Rail Research UK

The universities' centre for railway systems research

System Level Cost Framework

Prepared for The Railway Safety and Standards Board

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Report: RRUK/B4/1

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Preliminary "start-up" study for Project B4 (System level cost framework)

Summary:

This report summarises an initial short-term study performed in support of Project B4 for the Rail Research UK centre. It was funded from a start-up grant provided to RRUK by Railway Safety Ltd (now the Railway Safety and Standards Board).

This short study has started a literature search and initiated the production of a simple cost database - these tasks are on-going. As part of this process the methodology for project B4 has been refined, although a number of important constraints and questions have been identified and so the development of an effective methodology (one of the objectives) is not complete.

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1. Introduction

This report summarises an initial short-term study performed in support of Project B4 for the Rail Research UK centre. It was funded from a start-up grant provided to RRUK by Railway Safety Ltd (now the Railway Safety and Standards Board).

The overall objectives for Project B4 are discussed in the next section, but the aims of the initial study were as follows:

to perform a preliminary literature search investigating techno-economic assessment techniques,
to gather initial cost data,
to refine the methodology to be adopted for Project B4,
to produce a preliminary report outlining the scope and focus of Project B4.

This report provides some background to Project B4, the literature search is briefly reviewed and finally the refinement of the methodology for Project B4 is discussed.

1.1. Background to Project B4

The title for project B4 is 'Development of system-level cost framework for assessment of sub-system trade-offs', and this project is under the theme 'Whole system performance'.

There is now a reasonable amount of reliable information giving annual operating costs of UK railways, broken down into key categories such as infrastructure (renewal, maintenance, etc), and vehicles (acquisitions, maintenance, etc), staffing and so on. The breakdown between these costs is largely historical, and in some ways a legacy of traditional working practices, but there is no evidence that the current situation represents the optimum. In addition, new working practices, new technologies, etc, can affect the trade-off, Figure 1. One good example is the trade-off between vehicle and track costs: Can more money be spent on the track to enable cheaper vehicles to be used, or are there opportunities the other way round? Another is to understand properly the relative merit of vehicle and track based solutions for increasing capacity.

The main aims of the project can be summarised as follows:-

- Identify and quantify techno-economic tradeoffs within the railway system
- Specific objectives:-
  - Assess optimality of current system
  - Determine trade-off sensitivities
  - Establish cost database

The main tasks of project B4 have been identified as:-

- Establish cost breakdown
- Identify sub-system changes and technological innovations
- Interaction upon other sub-systems
- Build a quantified interaction matrix (Figure 2)

They key deliverables from the project will be:

- Better understanding of system tradeoffs
- Important tool for helping to assess and prioritise the Centre's projects

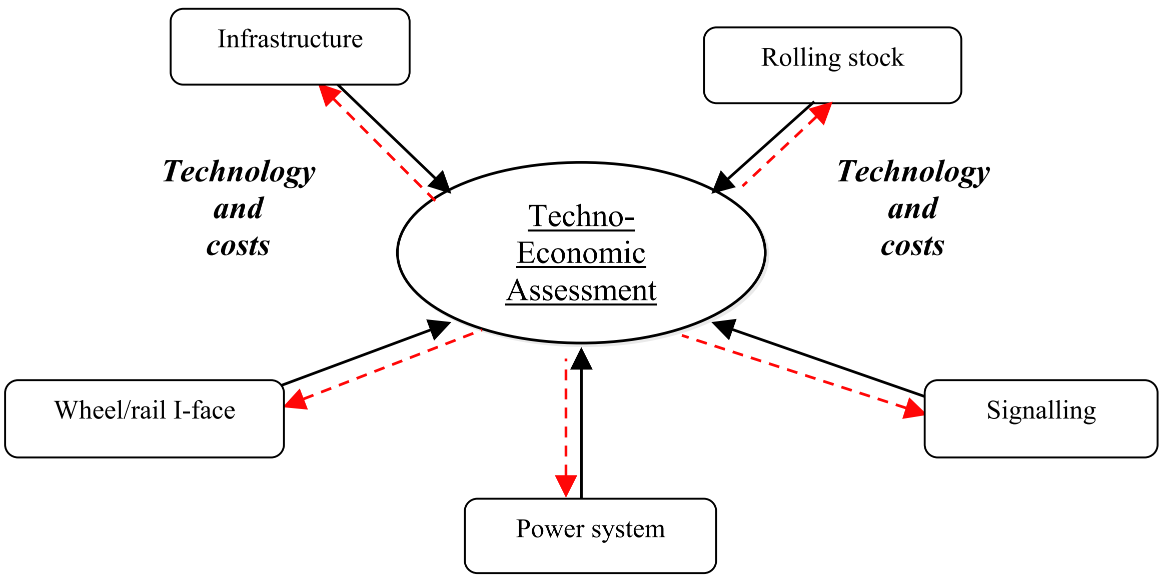

Figure 1 Subsystem Interactions

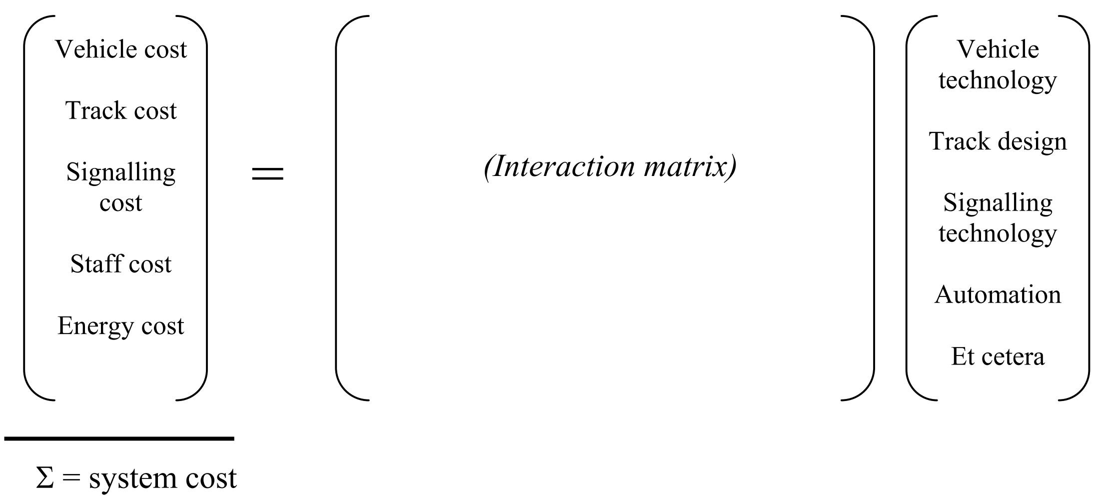

Figure 2 Interaction Matrix

2. Main Body of Report

2.1. Literature Review

A preliminary literature search, investigating techno-economic assessment techniques, has been performed. The following electronic databases have been searched:-

Metalib
Zetoc
OCLC
Aerospace and High Technology
BIDS
CASI Technical Report Server
Compendex
Edina
Inspec
Railways Performance Database - The World Bank's Railway Database provides information on scale, output and performance for over 90 railways worldwide permitting comparisons of performance and facilitating target setting by individual railways.
National Transportation Library - searchable database - USA http://ntl.bts.gov/
TAS Publications - analysis of UK public transport - http://www.tas-passtrans.co.uk/
Office of the Rail Regulator - UK - http://www.rail-reg.gov.uk/

The following key words or search phrases were used to search the databases listed above, as well as other electronic journals and web pages

Techno-economic (assessment/analysis/techniques./methods)
New technology (assessment/impact/railway/railway costs)
Railway Costs (database/technology/table/new technology)
Efficient Cost (assessing/assessment/technology/railways)

The main references identified are listed in section 5 at the end of this report.

2.2. Cost Information

Part of the project is to gather initial costs, and these costs have been broken down into the following sections:- infrastructure costs, operating costs, user costs and other costs - see Table 1.

Infrastructure	**Operating**	**User**	**Other**
Capital Costs - asset replacement Running Costs - maintenance - operation Track - variable with usage Table 2 - constant (drainage, vegetation etc) Signalling - inspection - servicing - renewals Structures Stations Depots	Vehicle Related - wear and tear of vehicles - fuel costs - staff wages - vehicle cleaning - vehicle servicing - vehicle maintenance - liability costs - depreciation Service Related - building maintenance Administrative - staff wages	Extra Time Costs - waiting time - travel time - crowding effects - search time - queuing time	Environmental - pollution - global warming - noise Accidents - risk value - material damages

Table 1 Cost Categorisation

The track related usage costs are primarily driven by vehicle characteristics (axles, axle loads, unsprung mass, suspension type, quality), track characteristics (quality, linespeed, numbers of switches and crossings), operating speed, and geography. Structure related usage costs, for example underbridges bearing the loads of passing trains, are typically driven by the weight, speed and composition of trains. The signalling related usage costs are driven by the number of trains passing key points, distribution of signalling assets, and the train characteristics (tonnage, speed, number of axles).

2.2.1. Track Costs

Track costs can be divided into three areas:-

i) a constant component which can be associated with environmental and safety related tasks, including drainage and vegetation control,

ii) a component which varies with volume, and

iii) a component which is largely directly variable with tonnage, of which the most important element is rail renewal.

Table 2 shows the track elements that are affected, at least to some extent, by usage. It should also be noted that these elements are also functions of track quality, as well as volume.

Cost	**Description**
Track Geometry	Vertical Geometry - deterioration is primarily due to differential ballast settlement under loading; this requires maintenance activity (tamping). The amount of maintenance will depend on the rate of deterioration, the standard required (line speed) and the effectiveness of maintenance.
Rail	One of the major causes of rail fatigue is loading (and cumulative loading); maintenance is required to manage defects; cumulative loading will determine renewal. Rail wear, which takes place on the railhead and on the side of rail in curves, is a direct function of usage.
Sleepers	These are affected by impact loads and (for concrete sleepers) abrasion due to contact with the ballast.
Ballast	Accumulation of fine material generated from usage (including the maintenance process itself).
Switches & Crossings	Subject to the same damage mechanisms as plain line track.
Maintenance	Inspection rates vary if total traffic passes threshold levels. Some minor maintenance activities, such as changing rail pads, are also usage-dependent.

Table 2 Track Costs variable with usage.

Railtrack (ref 16) has undertaken track usage cost modelling, and a model developed by them is shown in Figure 3. Axle-load and speed have been shown to be the dominant variables (ref 16).

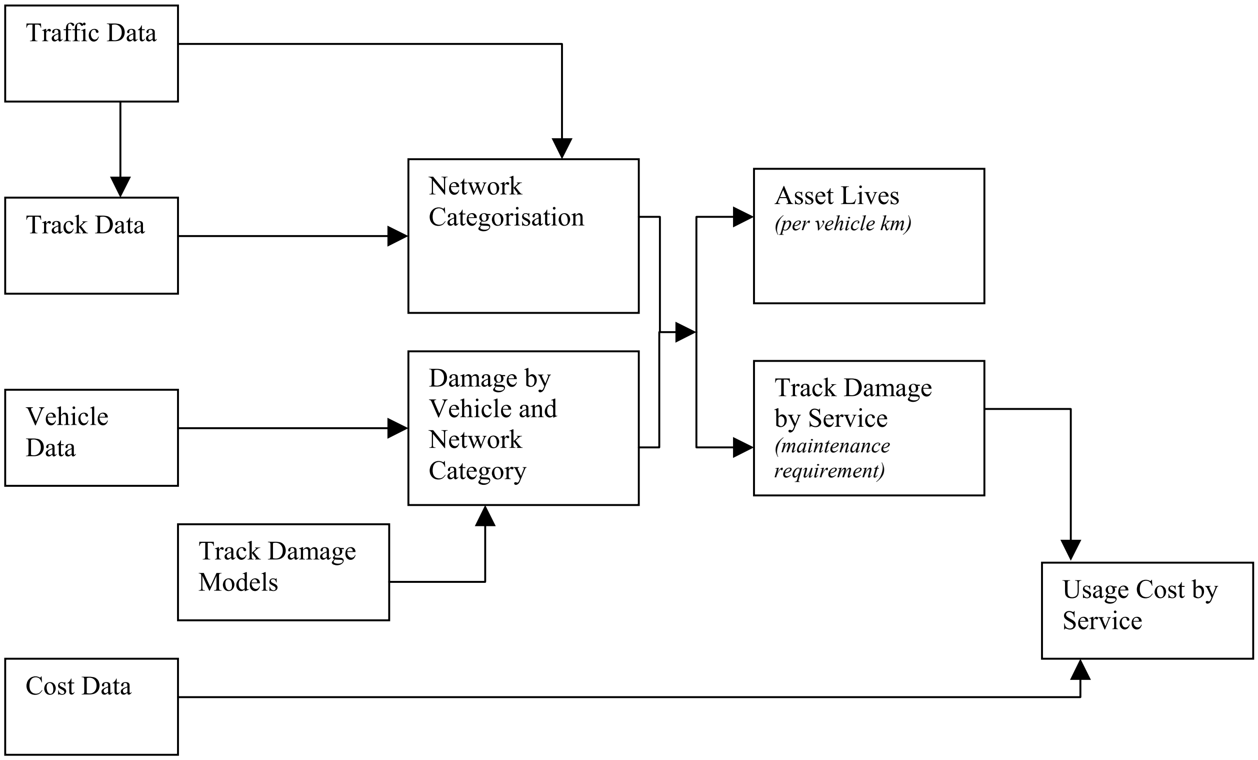

Figure 3 Track Usage Cost Model (Railtrack)

2.2.2. <u>Vehicle</u> <u>Costs</u>

Data for vehicle costs is still be gathered and consolidated. Table 3 identifies the main components of a typical railway vehicle.

<table>
<tr><th colspan="2">Component</th><th>Cost</th></tr>
<tr><td rowspan="10">Car Body</td><td>Car Body Shell</td><td></td></tr>
<tr><td>Interior panelling (floors, ceilings, partitions etc)</td><td></td></tr>
<tr><td>Car Body equipement (windows,doors, couplers)</td><td></td></tr>
<tr><td>Interior Trim (seats, lighting etc)</td><td></td></tr>
<tr><td>HVAC (heating and ventilation)</td><td></td></tr>
<tr><td>Electrical Cable</td><td></td></tr>
<tr><td>Auxiliary Converter</td><td></td></tr>
<tr><td>Battery</td><td></td></tr>
<tr><td>Electrical - other</td><td></td></tr>
<tr><td>Suspension elements</td><td></td></tr>
<tr><td rowspan="5">Bogie Frame (x2)</td><td>Frame</td><td></td></tr>
<tr><td>Transmission</td><td></td></tr>
<tr><td>Motors</td><td></td></tr>
<tr><td>Brakes</td><td></td></tr>
<tr><td>Suspension elements</td><td></td></tr>
<tr><td rowspan="2">Wheelset (x4)</td><td>Wheel</td><td></td></tr>
<tr><td>Axle</td><td></td></tr>
</table>

Table 3 Vehicle Costs

2.3. Technology-Cost Model Framework

This section proposes a preliminary formulation for the technology cost framework model. The aim of this model is to be able to assess the impact on railway technical productivity, infrastructure and costs created by the introduction of new railway technology. Different scenarios can then be used to assess the effects of the implementation of new technology.
Important inputs into this model are obviously technology and importantly its status, and this is discussed in the next sub-section. The relationships between design, performance and costs, and how these relationships are affected by changes in technology are discussed in section 2.3.2. The overall model is presented in section 2.3.3.

2.3.1. Technology Readiness Levels

One of the main results from the literature survey is the use of Technology Readiness Levels (TRLs), by a number of industries. These are important when the technology is not considered to be mature (i.e. for operational use), although for the "steady-state" situation with mature technologies the use of TRLs is not appropriate.

TRLs are widely used in the aerospace industry to estimate how far in a life cycle a given level of capability has progressed. There are some variations in the number of levels adopted but broadly they can be defined as follows:-

1 basic principles not yet established
2 conceptual design formulated
3 conceptual design tested analytically or experimentally
4 critical function/characteristic demonstrated
5 experimental system tested in relevant environment
6 pre-production system tested in relevant environment
7 in operational use

Changes in a TRL will incur additional costs (development costs etc) and time, but such a change may also reduce other costs such as production costs and or operational costs. Assigning costs and times associated with moves between TRLs enables them to be used for estimating cost and schedules.

2.3.2. Technology and Life-Cycle Costs

Part of the modelling process will involve addressing the links and relationships between performance and design (design and sizing relationships), and between performance and costs (Figure 4). Changes in technology will broadly impact in one of two ways:-

i) they will lead to improved designs/products, enabling a given level of performance to be achieved but with for example smaller or lighter components, or a higher level of performance for the same weight and size of components.
ii) they will lead to improved processes, i.e. a given design/product will be able to be produced or developed more efficiently.

It will be necessary to identify parameters and variables that characterise the technology modelled. Interrelationships between these technology parameters and variables will also be required to enable technological change to be quantified, for example relationships between weight and power for actuators. Cost relationships are also needed to translate measures of technology change from one value to another, to costs.

There are a number of ways in which a change in technology will have implications on costs, and these may be added costs or cost savings:-

i) changes in process and or design technology could lead to savings in production costs
ii) changes in process and or design technology could lead to added costs in order to achieve and implement the change
iii) changes in design technology could lead to savings in operational costs
iv) changes in design technology could lead to additional or reduced support costs

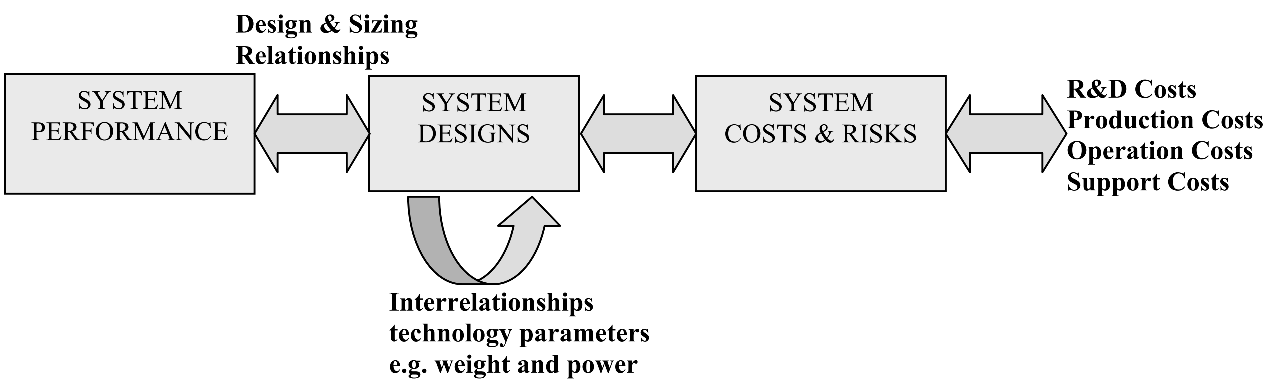

Figure 4 Technology Change Model

2.3.3. Technology/Cost Model

The provisional structure for the technology/cost model is shown in Figure 5, and is based upon a model proposed by Dodson [ref 1]. It incorporates the design/sizing relationships that take into account specific technology parameters and system interrelationships, both were discussed in section 2.3.1. The information embodied in the Technology Readiness Levels (section 2.3.2) would need to be tabularised to provide specific design and process technology values, and this would enable development costs to be estimated and included. Finally, the model also requires the cost interaction matrix (Figure 2, section 1.1) to be incorporated to provide estimates for vehicle costs, signalling costs, and operating and support costs.

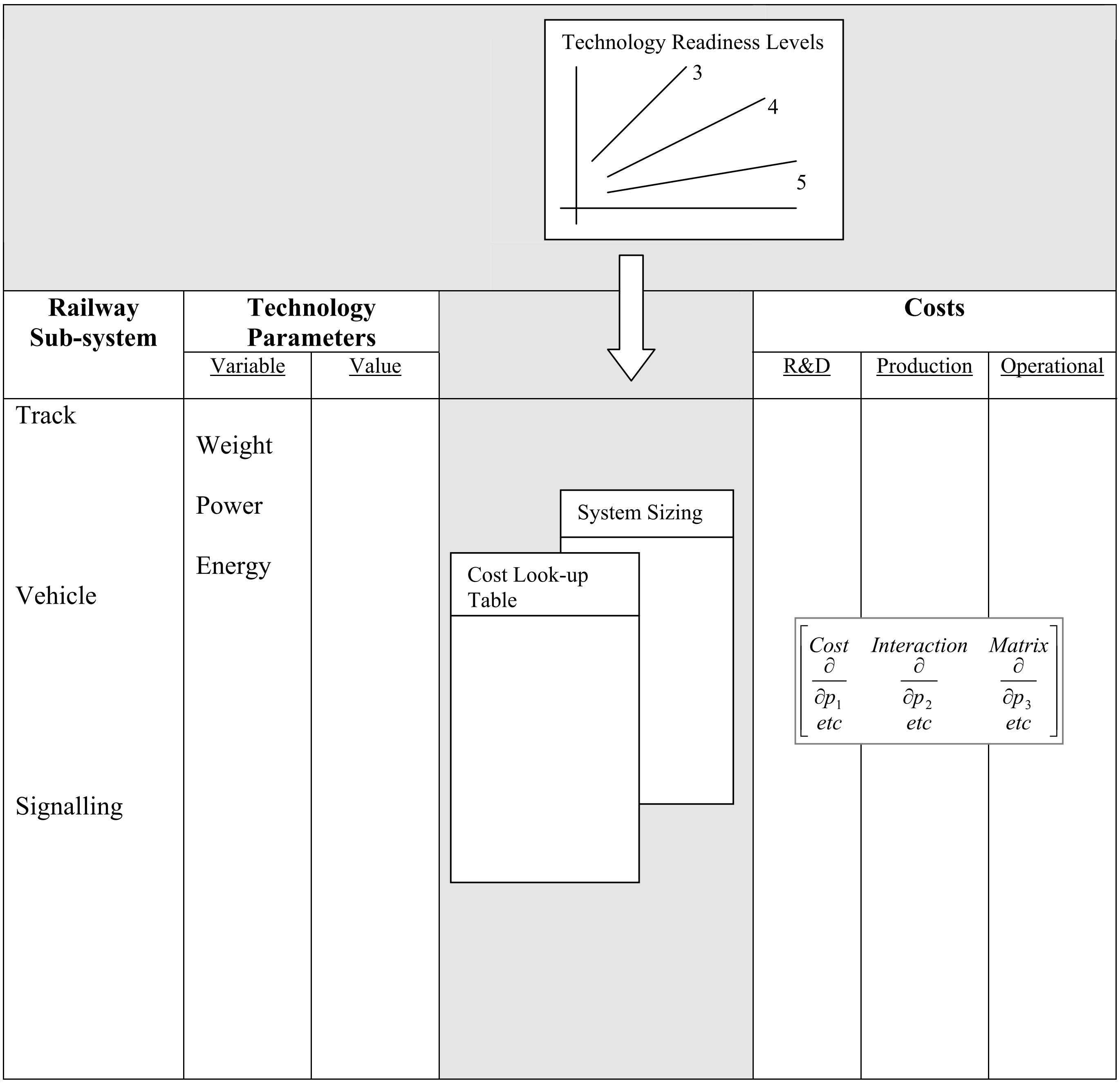

Figure 5 Technology-Cost Framework Model

2.4. Constraints and Difficulties

The early work has identified a number of constraints and difficulties, which need to be resolved.

The first question is that any optimisation approach relies upon a definition of the business scenario and the basic system objective that is to be achieved, and this will influence the way in which cost data are used. In a steady-state transport situation the objective may be to reduce the operating cost of the system, whereas when the market is growing (as is the case at present) then capacity increase is a key objective and cost reduction may be less critical. The situation is complicated by the fact that some technologies will be aimed towards different objectives so a holistic, possibly long term, view of the railway business needs to be accommodated if the techno-economic framework is to be usable.
The status of the technology also needs to be addressed. For instance, it will simplify the analyses if only mature technology in operational use is considered, however this may limit the effectiveness of the scenarios considered as realistically technology can be anywhere on a spectrum from 'basic concept' to 'in operational use' - see section 2.3 and 2.3.1.

Another issue relates to the traffic type and route characteristics. There are clear differences between passenger trains on a high-speed intercity route and freight traffic across a rural route, and the mixed traffic operation (intercity, regional, commuter and freight) that occurs on some parts of the UK railway.

In order to constrain the problem it will be necessary to determine a clear focus, for example assessing system cost reduction possibilities based upon a particular traffic type on a "stylised route" (i.e. one that has typical characteristics but is not a specific UK route).

3. Safety Implications

The nature of this preliminary study is such that there is no direct contribution to enhancing safety of the railways, although the incorporation of affordable safety levels is clearly implicit in any costing assessment. However, the final techno-economic assessment tool delivered by the system level cost framework study will enable engineers to evaluate the benefits of innovative safety technology and to put safety expenditure into a more objective basis.

4. Conclusions

This short study has started a literature search and initiated the production of a simple cost database - these tasks are on-going. As part of this process the methodology for project B4 has been refined, although a number of important constraints and questions have been identified and so the development of an effective methodology (one of the objectives) is not complete.

The techno-economic assessment tool will provide a better understanding of the system and sub-system tradeoffs, and more importantly will enable engineers and managers to evaluate the benefits of innovative technological developments on overall railway performance and costs. The results of techno-economic assessments of different scenarios will support the prioritisation and assessment of different research projects.

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