Planning tomorrow’s railway – role of technology in infrastructure and timetable options evaluation

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Abstract

Whether upgrading the railway infrastructure or improving rolling stock, investment decisions benefit from the consideration of many options – resignalling, route development, increasing competition (interoperability and open access), increased frequencies (freight on to the rails, faster, regular passenger services) – all of which should be assessed against several criteria – performance of the new railway, operator access requirements, engineering access, safety, revenue and cost. Traditional methods of assessment are often costly, slow and restricted to a subset of the available options.

AEA Technology Rail, working with Railtrack plc, have developed a powerful suite of software applications which radically improve the ability to assess many options quickly and reliably. At the heart of this suite is an infrastructure database containing current and future schemes and an automatic timetable generator, capable of satisfying operational and commercial constraints. In addition, this suite contains simulation models to assess the reliability of the timetable in operation and the signalling throughput, together with revenue and cost forecasting tools. These models have been used extensively in the UK to evaluate upgrade schemes faster, cheaper and more reliably than would otherwise be possible.

1 Introduction

The central points of this paper are:

- True assessments of capacity are easily overlooked when redesigning the network and service patterns. Timetable development techniques should be
utilised to analyse capacity, yet the deployment of such techniques is costly and is largely seen as a downstream activity.

- Timetable development should take place early in the planning process against a range of options in order to measure the gap between service aspirations and infrastructure capabilities. The only way to ensure this happens is through the use of IT to make the development processes faster, cheaper and more responsive to changing project needs.

- Currently the role of IT in timetable development is not targeted at the core activity of piecing the train paths together. Its current role is largely supportive and administrative rather than creative. As such it fails to address the time, cost and responsiveness problems associated with the process.

- Placing train paths together to form a plan is not unlike a giant jigsaw puzzle (albeit in several dimensions and without a picture on the box). Once the shape of each path has been described and some rules established on the placement of each path, it becomes possible to tackle this puzzle using IT.

- Software developed by AEA Technology Rail and Railtrack plc has been designed to piece together this puzzle. The concepts behind the Planning Timetable Generator are explained and the impact this new technology has on the planning process for development projects is also outlined. The modelling of infrastructure is described to demonstrate how PTG can assess the fit between service and network planning. Case studies demonstrating the effective application of timetable analysis using this software are also presented.

2 Planning Capacity Improvements on a Rail Network – the Role of Timetable Development

Capacity improvement schemes are common in the rail industry. Frequently, though not exclusively, infrastructure investments will be at the heart of these schemes. These may involve modifications to junctions which increase throughput, upgrades to existing lines and/or rolling stock to reduce journey times, or investment in an entirely new route. These schemes should be evaluated in terms of the cost and benefit they bring (e.g. revenue to the industry, social benefit, reduction in vehicle emissions).

In this section, it is argued that:

- Capacity is difficult to measure with confidence unless train paths are allocated and assessed against the constraints of the network.

- The only true measure of capacity therefore is the range of timetables that the network could support, tested against future demand scenarios and expected operational performance.

- Timetables are often the last stage of evaluating planned improvements. The techniques involved in producing timetables result in valuable diagnostics on network capacity which are lost during the latter stages of a project.

- The effect of the late development of timetables is that an insufficient consideration of the options may occur during the early stages of planning,
which is particularly important where capacity commitments are written in to investment contracts.

2.1 Understanding Capacity

Capacity on a rail network can rarely be defined and measured unambiguously. It is affected by a range of factors, not solely related to the engineering characteristics of the network and the rolling stock, for example:

- The mixture of operating speeds of services sharing common infrastructure.
- The required intervals between services.
- The variation in calling patterns of trains.

Although capacity can be estimated by investigating the throughput of the signalling system (usually via engineering simulation models), the true capacity is greatly affected by the order in which trains follow each other over junctions and into platforms. Simple attempts to define the theoretical capacity for a section of route rely on making general assumptions about a homogenous service pattern running over that route.

In practice, it is often only when a timetable is designed to satisfy train operators' preferences, taking account of the order and intervals between services within the operational constraints of the network, that a true measure of the capacity can be established. Further, the effective capacity of a network is greatly influenced by the operational performance of the trains, signalling systems and tracks.

2.2 Planning Changes and Investigating Upgrades

Where the infrastructure is modified, significant investment is required to deliver even modest changes. This investment may be provided by private backers or grants from national and supra-national bodies such as the European Union. Before money is released, evidence that the benefits (capacity increases) will be delivered is to be expected by funding bodies. Without the resources and time to evaluate the feasibility, there is a risk of entering into a contractual commitment to deliver which has not been properly assessed at the planning stage.

The process of planning modifications to the infrastructure and timetables may take the following pattern:

1. Designing aspirational service patterns with cost/benefit analysis.
2. Designing modifications to the infrastructure.
3. Evaluating engineering designs.
4. Fitting the service patterns on to the planned infrastructure (timetable production).
5. Detecting conflicts on the chosen timetable.

There are risks involved where the first two stages are not closely aligned. What is missing is a "gap analysis" between the aspirations of service planners, and the physical capabilities of the proposed infrastructure. There is little opportunity to gauge the true correspondence between service patterns and engineering plans until the first attempts at drawing the operational timetables have begun.
In the model of planning described in Figure 1, timetable production is a bottleneck. It takes a long time and can be unresponsive to changes in the overall project. It is tempting to schedule timetable construction as late as possible in the project plan, but this leaves little opportunity to feed back the capacity analysis that results from the process of matching trains to tracks. It also leaves little scope for the assessment of a timetable’s reliability.

![Figure 1: Current project design process](image)

3 Current Use of Information Technology in Timetable Development

Despite the current limitations of speed and responsiveness of the production process, there have been few successful applications of IT in the piecing together of a timetable. The main areas where Information Technology is currently used during development are:

- Demand/revenue forecasting and matching expected passenger flows to service plans (stopping patterns/service frequencies);
- To record and view the decisions of timetable planners;
- Engineering simulations e.g. to derive signalling throughput and journey times;
- Dissemination of information e.g. printing public timetables, connecting to operational systems.
Service planning takes a very high level view of the network, concentrating on flows of passengers and goods and looking predominantly at the increased demand for rail travel resulting from offering more attractive journey times, better connections and intervals of service.

Detailed network simulation models are used either at the initial stages of a project to assess the physical capabilities of engineering designs, or as a final check that the timetables do not contain conflicts between trains.

In between service planning and network simulation, the main role for IT in the planning of timetables is in the capture, representation and transmission of data. The main task of fitting the trains together is still a predominantly human activity. Although systems have been around for a while which can display train graphs and measure train separations, there has been little exploitation of the increasing power of computers to piece timetables together with sufficient accuracy. IT and computers therefore have to date done relatively little to improve the speed and efficiency with which timetables can be produced.

4 Automated Timetable Generation

4.1 Timetables and Jigsaw Puzzles

Creating timetables has long been viewed as a craft. A timetable planner will piece together a working timetable using pen and paper (or electronic equivalents). His/her vast experience is put to use to spot robust gaps in a schedule that could accommodate additional services. Over a lifetime, significant experience is gained and detailed knowledge of particular routes can be extremely valuable in resolving potential bottlenecks.

However, the task of creating a timetable is essentially a rule based one. Given knowledge of layouts, traction types and signalling systems, it is possible to define the separation required between any two trains. If one knows the running times of the trains (either from historical records or calculated by a computer simulation) and making allowances for the variation in actual running times, it is relatively simple to describe how any two trains can be placed next to each other. In this way, the rules governing how close trains can be spaced in the schedule are constructed. As illustrated in Figure 2, the path of any train has a particular shape, like each piece of a puzzle, which must be placed on the graph without overlapping any other piece. In practice, the graph is not two-dimensional. Alternative routes and platforms may exist, but while the problem becomes spatially larger, the fundamental rules governing train proximity do not alter.

It is also possible to describe the operators' service requirements as a set of rules. Trains may be required to leave at particular times, to take no longer than a specified journey time, to have a fixed interval between services, or to form connections at specified locations.
4.2 The Planning Timetable Generator (PTG)

AEA Technology Rail has collaborated with Railtrack plc to create the Planning Timetable Generator (PTG), a software system that will produce and appraise several thousand potential timetables for any combination of service patterns. Each potential timetable is assessed to check whether it contains operational conflicts and whether any service operators' requirements are not satisfied. By attributing a score to each conflict, or each failure to satisfy an operator requirement, the software uses a modified simulated annealing algorithm to search the solution space. This requires a mutation function which mimics the behaviour of a planner as they move departure times, schedule extra journey time or re-route services to devise the best timetable.

Having agreed the rules that will constrain the range of acceptable timetables, trade-offs must be established to allow PTG to make judgements in a congested network. This is done by assigning values against each of the operators' priorities. For example, a high priority may be placed upon satisfying connections where required, possibly at the expense of extended journey times. By setting low priorities on the rules governing the separations between trains, it is possible to use PTG to analyse where network bottlenecks would occur if the full set of service operators' requirements were to be enforced.
PTG will retain the timetables which, in terms of the trade-offs described above, best satisfies the range of commercial and operational objectives. PTG allows these timetables to be examined visually and provides feedback on how closely the aspirations match the effective capacity.

4.2.1 The Infrastructure Model in PTG

If PTG is to have a role in assessing the gap between service and infrastructure plans, it must be capable of evaluating the throughput and interaction of trains across the network as the timetable is pieced together. Additionally, it must be able to respond to changes in the planned layout as the development plans are updated. This section describes how the infrastructure model in PTG makes it suitable to fulfil this role.

The key to the infrastructure model in PTG is that it recognises the connectivity and throughput (margins and headways separating train movements) of the network. PTG is able to recognise where any two train paths cross and measure the separation between them. Using a detailed simulation model or observation, it is possible to derive the rules which separate the movements between trains based upon the physical characteristics of the signals and the traction type (e.g. slow, long freight trains need a greater clearance when crossing a junction). Because these are stored as a set of rules, and do not need to be calculated by simulating each proposed change to the timetable, PTG can rapidly assess the operational conflicts which may arise when the order of consecutive trains over a junction is changed.

As an example of how the level of detail in the infrastructure model is appropriate for the analysis in PTG, consider the layout in Figure 3. This layout is based upon a case study in the UK affecting one of the main routes between London and Scotland, showing the connectivity before and after a proposed upgrade.

![Figure 3: Grade separation scheme, showing connectivity before and after.](image)

The main change from this proposal is the removal of two potential points of conflict, so that trains can move from one side of the junction to the other without conflicting with trains travelling in the opposite direction. (In fact, four parallel moves become possible, subject to the signalling configuration with the proposed upgrade). While the engineering designs indicated a significant improvement to throughput, it was only when the timetable options over this junction and the surrounding area were investigated, with the required service intervals, connections and journey times, that the effective capacity could be gauged and the upgrade was found not to deliver the required improvements.
The level of detail required will depend upon the stage of the project. At the feasibility stage, it may be sufficient to describe the connectivity and estimated throughput (margins and headways) without detailed engineering designs and simulation studies. Before committing to a specific timetable, it will be important to consider a range of potential options to allow for variations in demand and changes to stock performance/reliability over the lifetime of the project, perhaps by concentrating on a repeating pattern rather than all-day timetables. As the project nears implementation, the network plans become more concrete and the operators’ requirements refined, the number of options run in PTG may reduce, but the model itself need not change radically. PTG allows for infrastructure to be modified, while tracking the development history, and also validates train routes to ensure integrity with the network plans as changes are applied.

4.3 Changing the Planning Process

In the process model outlined earlier in figure 1, the task of timetable production is a bottleneck, coming late in the infrastructure development project. By using technology to reduce timetable generation times and free up valuable resources from the task of creating a finished schedule, the following process changes become possible:

- Timetables may be used throughout the project lifecycle to assess the effective capacity as service plans are matched to the infrastructure.
- A greater number of infrastructure and timetable options can be considered.
- Network wide capacity assessments are easier, rather than a concentration on individual junction or station throughputs.
- Robustness modelling is possible to investigate how the timetable can be expected to perform under a range of operating conditions.
- Faster and more reliable feedback is available throughout the planning cycle (see Figure 4).

In addition to PTG, the suite of software includes integrated tools for the simulation of perturbed timetables to assess robustness (MERIT), demand and revenue forecasting (SCORES) and engineering simulations (VISION). These tools, which are outside the scope of this paper, support the capacity assessment and cost/benefit analysis during the development of the project.
Figure 4: The capacity management process

5 Applications

The Planning Timetable Generator has been used in infrastructure and timetable development in the UK since 1997. One early application involved an examination of the potential options for upgrading the East Coast Main Line in the UK. This line runs between London and Scotland via York and Newcastle. It carries high speed passenger traffic along its length, while the southern end carries a high volume of commuter traffic into London. In addition it carries significant freight traffic.

Several potential infrastructure schemes were identified including building viaducts to convert sections of the route from 2 track to 4 track and upgrading a parallel route to carry heavier freight and reduce signalling headways. PTG studies were carried out on many of the options. In some cases, it was shown that the favoured engineering solutions would not result in the required increase in capacity, as the bottlenecks were more to do with the mix of stopping patterns and speeds at the southern end of the route than the infrastructure capability. Based upon the analysis, it was shown that a specific combination of upgrading routes to divert freight off the main line, while providing satisfactory journey times to the freight operators, together with double tracking at targeted locations, was necessary to realise the investors’ requirements for service upgrades. Without PTG, it would not have been possible to investigate as many options nor to provide feedback on the effective capacity of the upgraded network so early in the planning process.

Since demonstrating its successful use on the East Coast study, PTG has been used on many studies including:
• The disruption caused to the timetable by adding in a regular interval service between London and her airports involving the addition of new lines joining the main corridors;

• The capacity improvements that are possible by recasting the service patterns on several of the trunk routes around the country without upgrading the infrastructure;

• The feasibility of service enhancements resulting from several incremental infrastructure improvements, none of which would otherwise have been assessed in combination.

6 Conclusions

The task of creating timetables is essentially one of piecing a giant jigsaw puzzle together. While the rules governing access to a network can be described in terms of required separation of trains and service operators’ requirements, the complexity of interactions and the sheer volume of the task make timetable creation extremely difficult. The traditional approach has been to rely on the experience of planners whose vast experience allows them to recognise patterns amongst the train graphs and respond accordingly to resolve complex scheduling tasks.

It is difficult enough to keep track of all the pieces of the timetable jigsaw puzzle without attempting to fit them together. Some pieces end up being hammered into place without the time to check their true fit. While computers are frequently programmed to complete rule based puzzles far faster than humans in other areas, the main use in timetable development has been to record where the pieces were last placed and to display the emerging picture.

With the Planning Timetable Generator and the associated suite of software tools, a potential extended role for IT in timetable generation has been demonstrated. With vastly reduced lead times and increased responsiveness, it is possible to use timetable production techniques to appraise capacity improvement schemes, not just to inform the public of train departure times. Without software such as PTG which is capable of creating and assessing timetables quickly and robustly, the true picture of the network’s capability may never emerge from the scattered puzzle.

References

