospatial imaging,
- softcopy photogrammetry,
- regional significance analysis,
- alignment optimisation.

The first technology area is concerned with how to obtain current data; technologies that are currently available provide access to low cost data containing far more information than was available in the past. The second two areas are concerned with extracting from that data information essential to the planning process. The final technology is about automating the way alignments are generated to produce low cost, high quality routes.

The convergence of these enabling technologies can have a major impact on the way various jobs are performed – or whether they are done at all. Separately, they can have a major influence on a large number of disciplines, but taken in combination they can change the paradigm of alignment planning completely. By taking tasks that were previously difficult, time-consuming and expensive, and making them easy, fast and cheap, they can change completely the way alignments are planned.

A transport route optimisation planning tool – Quantm (then Align3D, Gipps, 1992; Gipps and Gu, 1998; Quantm, 2000) – has been developed at CSIRO Building, Construction and Engineering which combines these state-of-the-art technologies to automatically generate low cost 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. The application of the package on various projects has shown that it can reduce construction costs significantly, cut months or years off the planning process and change the paradigm of conventional transport alignment planning. This paper describes the process from data-gathering to information extraction and alignment optimisation; and presents a case study of the Quantm application. The case study is a full-scale planning study using aerial photography and Quantm to identify the best transport corridors, to generate a set of low cost alignment options within the corridors and to assess the various options.

2. Data sources: geospatial imaging

Geospatial imaging 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 imaging systems such as the hyperspectral environmental mapping and applications paradigm (THEMAP, 1999), 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.

2.1. 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 of 60 km by 60 km. The digital panchromatic (grey-scale) images used to construct digital terrain models (DTMs) are based on a 10-m mesh, while the multispectral images used for the colour displays are based on a 20-m mesh (Fig. 1).

The new generation of imaging satellites provides spatial, spectral and temporal resolutions that have never before been available to the public (Carlson, 1997). The successful launch of Space Imaging's IKONOS satellite in September 1999 marks the beginning of the long-awaited era of 1 m resolution Earth imaging (Space Imaging, 1999). The IKONOS satellite produces 1 m resolution panchromatic images and 4 m resolution multispectral images. After the loss of communication with a high-resolution satellite, EarlyBird 1, at the end of 1997, Earth Watch Incorporated (2000) is now proceeding exclusively with the Quickbird 1 and 2 satellites which will be launched in the near future. The QuickBird 1 satellite features high spatial resolution (1 m panchromatic and 4 m multispatial), high geolocational accuracy, large area collection, and variable imaging collection times. QuickBird 1 will be deployed in medium-inclination, non-polar orbits, focussing their highest resolution capabilities on the more densely populated latitudes.

High-resolution images allow the user to identify relatively small objects. For example, in a 3 m resolution image, cars and trucks can be distinguished. However, there is a trade-off between the area of a data model and its resolution, and a compromise has to be found between the range and detail. The 10-m mesh over an area of 60 km square employed by SPOT IMAGE 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, a 1-m mesh would produce an image 100 times bigger than the 10-m mesh. In the case of transport route planning, higher resolution should be reserved

Fig. 1. SPOT satellite image with 20 m resolution (16 km across).

Fig. 2. SPIN-2 satellite image with 2 m resolution (1.6 km across).

for more detailed planning once corridors have been identified more precisely. Fig. 2 shows a satellite image with 2 m resolution from the Russian SPIN-2 satellite. Although SPIN-2 failed to make orbit in 1997, the archived database contains more than a terabyte of satellite and aerial images of most urban areas.

2.2. Hyperspectral imaging

Hyperspectral imaging is a relatively recent entrant into this arena and offers powerful new facilities. 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. Hyperspectral imaging provides an alternative that can integrate precision digital imaging spectrometer sensors and geographic information systems.

The imaging spectrometer can measure radiation from the electromagnetic spectrum in the range 400–1000 nm, and collects data in up to 19 bands, compared with the three bands that are obtained by scanning photographs. Subsequent atmospheric transfer modelling allows the effects of the atmosphere to be taken into account in order to filter out all light except that reflected by the target in question. The effect of these corrections is to provide a spectrographic signature that assists identification of the nature of the target, and substantially reduces the ground sampling required to identify and map-sensitive communities, species, locations, water quality and other environmental parameters which may be relevant for optimal route design. With the advent of fast synchronised recording of differential GPS signals in conjunction with the image data, geospatial data positioning in these new systems can exceed absolute global accuracies of 5 m or better, without the requirement for image resampling to ground-based maps or ground-control points.

The accuracy of the digital signatures produced by hyperspectral imaging allows one to distinguish between different species of trees, e.g., between different species of mangroves, or to determine algae concentrations in a river. Thus, once ground sampling has been used to create a database by matching the digital signature of a pixel to the vegetation or other ground cover, the system can classify the ground cover at all other locations with the same signature. This facilitates conducting a 100% environmental audit, so unique areas can be readily identified. One of the more common problems with environmental impact studies is that they identify species thought to be rare because previously no one has looked for them with any degree of rigour. Hyperspectral imaging solves the problem of establishing how widespread such species are within the study area. It also simplifies the task of undertaking detailed monitoring of changes produced by the construction of infrastructure.

Fig. 3 displays two examples of airborne spectrograhic imaging. The geocorrected images are derived from a flightline following the Tuggeranong Parkway and part of Black Mountain in the Australian Capital Territory. The left image corresponds to a three-spectral band colour composite, simulating air photography. The right image shows a different mix of bands, where the strong vegetation reflectance in the near-infrared is displayed in red. Ragged edges in the image were created by the aircraft roll correction software.

Geospatial images from any of these sources also provide a dependable source of data with regard to physical features in the study area that can place constraints on the location of an alignment. The images provide more reliable and current information on location of towns,

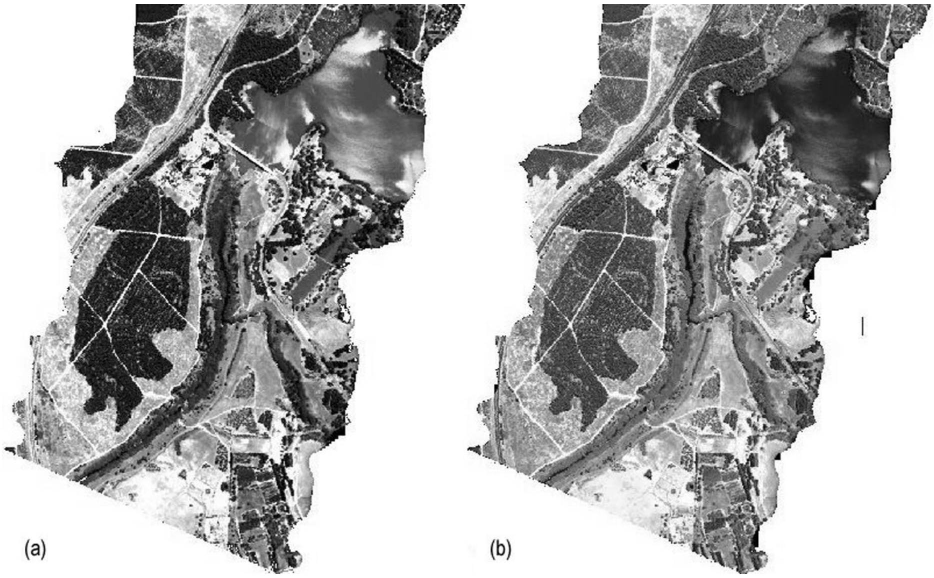

Fig. 3. Examples of airborne spectrographic imaging: (a) based on a three-spectral band colour composite, simulating air photography; (b) based on a different mix of bands, where strong vegetation reflectance in the near-infrared is more prominent.

buildings, tracks etc. than is likely to be available from other sources. Further, by keying the geospatial images to the models produced by softcopy photogrammetry, it is possible to ensure that constraints and terrain match precisely.

3. Information extraction

3.1. Softcopy photogrammetry

Softcopy photogrammetry uses pattern recognition algorithms to identify corresponding points on a stereo pair of images. From information about
- the location of a number of identifiable points,
- the position from which the images were captured,
- the relative changes in position of other points,

the program can estimate the altitude of the land surface over the area of overlap (Fig. 4).

Softcopy photogrammetry can be a very cheap approach to the problem of producing DTMs. The low cost means that the most cost-efficient strategy may be to create several DTMs for the one study. The first, based on coarse satellite data, would be used for concept planning. The second, based on more accurate (and expensive) data, can be limited to the area of interest identified from the first model. The introduction of a second more accurate model then raises the question of how accurate the first model needs to be. If the first model is not going to be the last, 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.

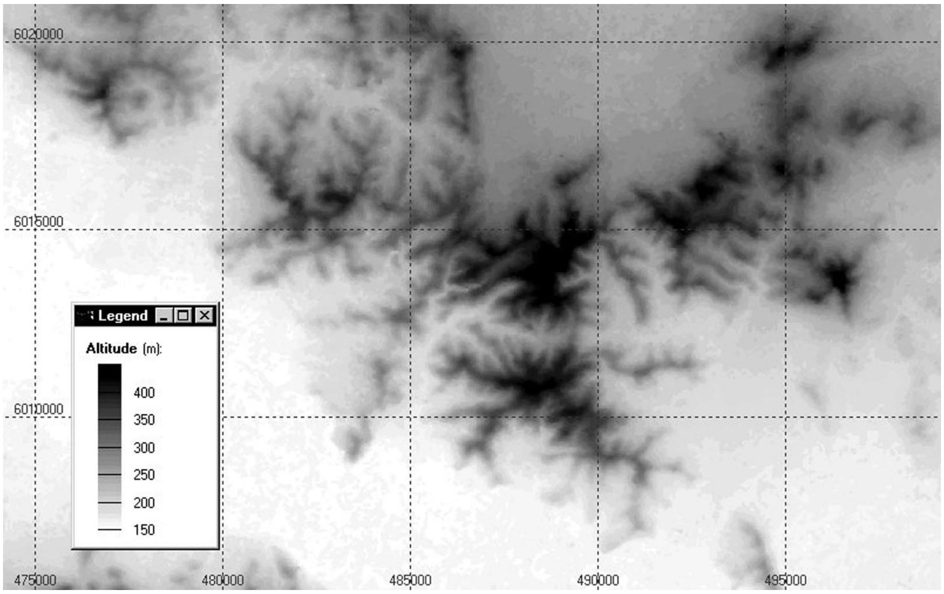

Fig. 4. Digital terrain model created by softcopy photogrammetry (20 km across).

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 m resolution will produce a DTM with a vertical accuracy of ±10 m. When the aim is to thread a road that may have a minimum radius of curvature of more than 1000 m horizontally and 10 000 m vertically between significant hills and valleys, the 10 m error represents an additional texture imposed on the general shape of the terrain. While the texture may affect the final location of the alignment, it allows the corridor to be identified with relative accuracy. There is very high potential for use of the additional spectral information supplied by airborne spectrographic systems as part of the automatic feature recognition in the soft-photogrammetric software.

3.2. Regional significance analysis

Environmental considerations and protection of biodiversity play an important role in planning transport infrastructure and urban development. Sensitive or unique areas need to be protected from development and from the damage resulting from improved access or increased use. The purpose of regional significance analysis (RSA) is to identify those areas within a region that possess similar combinations of environmental attributes (e.g., geology, slope, aspect, temperature, rainfall and incoming solar radiation), so that development can be constrained to avoid the unique or sensitive areas.

As biodiversity encompasses all life forms and biological processes, knowledge about the presence and absence of species is necessarily incomplete, and usually restricted to particular species groups. Therefore, any serious attempt at planning to minimize potential impact on biodiversity must be focussed at the scale of landscapes or broad ecosystem types, rather than a sole reliance on an exhaustive flora and fauna inventory and analysis of species numbers. RSA provides a rapid and spatially explicit method for dealing with this complexity and for ascertaining the broad implications. Such analysis does not obviate the need for a more focussed and rigorous assessment of specific ecological issues during the subsequent design phase, but it does provide a framework on which to base it.

RSA is an integrative technique developed at CSIRO Wildlife and Ecology that provides a rapid and spatially explicit framework for identifying broad ecological characteristics at regional scales. The theoretical basis for the RSA technique is provided by the concept of 'environmental stratification', which was well established in both Britain and the USA by the early 1930s (Margules and Scott, 1984). The underlying concept is that if observed environmental relationships (e.g., changes in vegetation type with aspect) can be defined at one location, then a similar relationship can be predicted with some confidence at other similar locations in the environment. As such, the concept can be applied as a procedure for identifying regional environmental variation. The procedure is most efficiently conducted within a geographic information system (GIS) and combinations of data layers such as terrain and climatic attributes are commonly used (see Fig. 5). However, where available, data layers consisting of vegetation types are often the most suitable for environmental stratification purposes, as they provide an integrated 'real-world' expression of environmental variation within a region (Fig. 6). The data collected from hyperspectral imaging can be particularly valuable in this regard.

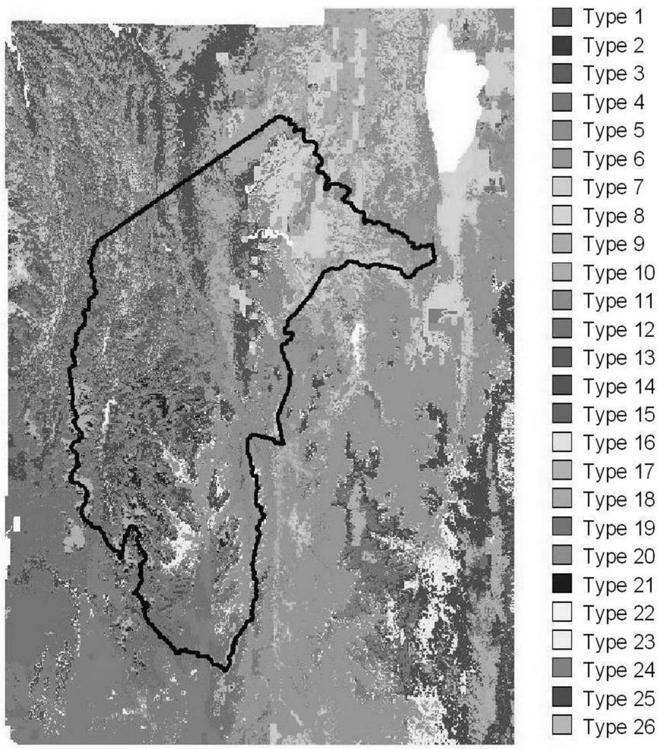

Fig. 5. Spatial prediction of vegetation types in the ACT region (adapted from CSIRO Wildlife and Ecology, 1997).

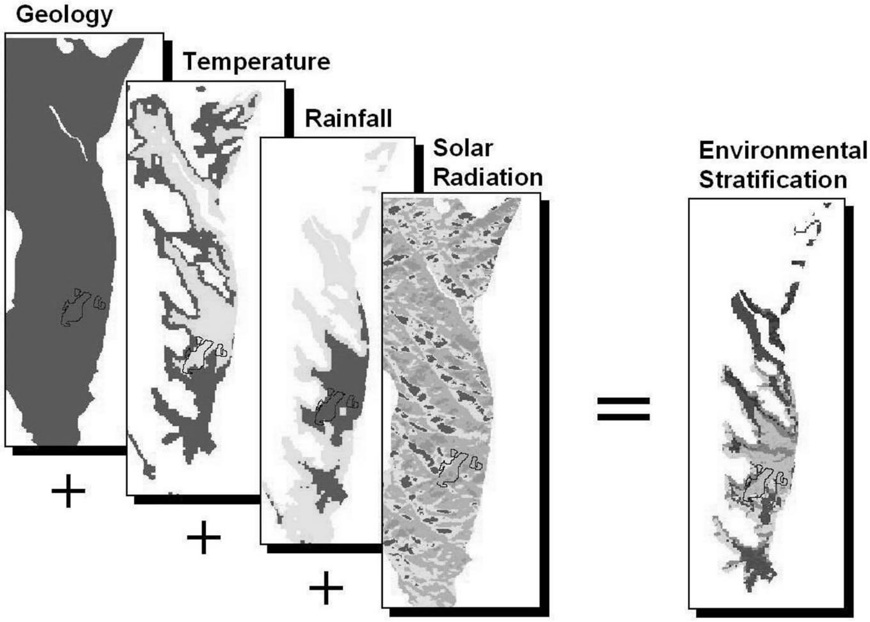

Fig. 6. Environmental stratification process involving the combination of terrain and climatic data layers within a GIS (from CSIRO Wildlife and Ecology, 1998).

While the RSA technique relies heavily on the concept of environmental stratification, it differs by incorporating expert opinion into the spatial framework, hence more adequately capturing the dynamic aspects of the environment. For instance, the RSA technique allows experts to assign probabilities to the likelihood of finding certain fauna and flora species within the spatial units identified (see Table 1). Furthermore, with regard to highly mobile fauna, such as many birds and mammals, these experts can also provide a temporal dimension by indicating how the distribution and abundance of these species changes over time. This can be useful for dealing with those species which migrate seasonally, or for predicting species responses to disturbances, anthropogenic or otherwise, which influence key ecosystem resources such as habitat availability or food supply.

The data captured in the expert opinion process can be presented in two different spatial forms (Fig. 7). The first, focussed at a species level, consists of a probability of occurrence map for each species of interest, while the second summarises the expert opinion data into an overall species diversity index. The species diversity index is produced by summing, for each vegetation type, the probability of occurrence scores across the range of species listed. Therefore, the higher the score, the greater the diversity of species that are likely to occur in a particular vegetation type.

The value of the RSA technique is that, rather than concentrating on the number of species affected by a route development, it provides a spatially explicit framework for ascertaining the regional representation of the remaining habitat (in this case vegetation types) in which certain species are likely to occur. This provides a regional context in which the potential ecological impacts of alternative routes can be rapidly assessed.

Table 1
Process of capturing expert opinion within an explicit spatial framework (in this case vegetation types) during regional significance analysis of uncommon ground and arboreal mammals in the ACT region (adapted from CSIRO Wildlife and Ecology, 1997)

		(A)		(B)			(C)				
Vegetation type	Area of Forest Unit Remaining (ha)	*Petaurus australis* Yellow-bellied glider	*Mastacomys fuscus* Broad-toothed Rat	*Dasyurus maculatus* Tiger Quoll	*Phascolarctos cinereus* Koala	*Pseudodomys fumeus* Smoky Mouse	*Phascogale tapoatafa* Brush-tailed Phascogale	*Sminthopsis leucopus* White-footed Dunnart	*Isoodon obesulus* Southern Brown Bandicoot	*Petaurus norfolcensis* Squirrel Glider	Species Diversity Index
1	3,269	1 0				2 2	2 1	1 1	2 0	1 1	9 5
2	69	1 0				2 2	2 1	1 1	2 0	1 1	9 5
3	396				1 0	1 1	2 1	1 1	1 0	2 2	8 5
4	3,349				1 0		2 1		1 0	2 2	6 3
5	30,134	1 0				2 2	2 1	1 1	2 0	1 1	9 5
6	87,791	1 0				2 2	2 1	1 1	2 0	1 1	9 5
7	20,128	1 0					2 1	1 1	2 0	1 1	7 3
8	445	1 0				2 0	2 0	1 0	2 0	1 0	9 0
9	879	1 0				2 2	2 1	1 1	2 0	1 1	9 5
10	10,205				1 0		2 1		1 0	2 2	6 3
11	6,885				1 0		2 1		1 0	2 2	6 3
12	1,182				1 0	1 0	2 0	1 0	1 0	2 0	8 0
13	324				1 0		2 0		1 0	2 0	6 0
14	6,596						1 1	1 1	1 0	2 1	5 3
15	36,258	3 3		3 1	1 0	2 2		1 1	1 1		11 8
16	1,025	1 1		2 1	1 0		1 1		1 0	1 1	7 4
17	17,063	1 1	2 2	2 1	1 0		1 1		1 1	1 1	9 7
18	12,948	3 2		3 2	1 0	2 2		1 1	1 1		11 8
19	89,798	3 3	2 2	3 2	1 1	2 2		1 1	1 1		13 12
20	26,458	3 3	1 1	2 2	1 1	2 2			1 1		10 10
21	7,344	3 3	2 2	2 2	1 1	2 2			1 1		11 11
22	16,056	3 3		3 2	1 1	2 2		1 1	1 1		11 10
23	455	3 3		3 2	1 1	2 2		1 1	1 1		11 10
24	38,334	3 3		3 2	1 1	2 2		1 1	1 1		11 10
25	52,643	3 3		3 2	1 1	2 2		1 1	1 1		11 10
26	12,554	1 1				2 2	2 1	1 1	2 1	1 1	9 7
Habitat Specificity index		37 29	7 7	29 19	17 7	34 31	31 14	18 16	34 11	24 18	

Legend and Key

(A) Recorded in the ACT with reasonable frequency (for rare and endangered fauna)
(B) Very infrequently recorded in the ACT Region.
(C) Not recorded in the ACT Region in recent times, but may occur.

0 = not present
1 = < 50% probability of occuring
2 > 50% probability of occuring
3 = present

1st number (large) = pre-European
2nd number (small) = present, 1996

4. Alignment optimisation

Quantm is a computer-based planning tool that undertakes cost-based alignment optimisation, to automatically generate low cost road or railway alignments that satisfy defined constraints. It generates sets of alternatives, rather than a single least-cost solution, to allow planners the free-

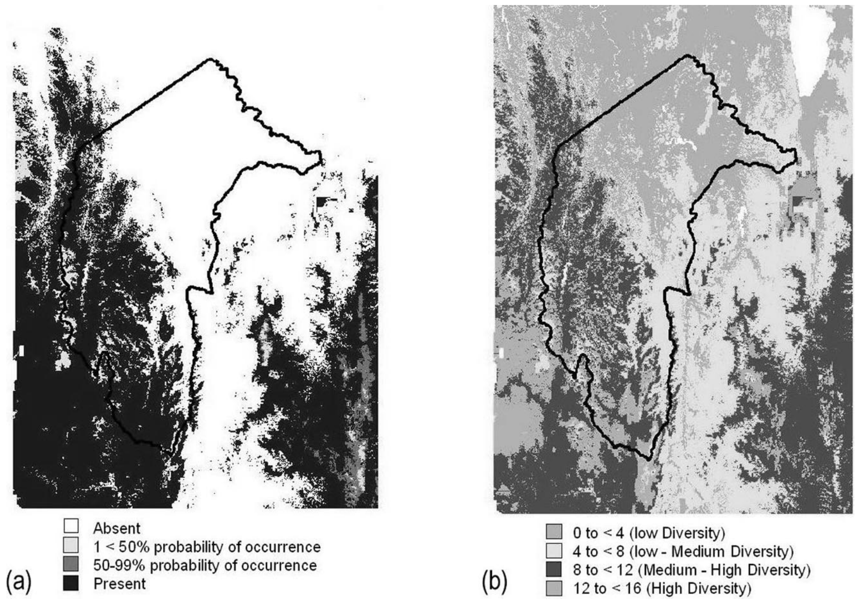

Fig. 7. Spatial representation of expert opinion: (a) shows the predicted distribution of the yellow-bellied glider throughout the ACT; (b) shows the overall predicted diversity of uncommon ground and arboreal (tree dwelling) mammals.

dom 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 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. One alignment for 100 km of freeway with hundreds of constraints may take only 15 min. 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.

4.1. Planning cycle

The relationship between the data sources, information generation and alignment optimisation 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 by 60 km area from the 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 seriously delay data collection. Once the corridors are identified, the cycle should be repeated using more accurate sources of data. The large-scale satellite images used in the first stage allow the problem to be viewed in context, and provide a relatively cheap means for identifying the most likely corridors. The more expensive and detailed data-gathering techniques employed in the second stage can then be confined to limited areas.

4.2. Goal of optimisation

The package, Quantm, used for alignment optimisation was developed as a planning tool not a design tool. In this context, planning determines where the route should go and obtains preliminary estimates of the construction cost; while design is concerned with defining the route, specifying earthworks and other construction details and producing more accurate cost estimates. The difference between planning and design affects the level of detail, and it is with the more global perspective of the planning stage that the greatest opportunities to contain overall costs arise.

Many of the issues in planning are subjective, contentious and political. What is the value that can be placed on ensuring that a freeway is kept out of sight of a scenic lookout? What is the social cost of land resumption? The cost of an alignment intruding into certain areas, such as private properties, is not a simple function of the extent of the intrusion, as extraneous (and frequently unquantifiable) costs such as legal charges and public relations have to be considered. Differences in construction costs between an alignment that intrudes and one that does not have to be balanced against such things as costs of acquisition and public relations to determine whether intrusion into the zone is worth considering. These issues make the task of generating a unique optimal alignment next to impossible. The alternative is to adopt a satisficing approach and recognise that there are many low cost alignments that have differing qualitative properties; and instead of trying to find a single 'optimum' alignment, produce a selection of relatively low cost alignments which meet the objective criteria. The planners or the community can then select the alignment that (in their opinion) represents the optimal balance between low cost and minimal adverse impacts, and customise the alignment if they feel the need.

4.3. Creating realistic models

There are many factors which can have a major impact on the optimum alignment of a route that needs to be considered during planning. Unless a model can cope with a minimum range of factors, it cannot provide the tools necessary to produce realistic solutions. To provide a minimum level of flexibility, a model needs to incorporate information about:

- Basic geometric standards – minimum radii of curvature, maximum gradients, and the location, bearing and gradients at the end points.
- A digital terrain model.
- Geotechnical information – every geological zone can have several strata, with their individual characteristics of batter, shoulder width and extraction costs.

- Linear features such as roads, rivers, railways and pipelines which may have to be crossed. Some crossings must be at grade, others must be at a different level and may involve a structure. The minimum description required of each feature includes the location of the feature, the nature of the crossing, and the required horizontal and vertical clearances.
- Zones which require special treatment for social or environmental reasons. A railway line may need to avoid a park, or a road may need to avoid a water catchment. Even when the alignment can pass through a zone, it may be forced into a cutting to reduce noise, or onto a viaduct with a minimum elevation when crossing a flood plain.

4.4. Costs

Quantm divides alignments into short segments in which the nature of construction remains constant and can be quantified relatively easily. The possible construction types are:

- Cuts and fills are costed on the basis of the volume of material and the costs of removing/placing that type of material. Retaining walls are included automatically if the cross-slope is too steep. They are costed as a linear combination of their length and their profile area. That is, the cost of a unit length of wall includes a fixed component for foundations plus a variable component that is proportional to its height.
- Culverts are costed as a function of the number and type of channels, and the length of channelling required to span the base of the fill in which they are embedded.
- Viaducts are costed as a linear combination of their length and their profile area. That is, the cost of a unit length of viaduct includes a fixed component for foundations plus a variable component that is proportional to its height.
- Tunnels are costed as a linear function of their length.

4.5. Subjective factors

Minimizing objective costs while preserving environmental amenity is very complex, as the questions of how environmental impacts are measured and how they are balanced against objective costs are basically a matter of policy. There are two basic strategies that can be followed. The first is to try to quantify the subjective aspects and to incorporate the resulting values in the objective function used in the optimisation. The second is to produce a number of alternative alignments based on optimising the objective costs, and then select between them on subjective grounds.

Quantification. This approach is not as simple as it might appear initially, as assigning a value to these environmental costs is fraught with difficulty. It may be possible to assign a monetary value to each square metre of a park based on the impact that the alienation of that square metre would have on the integrity of the park, and to create a contour map of the environmental costs of alienation of individual square metres. But, this does not address the more difficult problem of connectivity, which considers the impact of the alignment on the contiguity of the park. The approach is also subject to the problem that any interested party that disagrees with the result will contest the values assigned to the subjective factors; arguing for an increase or decrease depending on how they want the answer changed. Further, it raises the philosophical problem of whether a computer program should make decisions about subjective issues.

Choice. The second strategy recognises that once subjective factors are introduced, the problem becomes more complex with more than one solution. Environmental impacts are multi-dimensional so that any judgment about the value of environmental amenity also involves judgments about the relative values of different aspects of the environment. The strategy is to provide a range of low cost alignments to allow planners to balance objective cost against environmental impacts. If necessary, additional constraints can be imposed to investigate the costs of avoiding sensitive areas completely. This is the strategy based on the tenet that computer packages should not make decisions that are essentially subjective; rather they should be used to generate objective information which can be used by planners as a basis for their subjective judgments.

4.6. Optimisation technique

The generation of sets of low cost alternatives can be readily achieved by employing one of a number of stochastic optimisation techniques. Originally developed to optimise discrete systems by swapping the contents of randomly chosen pairs of locations, the methods can be adapted to working in a continuous space. The technique is similar to the methods employed by designers working interactively with standard packages, who move an intersection point defining the alignment subject to set constraints. The cost of the modified alignment is calculated and compared with the cost of the old alignment, and a decision is made to accept or reject the change. Once a decision has been made, another intersection point is selected and the process repeated. The rules governing the acceptance or rejection of a point provide the mechanism by which the alignment can escape from local sub-optima. The algorithm does not guarantee that the alignment will escape; it merely makes it possible. However, careful selection of the parameters controlling the process can greatly increase the probability of reaching the global optimum.

By locating intersection points in a continuous space, the final alignment can be specified to arbitrary accuracy. However, in practical situations, continuing the optimisation beyond a given accuracy does not contribute significantly to the value of the solution. Accordingly, optimisation can stop when the spatial range of the acceptable moves made by the intersection points declines to a value from which a designer can work without having to worry about the macro location of the route.

The stochastic nature of the technique also means that the solution is not a deterministic function of the starting alignment. If the initial rejection threshold and the rate at which it is reduced are chosen carefully, the final solution is virtually independent of the starting alignment. Consequently, the resulting alignments are not constrained by preconceptions of where the route should lie. This isolation of the final solution from initial alignment is important because it removes one more element of subjectivity from the solution. The cost of an alignment is critically dependent on the initial judgment of where the road should go, based on impressions of the macro-topography; but a value cannot be placed on it until much later when the alignment has been adjusted to fit the micro-topography.

5. Case study – Barton Highway

The Barton Highway forms part of the Australian National Highway system, and is also assuming increasing importance as a commuter link to Canberra from the evolving satellite developments around Murrumbateman. Following the opening of a section of dual carriageway to the north of Murrumbateman, the Barton Connector, there remains a length of approximately 32 km of a lower standard two-lane rural highway, inconsistent with the current levels of traffic and its standing as a National Highway. As a consequence, there is increasing pressure to at least identify route options to allow ongoing developments to be planned with a clear understanding of the future highway requirements.

As part of the investigation process, a value management study (VMS) was organised to bring together affected stakeholders to examine issues and concerns associated with the project, to investigate the scope of the project and its objectives, and provide direction on the route selection process. During a concentrated workshop, a project overview was presented with an analysis of its functional elements. Ideas for developing the project were generated, themes developed, and decisions and their implications considered.

5.1. Scenarios

The VMS nominated a number of potential corridors for inclusion in the study. These options were divided into two groups:

- The first group involved upgrading the highway generally along the existing corridor with an internal bypass to the east of the town centre.
- The second group was composed of a range of bypasses running several kilometres to the west of the town and possessing a variety of start and end points.

5.2. Methodology

Because greater accuracy was required and a more limited area was being considered, aerial photography was selected as the source of the data. A base-case upgrade was generated as a benchmark for the various options. It hypothesised constructing a four-lane divided highway with a centre line constrained to lie within 20 m of the centreline of the existing highway. The base-case alignment was divided into 100 m sections and costed at this level of detail. The other options were then generated using a pair of the 100 m points from the base-case alignment to define the location, bearing and gradient of their start and finish. Starting and finishing at the 100 m points meant that it was possible to replace the bypassed section of the base-case upgrade with the option under consideration and obtain an overall cost for the total route or compare the cost of the option with the cost of the section of the base-case upgrade it would replace.

In addition to potential corridors identified in the VMS, the fastest and most encompassing method was to treat densely settled residential areas as zones to be avoided and let Quantm identify the corridors between them. The resulting alignments formed families where variations between families were produced by areas where construction is expensive or prohibited. The arrangement of these families enabled the location and breadth of several corridors to be identified. Only when the program completely avoided certain ‘obvious’ corridors was it necessary to constrain the investigation to those corridors to determine whether the avoidance was based on costs or problems with the corridor geometry.

Treatment of Sensitive Areas. Because of the relatively dense settlement to the south of Murrumbateman, all alternative alignments experienced difficulty negotiating a band 2 km wide on either side of the existing alignment. While it was possible to generate alignments that avoided all the houses, major farm buildings and dams in this band, a secondary objective was to leave as wide a buffer zone as possible between existing houses and the options produced, and to avoid dividing properties or blocking access.

The general approach was to avoid defining hundreds of constraints at the beginning, but optimise with minimal constraints and gradually add constraints when necessary to keep the new alignments away from sensitive areas such as houses. Because of the high geometric constraints imposed on a divided highway and the patchwork of individual interests in the vicinity of the town, it was unlikely that any option would satisfy everyone, and the study was directed to finding compromises that balanced the interests of those most affected.

5.3. Results

Base Case. The base-case scenario, involving upgrading the alignment of the existing road while keeping the new centreline within 20 m of the old centreline, provided no serious challenges over the first 21 km and horizontal radii were maintained above 1000 m. However, in the section through and north of Murrumbateman, the existing alignment is so winding that even reducing the horizontal radii to 500 m was not sufficient to keep the optimised alignment in this corridor (Fig. 8). The failure to produce an acceptable alignment in this section was not unexpected as this is the section for which alternatives were being sought.

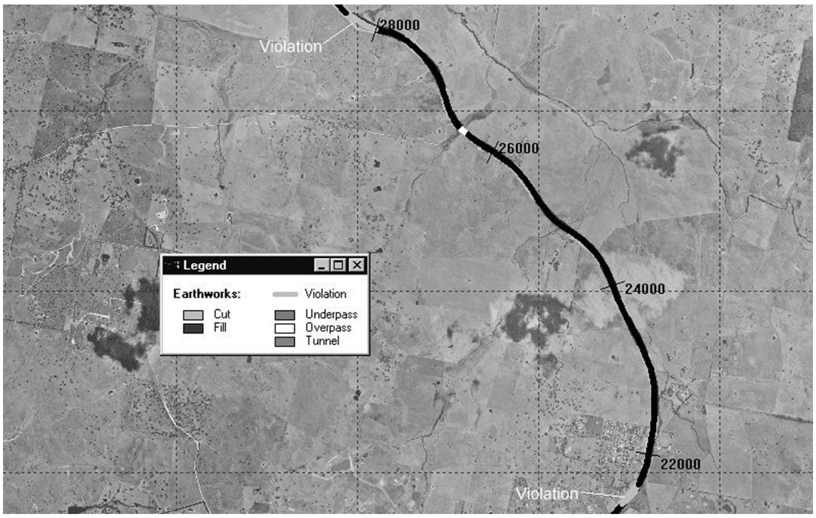

Fig. 8. Base-case alignment north of Murrumbateman, with violations marked where the alignment fell outside the nominated corridor (8.6 km across).

The cost of upgrading the alignment to the base case was approximately $111 million, based on the unit costs for construction and ignoring any land acquisition and service roads that might be required. Reducing the width of the alignment as it passed through the town reduced the cost only marginally under these assumptions, as the terrain is relatively flat.

Eastern Corridor. All the significant impacts of the two options were experienced in the south, where both ran through the flood plain between two creeks, posing potential hydrological problems and dividing the town in two. Although alignments could be generated that avoided all buildings, they passed very close to some, and the ability to lay the generated alignments directly on the ortho-rectified image proved invaluable in showing the extent of the problems (Fig. 9).

On the cost side of the equation, the inner eastern option differed very little from upgrading the existing alignment through Murrumbateman, and the outer eastern option incurred more substantial earthworks costs while crossing the ridge north-east of the sports ground.

Western Corridor. Three of the options that were nominated by the original workshop passed to the west of Murrumbateman. One was eliminated rapidly; superimposing it on the aerial photographs showed it to run through three new housing estates, and moving it sufficiently far west to avoid them left it equivalent to another option. Almost all the low cost variations of the two remaining options were superimposed as they passed through a relatively narrow gap. To explore these variations in more detail, the western corridor was divided into northern and southern sections with the join in the gap.

In the south, the relatively dense settlement on either side of the Barton Highway alignment meant that all alignments encountered difficulty negotiating a band 2 km wide to the west of the existing alignment. While it was possible to generate alignments that avoided all the houses, major farm buildings and dams in this 2 km band, a secondary objective was to leave as wide a buffer zone as possible between existing houses and the options produced. The primary determinant of

Fig. 9. Detail of the eastern options in the vicinity of Murrumbateman (4.3 km across).

cost for the five southern options in the west was the point at which they departed from the existing alignment.

There was relatively little settlement close to the existing highway in the area north of Murrumbateman, but several building complexes midway along the corridor complicated the generation of alignments. The alignments which ran furthest to the west in this area encounter unfavourable terrain and were distinctly more expensive, while the one closest to the town cut a large grazing property in two.

Comparison of Corridors. In general, upgrading the existing Baton Highway requires extensive horizontal realignment to attain the required standard. The eastern options are slightly more expensive and close to built-up areas, but they are closer to the existing highway and would be better suited to staged construction. While the western options bypass Murrumbateman, would be less expensive to construct and stay further away from houses, they are less suitable for staging as a relatively long length would have to be completed before any could be used. Because the terrain was gentler, the construction cost savings from optimisation were not as pronounced as in other studies, and the difference between the various options was only about 16%.

6. Transport and land use planning

Transport and urban land use are mutually dependent, which makes the coordination of urban development and transport activities difficult. Most transport plans take the land use as given and determine the demand for travel; while urban development policies are driven by the existing transport networks, that is, they assume the transport system is in the right place, and fit development around that infrastructure. An innovative view would be that the transport system could be changed to meet the needs of new development, rather than to force the land use to fit the transport system; while new land use development could be redirected to desired transport corridors. The development of new technologies such as geospatial imagery technology has enabled urban planners and transport professionals to visually analyse transport projects in the context of the whole urban area. The end of the process is to develop an integrated transport and sustainable development plan.

The technologies described above were originally assembled to determine where to locate infrastructure to best serve the needs of existing communities; however, the focus can be shifted to look at the more general question of how to promote sustainable development and infrastructure. A new freeway or arterial road and its access points generate development as well as servicing existing land uses, so that the ability of planners to manipulate the location of these access points prior to construction provides a means of controlling urban development. Taking the sustainable development viewpoint still further: the data gathered for infrastructure optimisation can also be used to identify the land where development will have minimum impacts because of land form, soil types, sensitivity (or degree of degradation) of existing natural environments, etc. Having identified the best areas for development, the new infrastructure can be optimised to encourage appropriate land use in those areas.

7. Summary

The combination of geospatial imaging and alignment optimisation in the case study proved to be very beneficial. The geospatial imaging provided recent reliable data, and the ability of Quantm to lay the generated alignments directly onto the ortho-rectified images enabled many unacceptable routes to be rapidly eliminated.

By processing the remotely sensed data such as DTM and information on the substratum using regional significance analysis, the broad ecological characteristics of a region can be identified. This is particularly useful for environmental impact analysis for route selection. The speed of optimisation enabled changes to be made to the underlying constraints and evaluated rapidly. For instance, part-way through the planning for the Barton Highway, it was decided that the specification of the geotechnical characteristics of the alluvium that cover most of the study area needed to be changed – only the top 0.5 m should be discarded as spoil, rather than the top 2 m. After making the change, it took only two days to re-optimise the 11 corridors that were being investigated at the time, shifting them vertically and horizontally to obtain the most from the 'new' conditions.

The speed allowed the program to explore the whole transport corridor thoroughly, and to consistently produce low cost alignments uninfluenced by preconceptions of where the route should run. The application of new technologies, such as geospatial imaging and the transport route optimisation tool Quantm, not only significantly reduces the time, cost and effort of data acquisition, but also allows planners to review, compare and refine the optimised alignment to balance the environmental and social impacts against route costs.

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