The model railway – an integrated approach to system design and simulation

Mark G Eaden
Brown & Root Services

Abstract

This paper will describe the systems approach to Railway Infrastructure Computer Aided Design on the Thameslink 2000 programme. It will describe the development of our Model Railway.

The paper will describe the philosophy that drives our systems approach. This project is taking deliberate steps to ensure that data produced through each stage of scheme development can be used as a stepping stone for subsequent stages. Each step along the road to completion of the programme has been assessed and providing we remain focused on the deliverables, we can ensure full integration of the railway disciplines. With the increased certainty that will come from this integration, we can reduce the adverse risks associated with a lack of knowledge.

We are building a fully three dimensional, true to scale, animated and interactive model of the proposed new railway infrastructure. Nothing new perhaps? The difference is that through our approach it has the potential to be a “working model” of the railway.

This paper will describe the development of this model and the integration of design outputs from the various railway disciplines. It will show how through development of the model we have developed a better understanding of the design itself, and how the model has influenced the design decisions. It will describe the technical aspects of the system, the problems we have faced and describe the tools under development at the time of writing. It will also show that aside from relatively small development costs we have spent less money than we might have otherwise had we employed a more “conventional” approach.
The paper will suggest proposals for future development, including a description of how the model could potentially be developed into a fully interactive simulation and training tool.

1 Introduction

1.1 Background

The approach that we are taking to the design of the railway infrastructure on the Thameslink 2000 programme presents an alternative to current practice in the UK railway industry. We believe that in this technologically advanced age we could and should be doing things better. We sometimes observe a critical lack of integration between parties to projects at the stages of design, implementation, and operation. A railway is a complex system that will only operate efficiently if the interfaces are properly understood and defined.

Development of scheme design by management of the separate railway disciplines under separate contracts without the existence of a systems framework only serves to stifle creativity in output and practices. Computers are often used as little more than electronic draughting boards. The completed design is then presented to clients on paper rather than electronically, at which point it loses a great deal of its usefulness for later stages of design development.

The frustrating issue with the current state of design practice is that many of the tools and techniques that we need to ensure proper systems integration already exist. We believe that nobody has attempted to pull them all together, until now.

Thameslink 2000 is a complex and ambitious project with a number of design issues peculiar to the programme. If we were to succeed in delivery, it was clear that a different approach to verification and validation of systems requirements would be required.

1.2 Thameslink 2000

The existing Thameslink network was introduced in 1988 connecting Bedford to Brighton via London Bridge and with a “metro” loop via Sutton. Since 1988, levels of patronage have increased significantly which led British Rail to develop proposals in the early 1990s to upgrade the network.

The concept of Thameslink 2000 [1] is to expand the existing service, providing more destinations north and south of the River Thames with railway access through Central London. The train frequency will be increased through the core area from the rush hour 8 trains per hour to 24 trains per hour, providing passenger carrying capacity of some 22,000 per hour in each direction on Thameslink alone.

The railway infrastructure works that are required to service the operational requirements of the programme are extensive. In the Central London area the
approaches to London Bridge and Blackfriars stations are to be totally remodelled along with associated interlocking and control centre renewals. In addition to the service improvements provided by this £1 billion programme, construction works will be the noticeable features of the project with three major station re-developments and two new major structures. A brand new sub-surface station beneath St Pancras with new tunnels connecting to the East Coast Main Line is to be provided by the Channel Tunnel Rail Link.

1.3 A way forward

The application of systems engineering in the UK rail industry is still somewhat embryonic [2]. What was needed was an approach that was practical in its application, which would assist in the understanding of how the railway works as a system. We needed a model of the railway; this model would assist in the definition of the interfaces between engineering disciplines. It would be one model and would contain all the information that we need to ensure that the design has integrity.

2 Philosophy

The academic application of systems engineering will create a model of a system, identify requirements and define interfaces. These “models” however can be somewhat esoteric and do not necessarily assist in the understanding of the specific interfaces in the way that a physical three-dimensional model can.

The seed of the idea for our railway model had been germinating for some time. We are developing ideas from Brown & Root experiences in the petrochemical industry and other railway projects to apply a “first hit, best hit” approach to the design. It struck us that with suitably accurate surveys we could create complete scheme designs with proven geometric accuracy suitable for setting out and manufacturing purposes. With the scheme designed within the software at 1:1 scale, the finished product can be presented in a medium to suit the audience. The data model is the design.

Technologies and ideas develop faster in the pressurised environment of a live project than they ever could by deliberate R&D and it soon became clear that we had an opportunity to do something rather different and special. Developments in computing power and software functionality pointed the way. In the infrastructure design team, we are deliberately setting out to use the full functionality of software and hardware to build a model of the railway that has the potential to incorporate all of the railway system requirements. At each stage of development the model will be used to test the integrity of the scheme design. We anticipate that this approach will last through the life of the project and beyond.
Our aim is to apply a new philosophy of design development and integration to this railway. There is one model representing the whole design which can be used to validate the system requirements.

3 System development

3.1 System requirements

At the outset, we would have liked to be able to make the following statement with regard to the content of the model:

*The model shall include all system functions that occur on the railway.*

This is a rather ambitious statement. Technology at the time of writing is not far enough advanced (or affordable) to allow us to carry out all the tasks that we would like. Nevertheless, we know that it will be very soon, so we have chosen to wait, the model is being built in anticipation of technological advances.

Our approach is not, and never could be, a “Big Bang” [3]. The model has grown as the project has grown, and will continue to do so. It will serve as a tool for subsequent avenues of design development and investigation. With a considered approach, a programme need not notice the costs of development, at least not as an extra over R&D cost. In building the model we produce the necessary deliverables to ensure the success of the programme, the “nice to haves” occur naturally.

Therefore, we must re-state our requirements for the content of the model:

*The model shall be developed so that it will have the capability to include all system functions that occur on the railway.*

3.2 System core

A seed needs fertile ground to germinate and develop a healthy root system. Before we could start to grow our model we had to ensure that the data we were to work with was sound. The integrity of the whole model depends upon accurate and complete survey of the railway. From these roots will grow the trunk of the scheme design for the railway.

3.2.1 Surveys

Before we had started the integrated approach to the scheme design, a number of discrete projects had been procured across the inner area of the Thameslink 2000 programme. With each work package came a requirement for surveys. The lack of integration left us with X number design packages based upon Y number surveys (often overlapping) on Z number different control grids with X number different sets of feature codes to Y number different levels of accuracy.

The existing data was transformed into workable survey models. Style sets and feature codes were developed and the model structured such that the design process and subsequent presentation of results would take less effort. All
elements are now designed on one grid system. All new surveys commissioned by the programme have been carried out to a new and strict specification for structure and accuracy. Previous to this specification, much time was wasted tidying data for use by the design tools. New surveys have been carried out to two different levels of accuracy depending upon the design requirements.

Level 1 surveys have been completed to an accuracy suitable for setting out and manufacturing purposes covering all areas of infrastructure remodelling. We have used a mixture of conventional and cutting edge survey techniques. Lasergrammetry is being used to survey the core tunnels to the accuracy necessary for “zero clearance gauging”. Level 2 surveys have been completed for those areas where infrastructure changes are minimal and high detail is not yet required. Surveys have been created from aerial photography and tied into the project grid. In addition, the surrounding cityscape has been surveyed from the same photography to give the depth and dimension to the model that is required by tools described later in this paper.

3.2.2 Permanent Way scheme design

The permanent way design package [3] was chosen for its power, accuracy and ease of use. It is particularly clever in the way it creates and places switches and crossings.

Initial scheme development can be progressed at a pace un-imaginable even ten years ago. The whole of the inner area scheme design is covered by two CAD engineers backed up by the experience of only one Permanent Way engineer. This includes the remodelling of over 180 point ends, four major stations, a grade-separated junction and an eleven-track viaduct. The incarnations of the London Bridge station scheme design have each taken 10 working days to complete horizontal and vertical alignments. In the past, we might have expected such a task to take 10 working weeks with a considerably larger team.

3.2.3 Signalling scheme design

The signalling scheme design has been carried out using PLANS; a Railtrack mandated software package for the production of signalling scheme plans. By comparison with the Permanent Way design software it is relatively primitive, essentially consisting of a library of standard symbols that can be linked to a schematic representation of the railway along a datum line.

In the past, the signalling scheme plans have been drawn following a straight datum line. Such presentation does not give a good appreciation of the geography of the railway. We have overlaid our signalling plans on the permanent way plans to create a more geographically correct representation of the railway. The “line of way” datum has been created within the railway model so that equipment positions can be located in their true geographic location within the model.
3.2.4 Structural and architectural designs

A lack of definition of systems requirements early in the project life cycle has resulted in scheme designs being delivered in a number of different data formats and structures. Lack of a common structure has resulted in some considerable re-working of data to allow import into the model. To remove this problem for future development we have produced a specification to define the conventions to be used when building structural and architectural models. This does not mean that in the future our consultants will be mandated to use one particular software package, but the data labelling conventions will be.

3.3 System tools

A number of tools and processes have been developed by the programme to make the building of the model railway more efficient.

3.3.1 Signal sighting tool

It was the development of this simple but powerful tool that has led us to dare to dream to develop our model railway to its fullest potential. The signal-sighting tool is a specially developed add-on to the permanent way design software that allows us to test a driver's ability to see a signal.

With the PWay and signals designed to the same reference CAD datum line, data from the signalling scheme design, regarding signal type and location, is extracted and input to the track design model. The signal is positioned relative to its track by co-ordinates or by chainage and offset to the track. Direction, azimuth, dip, and beam focus are set for each signal. The sighting of a signal is tested to the following criteria:

- Line of sight, which can be tested at selected points, or points defined as default values calculated relative to line speed, at driver's eye position; and
- Time in focus, calculated at a given line speed and presented on a "rolling road" animation with the camera at driver's eye position.

The calculations are pure and precise. Provided the survey and the design is sound we can be sure that a signal has been placed correctly (or not). If there are problems with the sighting the signal can be re-positioned and analysed in minutes. The graphical interfaces of the tool give the engineer a good feel for the practicalities of signal positioning that would not always be obvious in the schematic diagrams or even from aerial plans. Reports are produced automatically for each signal.

By using this tool, we can prove beyond doubt that the signal can be sighted years ahead of its installation. It is being used to define protected zones within the designs for the new stations and structures, within which no structures or equipment may be placed that interferes with the sighting to a signal. We are also saving time and reducing risks by addressing these issues now. We estimate
a saving of around 10,000 man-hours on site to test the positioning of the signals.

The graphical presentation of the results of the signal-sighting tool is actually quite crude. Surfaces are simply rendered and the beam of light is represented by rays emanating from a point. This presentation is adequate for the engineer in most instances, but there are certain other issues such as lighting conditions, moving trains and the possibility of confusion with other signals that can not be so easily understood. The output from the tool is exported to graphical rendering packages so that all of these issues can be simulated, assessed and dealt with. This process is described in section 3.4.

3.3.2 Third rail design tool

Much of the Thameslink 2000 works are on a DC electrified railway, traction power supplied to the rolling stock via a third rail system. The third rail design tool is another specially developed add-on to the permanent way design software. The third rail is placed into the layout following built in rules for positioning in relation to permanent way and signalling features (though this is not a fully automatic process). With the rails and cables positioned, the tool tests the electrical continuity of the system. “Trains” are moved through the system to test the continuity of supply to ensure that a train does not stall after being stopped at a signal. Switching between sources of electrical feed (an issue when sections require isolation) and subsequent continuity of supply is tested.

3.3.3 Overhead line design tool

The northern area of the Thameslink 2000 network is overhead line AC electrified. The interface between AC and DC sections is being moved by this programme from Farringdon to Blackfriars and we have new tunnels between the East Coast and Midland main lines. At the time of writing, the tool is in development. Its requirements will be broadly similar to the third rail tool but will incorporate graphical modelling elements for use alongside the signal-sighting tool.

3.4 System progression

At the beginning of this section we mentioned “nice to haves”, those developments that we would like to have available to us, but we can not necessarily justify on grounds of cost, be it time or finance. In adopting our systems approach to the use and development of technology, we have managed to save enough time and money to justify further development. The trunk of our systems tree is strong and flexible; the “nice to haves” are branches on the tree that occur as a result of the organic growth of the model.
3.4.1 Signalling visualisations

Our "conventional" railway-signalling scheme has come up with a rather un-conventional solution to providing the necessary headways through the core to provide a 24 trains per hour service. The combination of closely spaced stations, long trains and short dwell times results in signals being spaced as close together as 80m, with two mid platform signals through each of the ten core platforms. With the perception that this would cause a somewhat stressful driving environment for our drivers, even with the added protection of TPWS, we are duty bound to make a rigorous assessment of the "Human Factors" issues. How will a driver react to certain scenarios? Will a driver be confused by other light sources? Will the change from darkness to bright sunshine temporarily blind a driver? On the eleven-track approach to London Bridge station, will a driver mistake a signal controlling an adjacent track for his own? The questions are myriad and endless.

![Figure 1. Slide showing signalling visualisation](image)

We have spent time and money building a model consisting track, signals, electrification, structures and stations, new and old. We had to do this as part of the design process. The combination of advances in graphical rendering hardware and software means that we can quickly and in-expensively give our models a degree of visual realism and believability. Four years ago the hardware required to create such images cost upwards of half a million pounds. Today, hardware of greater performance costs less than one hundredth of that price.
We use a rendering software package to give the believability to the model. A high specification application used extensively in television and the movies was chosen due to the way in which it deals with simulated light sources. As a result of the powerful lighting characteristics we have found that it has not been necessary to apply too much effort to the artistic merits of surface rendering. Simple surface textures and patterns are all that is required to give the model the level of believability required to be able to assess the kind of issues described above.

3.4.2 Construction sequencing

A programme as complex as Thameslink 2000 will of course take some years to implement. Over a five year period there will be almost 100 distinct phases of work ranging from the installation of a crossover to a blockade of the tunnels to signalling commissioning. We need to be confident that the works are achievable, as individual phases and as a sequence of events.

As we build the model we can assign attributes to the elements within the model, these attributes include among other things location, time-scale, and maintenance information. We can call into the model certain elements according to their time in the programme, including temporary and permanent works. At each phase, we can test the system integrity. The animations that we produce for each stage will be used as route familiarisation for drivers during the construction works.

3.5 System future

What does the future hold? As a major transportation project Thameslink 2000 is subject to public inquiry under the UK Government Transport and Works Act. In the meantime, we are progressing the scheme through the detailed design phase in anticipation of starting construction in the new year of 2002.

The potential for development of the model is limited only by what we can justifiably spend (and our imagination); technology no longer stands in our way. There is no firm guarantee that the project will commence, that can only be decided by the inspector at inquiry. We must therefore be very careful in deciding how we spend our money. The branches of the model development that are described below are, at time of writing, conceptual ideas. Some will no doubt see fruition as a tool to mitigate against risks at inquiry; others will be progressed on planning permissions being granted. The more ambitious may not be developed within the lifetime of this project, but we know they are possible and the lessons learned will be remembered and taken on by other programmes.

3.5.1 Construction management

Design, management and construction contractors will be appointed in the latter half of the year 2000. They will be obliged to carry forward the systems approach and progress the scheme design through to implementation and
operation. Programme management will ensure that the model is further developed and populated. The construction sequencing techniques mentioned in 3.4.2 above will be used not only to plan construction phasing, but to track changes to the railway through the five years of construction. The model becomes an as built record of the railway at a point in time.

3.5.2 Gauging studies

The model is constructed from data that has mm accuracy. Routines will be developed to automatically check critical clearances to the swept path of kinematic envelopes for new and existing rolling stock.

3.5.3 Driver training simulation

A natural progression of the signalling visualisations, mentioned in 3.4.1, above will be to develop a fully functional driver-training simulator. The model data has been structured deliberately for this purpose. Our approach means that much of the expense associated with simulator developments, which is the building of the model itself, has been carried out already. The “driving” routines are well known and can be simply applied to the model.

3.5.4 Multi train simulation

The project is currently using the VISION simulation package to test and prove the service requirements. The model as developed contains much of the data that such simulators require: geometry data including curvature and gradient; point positions; signal positions; line speeds; platforms; etc. Data reports from the design software can be tailored so that data input to the simulator software can be automated.

3.5.5 Interactive network simulations

Brown & Root have expertise in the limited application of such techniques from our involvement on the Docklands Light Railway. Computers running the vital signalling and control functions, and train regulation and scheduling, were linked with computers simulating track and vehicles. Commissioning tests could be performed on the simulator, resulting in optimal use of “real world” testing resources.

The ultimate development for the model will be to make the simulations described above fully interactive, not only with human interface but also with each other. We can build a working model of the railway, which will include: infrastructure; trains; drivers; signalling control centre; signalmen; traction power control centres; passengers; weather; and construction activities [4]. We know that it is possible to make computers talk to each other and that the processing power available to us means that tasks that required a mini-computer
five years ago can be carried out on your average home computer. This system can be made to work across a handful of networked PC’s.

The core of the network model is the railway infrastructure, containing all the data we need to run a railway: track; signals; power; stations; etc. This is the trunk of our systems tree. We have a driver-training simulator (DTS). This driver-training simulator can talk to the multi-train simulator (MTS) so that trains within the MTS are “driven”. Train position information is passed between the model, the DTS and the MTS so that “driven” trains and simulated trains appear in the DTS simultaneously. With an interactive link to the MTS, we can also control signals and pathways. The MTS becomes part of a signalling control centre (SCC) simulation. The signalman controls the routing of trains, “driven” and simulated through the network. Traction power control (TPC) simulators can be linked similarly, traction power characteristics can be assigned to trains running through the network.

We now have included in the model most of the variable factors that make simulation packages so difficult to apply to the real world. Train drivers do not all drive the same, some drive aggressively, some defensively, their respective trains have differing performance characteristics. Signalmen likewise are different animals, the experienced signalman knows immediately how to deal with crisis and delay. Weather conditions can be easily simulated, as can traction conditions. Our other main variable is the travelling public although on a commuter railway, some say, surprisingly predictable. The programme is already simulating passengers interaction with each other, the station concourse and platforms, and the platform/train interface to assess issues of station crowding and platform dwell time. We can reasonably predict how many passengers will enter the network from the north and south and even how many will board and alight at each station. What is less easy to predict is whether the passengers will delay the service. Therefore, the last module of our network simulation would be for simulated passenger interaction (SPI).

3.6 System architecture

The structure of a system can inevitably be presented in a number of different ways dependant upon the audience and the message.

3.6.1 System tree

The systems tree describes the organic growth of the model, from concept through to development and future growth. Ref. Figure 2

3.6.2 Interactive network simulator

This diagram, represented as a simple computer network, shows the likely structure of our interactive network simulator. Ref. Figure 3
Figure 2. Systems tree

Figure 3. Interactive network simulator
4 Conclusions

The philosophy described in this paper can be applied to any other railway. The philosophy is not only applicable to railways, but can be applied to any complex system development. We have taken advantage of advances in technology and existing techniques to make our lives easier and give ourselves more time to think about the interfaces and their impact on the system. Our structured and considered approach to the model development has resulted in real and measurable reductions in cost that far outstrip the time and money spent on R&D.

The development of this model railway was born out of the need to express our scheme proposals as an integrated system in a way that is easily recognisable to railway engineers. Our approach has resulted in the creation of a tool whose potential could be greater than the sum of its parts. The initiatives that others and we have developed are fantastic tools that can remove a great deal of uncertainty and adverse risk from scheme proposals. Bringing them all together would give us a great opportunity to increase our understanding of the railway as a system whole during the development of scheme proposals. We could analyse more precisely the impact of our decisions on the operation of the railway for the final scheme and during construction.

References