TECHNICAL PAPER

Title: **The Future of Network Planning—Virtual Desktop Modeling**

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THE FUTURE OF NETWORK PLANNING – VIRTUAL DESKTOP MODELING

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Abstract—*This paper illustrates the virtual survey tool (VST) specifically developed for Bechtel on a current project in the United Kingdom. The tool was developed as a design aid for network planning along the rail network. It incorporates a number of synchronized views, which visually represent a wide variety of data sets relating to the topography along rail routes. The VST has the potential to be developed further to realize benefits beyond radio frequency (RF) planning and to be of use for any cell site rollout project.*

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INTRODUCTION

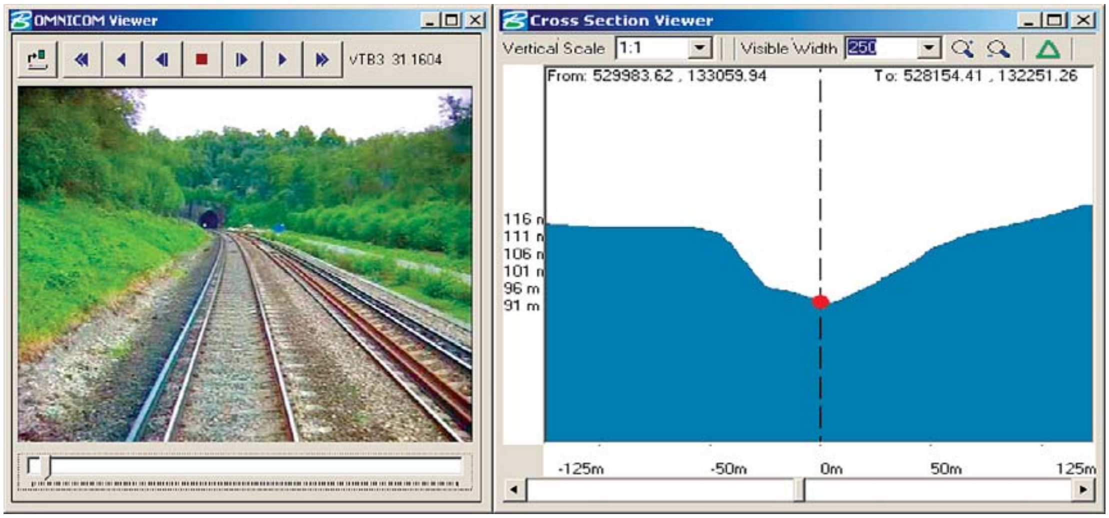
Designing wireless coverage within the rail environment presents a host of new challenges over those facing standard wireless telecommunications projects. The linear and restrictive nature of the railway, coupled with a typically more severe surrounding topography, adds a level of complexity to the coverage planning process.

In traditional wireless telecommunications projects, sites are distributed over a smaller geographical spread than in the railway environment. On a current Bechtel project, for example, several hundred planned sites are spread over 3,000 km of railway track across the length and breadth of the United Kingdom's complex rail network infrastructure. The routes invariably pass through land owned by a large number of individuals and within the jurisdiction of various local planning authorities (zoning boards). Often, these sites are in rural areas of outstanding natural beauty or national parks, making access to the sites extremely difficult.

From a network planning perspective, a number of features make the design of rail-based projects more challenging than that of conventional projects, most notably:

- Deep cuttings, often deeper than 10 m and/or lined with trees
- Tunnels
- Raised embankments
- Bridges and viaducts

Figure 1 shows the kind of environmental challenges facing rail-based site rollout projects, depicted from a point along a rail route. The video snapshot shows the railroad track in a deep



Vertical Scale 1:1
Visible Width 250
From: 529983.62 , 133059.94
To: 528154.41 , 132251.26

Figure 1. Example of Challenging Planning Environment Encountered on Rail Projects

ABBREVIATIONS, ACRONYMS, AND TERMS

3D	three-dimensional
DSM	digital surface model
DTM	digital terrain model
GPRS	general packet radio services
GSM	global system for mobile communication
IFSAR	interferometric synthetic aperture radar
LOS	line of sight
LPA	long profile analyzer
RF	radio frequency
TACS	total access communications system
VST	virtual survey tool

Metric-to-Imperial Equivalents

12.5 cm = 4.92 in.	15 m = 49.2 ft
25 cm = 9.84 in.	1 km = 0.62 mi
70 cm = 27.56 in.	2 km = 1.25 mi
1 m = 3.28 ft	10 km = 6.21 mi
5 m = 16.4 ft	3,000 km = 1,864 mi
10 m = 32.8 ft	

The main objective of the VST is to reduce the number of site visits by providing decision support information directly to a desktop environment.

cutting leading into a tunnel. The cross-sectional view verifies that the depth of the cutting is approximately 15 m.

Many conventional planning/mapping tools do not address the railway environment. For example, the resolution of digital terrain models (DTMs) is often larger than the width of the track. Since the accuracy of desktop propagation predictions in isolation cannot be relied on, they must be visually verified. This leads to inherent cost burdens and safety risks.

VIRTUAL SOLUTION

To assist with overcoming some of the challenges faced when planning and acquiring sites under such complex circumstances, the virtual survey tool (VST) was developed. The main objective of the VST is to reduce the number of site visits by providing decision support information directly to a desktop environment. This allows design decisions to be highlighted, resolved, and avoided at an earlier stage than is typically possible on telecommunications projects.

It was recognized that a wide variety of disparate datasets could be brought together and "registered" against a common frame of reference, in this case a geographic model of the British Rail Network. This data "registration" philosophy enables data to exist independently, yet meaningful comparisons can be made because the data shares the same frame of reference. The model is inherently future proof: Any dataset, present or future, can be registered against it [1].

The following principal datasets have been identified and developed for the VST for application on a rail project:

- Raster mapping (1:10,000)
- Aerial photography (12.5 cm and 25 cm resolution)
- DTM (5 m horizontal accuracy and 70 cm vertical accuracy)
- Digital video footage of all routes, providing front, left, and right views of the railway corridor
- Database composed of all existing and proposed site locations
- Detailed route and track map of the entire British Rail Network

The VST allows for simultaneous and synchronized views of any or all of the above information at any location on the rail network (**Figure 2**).

To complement and enhance analysis using the datasets, a number of advanced measurement features—desktop analysis, cross-section analysis, and longitudinal analysis—have been developed. These features, which are beginning to make site surveying a desktop exercise, are discussed later in this paper. First, a brief discussion of various datasets follows.

Raster Mapping and Aerial Photography

In **Figure 3**, the raster mapping overlays the rail map to show detailed structural boundaries and rail rights-of-way. Aerial photography was available for all of Great Britain at either a 25-cm or 12.5-cm resolution and was purchased in 2-km strips along all rail routes. This data provides additional details on the aboveground structures, trees, and vegetation surrounding the rail environment.

The scope of the project required more than 800 raster maps and 9,000 aerial photographs, in raw format. Delivering an acceptable level of performance while working within the physical capabilities of the graphics hardware to register this volume of imagery was a serious concern. Consequently, all images were subdivided into many small square images. The coordinates of the extremities of each image are stored in a database and can be retrieved within a 1-km tolerance into the mapping viewer as the active location changes [1].

High Resolution DTM

As with the raster and aerial data, the sheer size and complexity of the DTM data meant that it had to be organized very carefully. Each of the 385 10-km squares contains 4 million three-dimensional (3D) points at a 5-m grid. Again, this information is managed by storing the data in its raw format, linked to a database that references its extremities.

The DTM (created by Intermap [2]) used in the VST is generated using a sensor called an interferometric synthetic aperture radar (IFSAR). IFSAR builds on the principle of radar: Because radio waves travel at a constant speed, they are a good indicator of distance. To measure the distance to a particular object simply requires measuring the time needed for a radio pulse to travel from its point of origin to the object, bounce off that object, and travel back. The length of time is then divided by two and the result is multiplied by the speed of light.

Interferometry relies on picking up the return signal using two antennas at different locations. Each antenna collects data independently of the other, and the images received are nearly identical except for the almost insignificant difference in their range to any specific target. With the interferometric radar, the pattern of light waves emanates from the same point on the ground, and the light waves then strike each other independently. The phase difference between these light waves occurs at a given rate on a flat surface. If the phase change occurs more quickly, it indicates an increase in elevation; conversely, a slowing of phase change indicates a decrease in elevation (from the previously measured point).

With IFSAR, these results are further improved by generating a synthetic aperture. Any device, such as a camera, that uses an optical principle to form an image has an opening (called an aperture) that collects incoming radiation. The larger the aperture, the better the resolution. IFSAR digitally combines all of the return signals collected aerially from the aircraft and thus permits the point on the ground to be viewed from a much wider angle.

The DTM used in the VST has a horizontal accuracy of 5 m and a vertical accuracy of 70 cm.

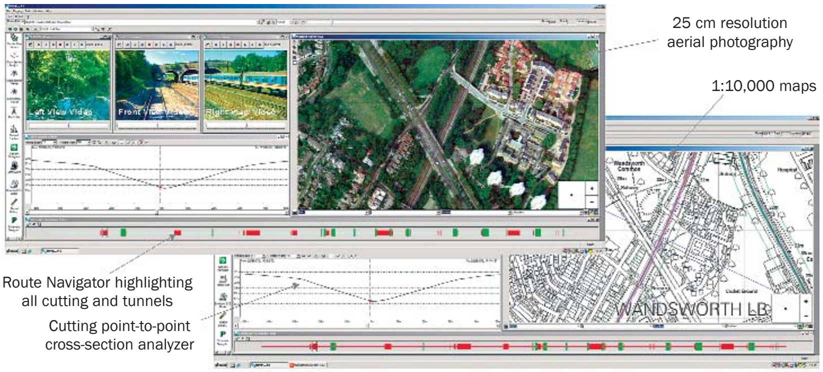


Figure 2. VST Showing Simultaneous and Synchronized Views

This allows surface features such as cuttings and embankments to be clearly picked up by the planner. The high accuracy DTM is also used dynamically to analyze and measure the terrain height around the track, including cross sections of cuttings. A link to Bechtel's network planning database enables the user to display sites with respect to the location of the train and conduct point-to-point terrain height analysis.

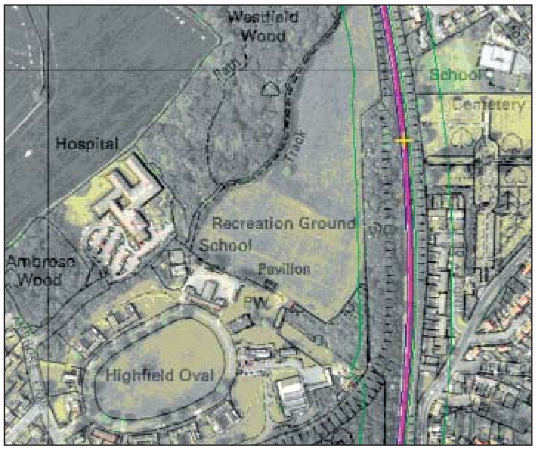


Figure 3. Example of 1:10,000 Raster Mapping Transparently Overlaid over 25 cm Resolution

Digital Video

Digital video for the entire British Rail Network already existed, bringing with it the benefit that it was "pre-registered" against the railway referencing system. The video data is registered against the network model by forming a relationship between each video and its start and end locations along the route.

Continuous video data is available for each route, including the function of panning left and right so that possible site locations can be considered. This helps ensure that problematic cuttings, tunnels, and bridges can be more easily identified, referenced, and accurately mapped.

DESKTOP ANALYSIS

Further successful application of the VST can only be truly realized by the development of a number of advanced measurement and analysis features. These features, which would harness the power of the available datasets, can be developed on an ad hoc basis to meet the changing needs of any given telecommunications project.

Deep Cuttings Analysis

Because a train cannot travel over any area that is too steep, cuttings are often formed (the landscape is cut into so that the rail can pass through it). The size of a cutting varies in terms of width and depth. Rail cuttings that are narrow, steep sided, and/or surrounded by trees are the most problematic. The deepest cuttings can be considered "daylight tunnels," surrounded only by earth, rock, or foliage. It is important to locate these cuttings as early as possible in the project to allow sufficient time to provide specialist coverage solutions.

Any data in the VST that has spatial referencing can be recorded against the mapping model. These datasets can be queried and the resultant analysis displayed within the tool. One application of this capability has been in the field of "deep cuttings" analysis. Based on the DTM data, a query compares the track level against the level of all points perpendicular to the track at given intervals. Any locations where the deviation is greater than a predefined amount are stored against the model as areas constituting deep cuttings.

The deep cuttings analysis can be visually plotted on a mapping viewer and/or a schematic route navigation panel representing the extent of the route. This facility, combined with desktop visual inspections of video and photography, allows the user to identify the areas where providing mobile coverage will be difficult. It can also assist in pinpointing a suitable site location that looks into the cutting and resolves the problem.

Cross Section Analysis

Since the railway environment is often not considered in the DTM, it is difficult to accurately predict if the required line of sight (LOS) or signal penetration between a proposed site and its coverage area is achievable. For rail-based projects, this coverage area is a predetermined distance along the track, based on factors such as carriage penetration and train speed. The cross section analyzer enables a cross section of the DTM to be drawn at any point perpendicular to the rail track. Any sites within a defined distance from this point can be analyzed to determine if LOS to the rail route exists.

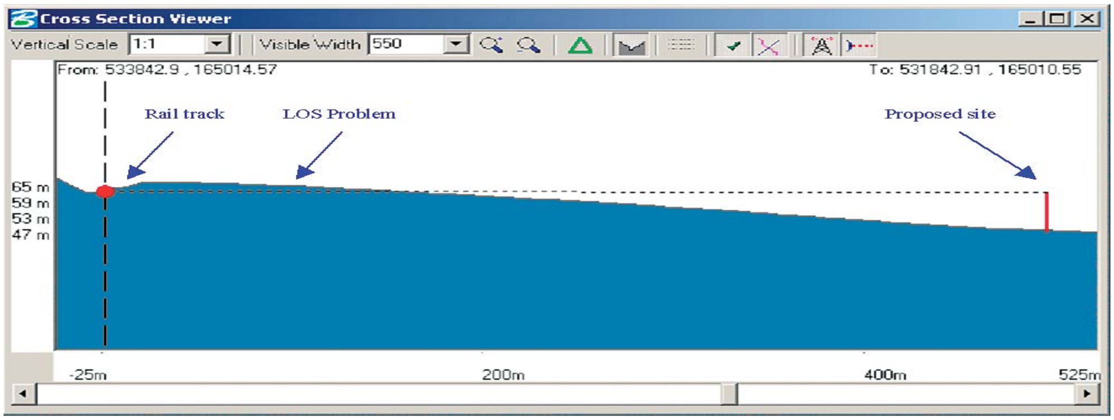
When a request to produce a cross section is submitted in the VST, the collection of 3D points making up the DTM within a tolerance of the section is queried from the raw data through the database. The returning points are triangulated, sectioned, and then displayed. Simultaneously, a proximity check determines if any telecommunications mast is located within the spatial tolerance of the section and annotates it on the section; the entire process takes only a few seconds.

Figure 4 demonstrates that a site being considered for coverage does not have LOS to the cutting. To achieve the desired coverage in the cutting, the planner has the choice of moving the site closer to the track or increasing the height of the mast. The VST allows these changes to be made to the mast so that subsequent analysis can be carried out until a suitable cell site location is determined.

Longitudinal Analysis

As with a cross-section analysis, it is difficult to ensure LOS or coverage overlap between sites—especially important for handovers in the rail environment—without carrying out a site visit. **Figure 5** demonstrates the long profile analyzer (LPA) for analysis between an existing site and a proposed location for a Bechtel new build, with respect to the railway. The analysis clearly shows that, based on the bald earth DTM, an LOS problem exists. Using the LPA in conjunction with overhead aerial photographs of this location, it is possible to identify other candidate locations for the proposed site where there is no LOS.

When planning sites for railway coverage, it is important to allow a predetermined distance of overlap between the coverage areas of each cell to ensure successful handovers. The amount of overlap depends on the predicted speed of the train in the area being planned. This is especially important when designing for general packet radio service (GPRS), to allow for cell reselection periods, which are longer than the normal global system for mobile communication (GSM) handover. The LPA helps predict the affective range of a cell to certain points; then, by performing the same analysis on neighboring cells, it helps to work out these overlap periods.


Cross Section Viewer

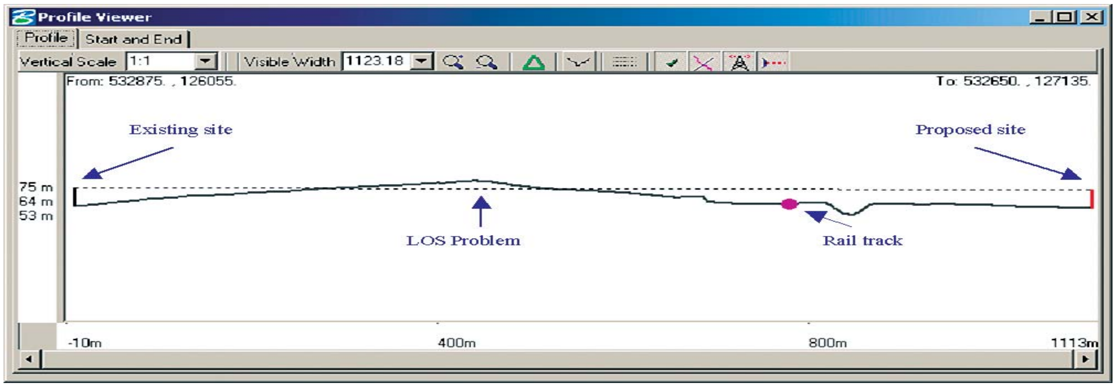
Vertical Scale 1:1

Visible Width 550

From: 533842.9 , 165014.57

To: 531842.91 , 165010.55

Figure 4. Cross Section Analyzer


Profile Viewer

Profile | Start and End

Vertical Scale 1:1

Visible Width 1123.18

From: 532875. , 126055.

To: 532650. , 127135.

Figure 5. Long Profile Analyzer

POTENTIAL SAVINGS

The VST was developed and applied throughout the project's major offices and has provided state-of-the-art technology with a range of tangible benefits for the project team, most noticeably:

- Fewer site visits, especially for sites on network rail property and within cuttings and embankments where site visits to survey the area would otherwise be required
- Identification of all objects that could prevent signal propagation but are not referenced on maps
- Visual verification of the coverage predictions—an essential quality control measure in light of the required network performance requirements
- Ability to determine way-leaves up front
- Additional information to enhance the LPA application
- Increased safety, since near-rail surveys can be avoided

FUTURE ENHANCEMENTS

Future enhancements for the VST include the possibility of 3D modeling or virtual reality modeling. An accurate, high density, complete digital surface model (DSM) is now available for all of Great Britain (see **Figure 6**). DSM is a first-surface view containing both location and elevation information. Independent elevation measurements are taken at 5-m intervals and have a nominal vertical accuracy of 1 m. These measurements are derived from the return signals received by two radar antennas located on

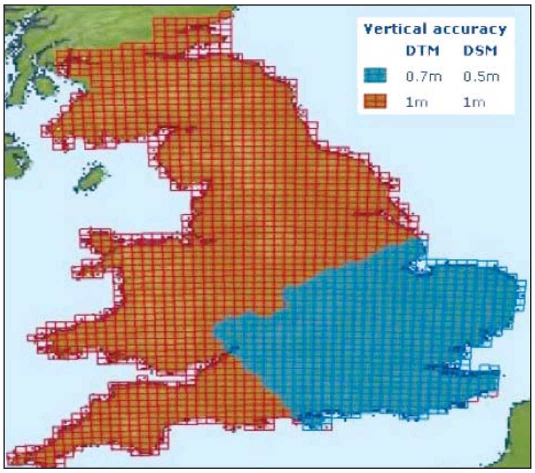


Figure 6. Elevation Model Availability

an aircraft. The signals bounce off the first surface they strike, making the DSM a representation of any object large enough to be resolved, including buildings, roads, and railways, as well as natural terrain features. DSM could potentially be draped over the digital aerial photography to aid visualization and provide real-world interpretation of an area.

Accuracy of LOS analysis will be greatly improved as initial obstruction information is obtained from the surface model.

By combining the use of the DTM with the DSM, it will also be possible to turn the tool into a 3D view and look at the surroundings from the antenna's perspective. As enhancements in hardware and software capabilities continue, the performance of such tools will make the automation of increasingly complex datasets possible.

Virtual reality technologies have already been applied on a number of Bechtel rail projects, and this technology certainly represents the next realistic and beneficial step for desktop surveying within the telecommunications sector.

An additional enhancement identified is to incorporate asset management information into the VST. Providing valuable information on existing sites and potential site locations at the site selection stage will enable radio frequency (RF) engineers to make more astute planning decisions.

> *The VST has proved invaluable by enabling RF engineers and acquisition agents to visually inspect track locations in a way that previously has not been possible.*

CONCLUSIONS

The VST has proved invaluable by enabling RF engineers and acquisition agents to visually inspect track locations in a way that previously has not been possible.

Adding prediction data and algorithms will make it possible for what is now a useful planning design aid to become a true virtual planning tool. In addition, with the introduction of further acquisition input to show potential site locations, the tool will be able to network-plan an area to the user's desired specifications automatically.

Although initially developed for a rail-based telecommunications project, these principles can easily be applied to other telecommunications projects. ■

ACKNOWLEDGMENTS

The authors would like to thank Payam Taaghol, John Bailey, and Andrew Codd of Bechtel, together with Harry Ramsden and John Boyle of Bentley Systems, Inc., for their valuable contributions and assistance in developing this tool.

REFERENCES

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[2] Intermap Technologies Corp. (http://www.intermaptechnologies.com).

ADDITIONAL READING

- Getmapping PLC, www.getmapping.com.
- Intermap Product Handbook and Quick Start Guide, Intermap Technologies Corp., Version 3.2, 2003, pp. 17–52.

BIOGRAPHIES

Richard Baxter has been a senior RF engineer for Bechtel Telecommunications since January 2003. Currently, he designs RF sites and develops specialist RF railway GPRS coverage solutions for a major wireless project in the United Kingdom.

Before joining Bechtel, Richard was involved in planning and optimizing GSM 900 and 1800 projects in Belgium (KPN Orange/BASE), Holland (Dutchtone/Orange), and Italy (BLU). He also worked on Nextel's IDen network in Denver, Colorado.

Richard began his career with Vodafone in the United Kingdom, where he was initially involved in network operations of the analog TACS network before moving into GSM operations and then RF engineering. He has 14 years of experience in the telecommunications industry.

Stephen Smith currently develops, integrates, and maintains network planning tools for wireless network projects for Bechtel in the United Kingdom After joining Bechtel as a college graduate in 1997, he worked within the Petroleum & Chemical and Civil Global Business Units before transferring to Telecommunications in August 2003.

Stephen graduated from Aston University, Birmingham, England, with a BSc in Business and Administrative Studies. He has since obtained the Chartered Institute of Purchasing and Supply professional qualifications and is currently studying for the Oracle Certified Professional qualifications. His professional experience lies in the fields of systems analysis, Oracle applications development, and database integration.