

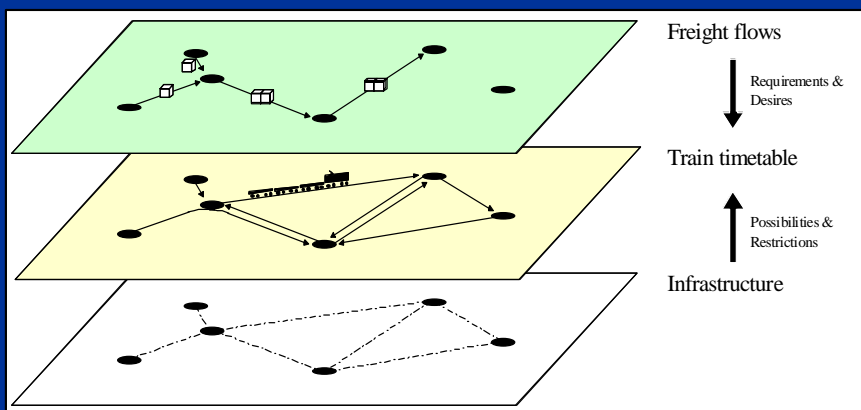
Activity-Based Rail Freight Costing

A model for calculating transport costs
in different production systems

GERHARD TROCHE



**KTH Architecture and
the Built Environment**



Doctoral Thesis in Railway Traffic Planning
Stockholm, Sweden 2009

KUNGLIGA TEKNISKA HÖGSKOLAN
Royal Institute of Technology
Division for Transportation & Logistics
Railway Group

TRITA-TEC-PHD 09-002
ISSN 1653-4468
ISBN 13:978-91-85539-35-2

Activity-Based Rail Freight Costing

**A model for calculating transport costs
in different production systems**

Gerhard Troche

Doctoral Thesis

Stockholm, February 2009

© 2009 Gerhard Troche
gerhard@infra.kth.se

Division for Transportation & Logistics
- Railway Group -
S – 100 44 STOCKHOLM
Sweden
www.infra.kth.se

Printed in Sweden by Universitetservice US AB, Stockholm 2009

Innehåll	
Preface	7
Summary	9
1 Introduction	17
1.1 Background	17
1.2 The need for information on railway costs	23
1.3 Goals and purpose	26
1.4 Delimitations	28
2 Literature review	31
2.1 Introductory remarks	31
2.2 General theory of costs and cost calculation	33
2.3 Transport cost models for rail freight	51
3 Methodology	67
3.1 Research approach	67
3.2 Selection of activities and cost items to be depicted	71
3.3 Model validation	75
3.4 Methods of data collection	78
4 Structuring the rail freight system	83
4.1 Products and production systems	83
4.2 Operating principles for freight trains	90
4.3 Changing organizational structures in the railway sector	99
5 Cost allocation in the rail freight system	103
5.1 Allocating costs in a specific transport system	103
5.2 Handling the joint and common cost problem	108
5.3 The Empty Wagon Problem	111
6 General structure of the model	115
6.1 Overview	115
6.2 The infrastructure level	117
6.3 The train service level	121
6.4 The freight-flow level	122
6.5 Utilization model	123
7 Databases in EvaRail	125
7.1 Overview	125

7.2	Freight flow database	128
7.3	Infrastructure database	129
7.4	Train database	131
7.5	Commodity database	133
7.6	Vehicle database	134
7.7	Load unit database	136
7.8	“Interconnecting” databases	137
7.9	Other cost databases	139
8	Cost calculation in EvaRail	143
8.1	Overview	143
8.2	Wagon capital or leasing costs	148
8.3	Wagon maintenance and service costs	152
8.4	Locomotive capital or leasing costs	154
8.5	Locomotive maintenance and service costs	159
8.6	Driver costs	161
8.7	Energy costs	163
8.8	Infrastructure charges	168
8.9	Activity costs	172
8.10	Other costs	178
8.11	Empty running factors	184
9	Examples of results in EvaRail	189
9.1	Applications with analysis of cost structure	189
9.2	Unit train Mora-Gävle	190
9.3	Wagonload Helsingborg–Sundsvall – heavy freight	193
9.4	Wagonload Helsingborg–Sundsvall – light freight	197
9.5	Liner train system and dual-power locomotives	199
9.6	Intermodal traffic	201
9.7	Express freight trains	203
10	Discussion and conclusions	205
10.1	Methodological issues	205
10.2	Model results	209
10.3	Further model development and improvements	211
11	Literature	215

Preface

This thesis is the concluding report of the research project ‘Cost and supply model for rail freight’, carried out between 1999 and 2008 at the Centre for Research and Education in Railway Engineering at the Division of Transportation & Logistics at the Royal Institute of Technology (KTH) in Stockholm.

My principal supervisor has been Bo-Lennart Nelldal, adjunct professor in train traffic planning at KTH, assisted by Arne Jensen, professor in transport economics at the School of Business, Economics and Law at Göteborg University. All material in this thesis has been produced by the author. The project was financed by Banverket, the National Swedish Rail Administration, via KTH Railway Group.

My sincere thanks are due to all the people who contributed to the project with information, knowledge and valuable comments. It was a pleasure for me to find people with a genuine experience of, interest in and fascination with railways and freight transport. I would also like to thank my supervisors Bo-Lennart Nelldal and Arne Jensen for their invaluable help – and sometimes also their patience – without which this thesis would not have been possible. Finally, for their patience and understanding, my special thanks go to my parents, all my friends and especially to those people who accompanied me and formed a part of my life during the years I worked in this project and who reminded me that there is a life even outside cost models and railway yards.

Stockholm, January 2009

Gerhard Troche

Summary

Europe's railways are at present undergoing far-reaching changes. The restructuring takes different forms in different countries and the pace also varies. One common denominator, however, is the growing influence of market forces on development, principally of freight traffic, in almost the whole of Europe. Freight traffic, as opposed to a large proportion of passenger traffic, is operated – and forced to maintain its position – under commercial conditions. The restructuring also affects the cost structure and – which is important in connection with the present thesis – how this can be illustrated in a cost model for rail freight traffic.

The above means that costs and revenues, and the relationship between the two, are two key aspects that ultimately determine the railway's future position in the freight transport market. Knowledge in these areas is therefore important, partly for the railway companies themselves, but also for other parties in the sector who are in some way affected by, and/or take decisions that have relevance for freight traffic. These might for example be transportation customers, infrastructure operators, politicians and researchers.

This project focuses on the cost side, where knowledge is today inadequate, not least outside of the railway companies. Figure 1 illustrates fields where cost information is used and needed.

A cost model that illustrates the railway's many and rather complex production systems would thus satisfy many different players' need for cost information. The aim of this project was to develop such a model and use it in selected case studies to analyse the cost structure and the effect of changes in the railway system, thus increasing understanding of what factors are the cost-drivers in the railway system.

The cost model has been delimited to constitute a business economics model from a train operator's perspective. External costs are thus not calculated. The model calculates transportation costs at the flow level. By being able to handle several flows, the model also makes it possible to calculate costs for larger transport systems, in which cases the

delimitation of such a system may vary depending on the user of the information (for example train operator, transportation customer, etc). Detailed information on all these flows is, however, a requirement.

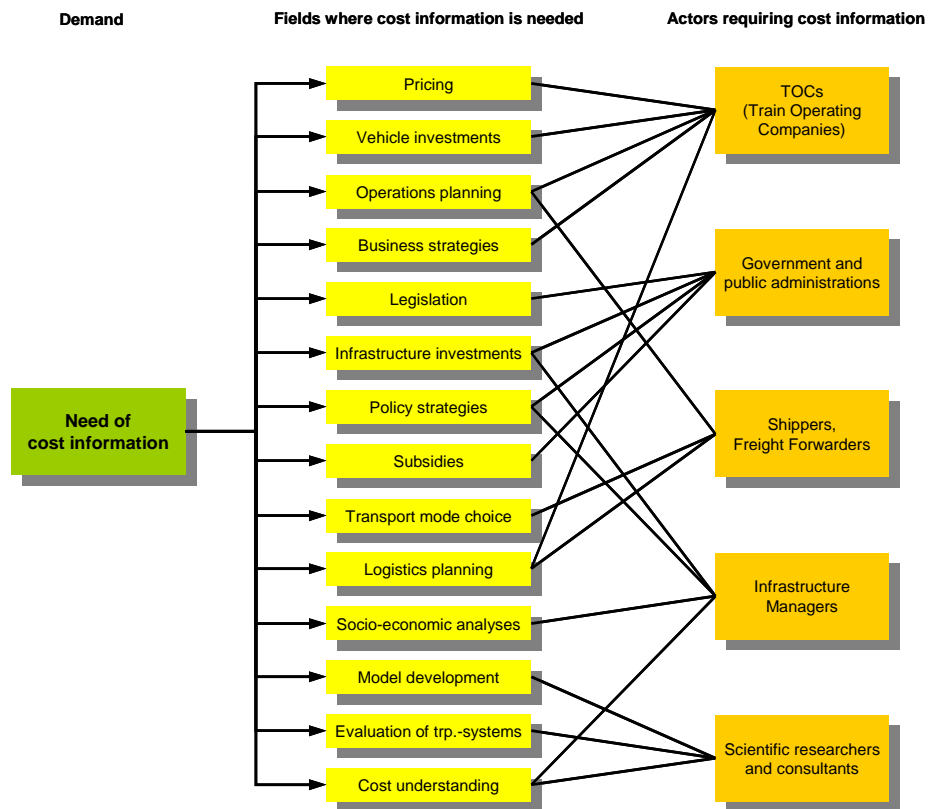


Figure: *Fields where information on costs in rail freight is needed and players who require information (G.Troche)*

The model was developed with a view to being able to illustrate different production methods. It is thus not limited to a certain kind of traffic or production arrangement. This means that the model in this sense is a general one, which also opens up for using the model to evaluate new production methods.

The model also provides a basis for calculating transportation prices; the costs, however, are only *one* (albeit important) factor in pricing transportation. The other important factor is the market price, which is determined by the competitive situation. It is, however, reasonable to

assume that in a longer perspective there is a strong linkage between transportation prices and transportation costs. By setting a profit margin, based on an assessment of the competitive situation, a user of the model can thus also calculate a transportation price.

The project was conducted in six steps:

- 1) Literature analysis
- 2) Mapping of production systems in rail freight traffic
- 3) Identification of activities, resources and costs
- 4) Definition of cost allocation principles for shared costs
- 5) Construction and programming of the model
- 6) Validation and calibration of the model

The literature review showed that few detailed transportation cost models exist for railways. The models often only illustrate certain production methods. The lack of transportation cost models for railways and the shortcomings in the few models that do exist can partly be explained by the complexity of the railways' production methods that is much greater than for practically all other types of transport. This makes it very difficult to adapt by any simple means a model for truck transportation, for example, to also suit rail transportation. Another important reason is the difficulty involved in obtaining relevant cost data because the necessary data is to a large extent confidential. This fact also explains why information about the models is sometimes very scanty. On the other hand, these shortcomings also illustrate the need for a general model.

The ABC (Activity Based Costing) model was identified as a suitable type of model for calculating transportation costs. Most existing models are also of this type. Compared to TCS (Traditional Cost Accounting), ABC models have the advantage that most of them are especially suitable for operations with high overhead costs, strongly diversified products and complex production structures, conditions that apply to the railways to a very high degree.

The mapping of the railways' production systems showed a great many different systems (figure 2). This project also included systems that may be brought into use in the future. Each individual system can itself be fairly complex, but the complexity of rail freight traffic as a whole is increasing, not least because the systems are not clearly delimited – and consequently, in a model, are not *delimitable* – against each other. One single transportation assignment may pass through different production

systems on its way between consigner and consignee and/or during empty trips.

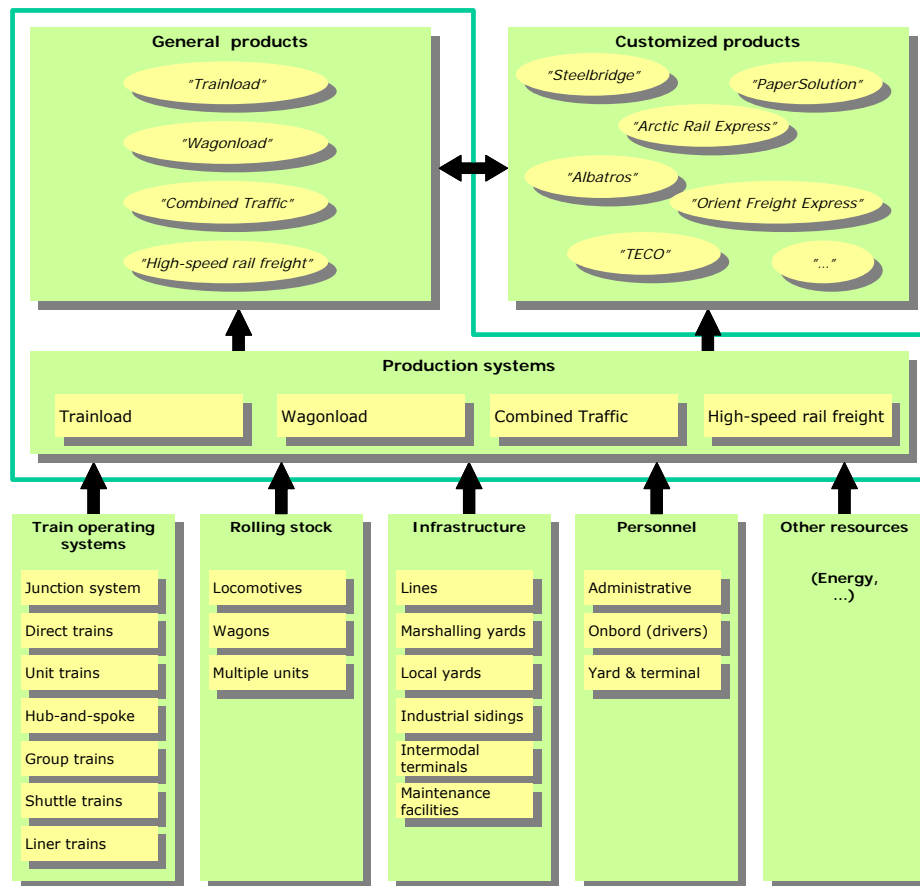


Figure: Clarification of the terms "products" and "production systems" (Gerhard Troche)

The approach chosen to handle this in the model is to break down the production systems into activities. Many activities occur in several systems. A production system is thus a result of a specific combination of activities and what characterizes them. No production system is thus specified in the model, but the activities in each respective chain. If the user adds several flows, the production systems thus grow on the basis of how the user specifies the transportation arrangements. This has the advantage that the definitions and the bases for dividing the production

systems can then be chosen freely dependent of the purpose of the analysis without this affecting the model's cost calculations.

	Trainload	Wagonload	Combined Traffic	High-speed rail freight
Train hauling	+	+	+	+
Shunting	o	++	o	o
Marshalling	-	++	-	-
Loading/unloading of freight in/on/from wagon	+	+	-	+
Transloading of freight between wagon and truck	+	+	-	o
Transloading of Loading Unit between wagon and truck	-	-	++	o
Transloading of Loading Unit between wagon and wagon	-	-	+	-

- ++ very common
- + Common
- o Seldom
- Never or almost never

Table: Activities in the rail freight system and in which production systems these occur. (G.Troche)

Cost information about resources and activities have primarily been obtained through interviews with experts. This type of information is not normally available from open, printed sources – at least not as primary sources. Some data has also been able to be obtained from industry journals.

Shared costs have been allocated according to the following criteria or combinations of criteria: (1) time, (2) distance, (3) weight, (4) number of wagons/vehicles, (6) number of load round trips. By splitting up the costs as far as possible, a relatively accurate distribution of the costs can be made. The user can, for example, distribute part of the maintenance costs by distance, part by time and yet another part by the number of round trips. An attempt has been made to keep the need to distribute shared

costs to a minimum by applying, where possible and meaningful, a bottom-up principle when calculating costs, which means that the costs are then direct costs.

The model consists of three “levels”, where the lowest is made up of the infrastructure, i.e. the track network, consisting of nodes and links. There is thus a network in the model that is used to calculate distance and specify train supply and transport flows, which are the other two levels. The model contains an automatic route assignment, but it is possible to determine the route manually as well; the train supply is input manually.

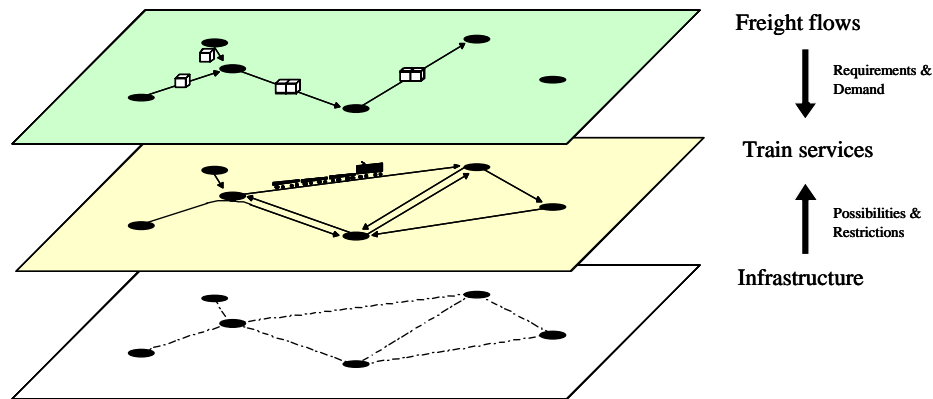


Figure: The three levels in the model (G. Troche)

The model was validated and calibrated through discussions of output data and model structure with experts. The model has subsequently been applied in a number of fictive, yet realistic, transport concepts to test the model’s technical functionality and in an exemplifying manner analyse the effects of different improvement measures in the railway system. Examples of measures that have been studied include higher axle loads and bigger loading gauge and the introduction of new traction in the form of dual-power locos. For these, the cost effects were quantified for specific flows. The results of these calculations have also been discussed with experts and were included in the calibration work.

The project has thus resulted in a model that is able to illustrate and cost complex transport chains, including complex chains, in the railway system. The most important future development opportunities lie in integrating automatic route allocation for empty-running locomotives, to be able to handle systems with many dispersed flows (e.g. in the

wagonload system) more easily, and an improved resource utilization model. Interfaces also need to be developed to other models, e.g. demand forecast models and transport choice models. A combined cost and demand model or model system would constitute a powerful tool for quantifying both cost *and* demand effects.

The most important conclusion from the calculations that have been performed using the model is that there are two approaches that can be used to improve the railways' competitiveness:

- Give the railways better possibilities to utilize economies of scale, principally in the form of higher axle loads, a bigger loading gauge and longer/heavier trains. This does not in principle require any system changes, “merely” an increase in the present maximum values of the above parameters.
- Introduce new production systems such as liner trains in order to reduce the costs at each end of the transport chain and to widen the market by covering even more disperse goods flows. This also assumes new innovative vehicle concepts such as dual-power locomotives and new transshipment technologies for small-scale low-cost terminals.

Resource utilization has a great impact on transportation costs in all production systems. The implementation of some of the proposals mentioned above could contribute to a better resource utilization.

1 Introduction

1.1 Background

From development hitherto and the present situation of rail freight in Europe, it can be concluded that there is an urgent need to take both short-term and long-term measures to improve rail freight's profitability, performance and competitiveness.

In 1970, the railways in Europe (EU 15) had a market share of 31% of total freight transportation measured in ton-kilometres. Road traffic accounted for 54% at that time and domestic shipping transported the remaining 15%. By 1995, the railways' market share had fallen to 15%, while that of road haulage had increased to 77% and shipping's share had fallen to 8%. Over the course of little more than three decades, the railways' market share has been halved.

During the last decade rail's market share in the enlarged European Union (EU 27) has been rather stable, seen for Europe as a whole. However, the development is not any longer as uniform as it has been before in a smaller EU, when almost all countries showed a general downward trend for rail freight.

Looking more closely at the present situation – also including the new EU members – it can be observed that rail's market share in most new member states is still significantly higher than in the rest of Europe. However the transition from planned economy to market economy has resulted in heavy losses for rail, often accelerated by a lack of ability – and maybe sometimes even a lack of willingness – on the part of the member states to adapt their railways to the new conditions, regardless of whether it is a matter of infrastructure, organization, finances or culture.

In the old EU member states the development isn't uniform neither and several countries now show a significant positive trend for rail. Generally countries with a deregulated rail freight market and strong intramodal competition show – thanks to the positive effects of these measures on costs and service quality – an increase in rail freight, while countries less

committed to deregulation of the rail freight market still continue their downward trend.

In Germany rail freight ton-kilometres have grown continuously by almost 50% from 2001 to 2007 and increased its market share from 15,7% to 17,3%. In Great Britain rail freight has increased by more than 70% within little more than a decade from 13,1 billion ton-kilometres 1994/95 to 22,2 billion ton-kilometres 2006/07 and holds now a market share of 11% compared to 9% before. In Sweden rail freight ton-kilometres reach an all-time high in 2007 and were 16% higher than 2000; the market share is stable on a compared to other European countries very high level of 23%. On a European level rail freight ton-kilometre have increased by almost 14% from less than 390 billion ton-kilometre in 2002 to more than 430 billion ton-kilometres in 2006.

Modal split ton-kilometres EU-27 1995 - 2006

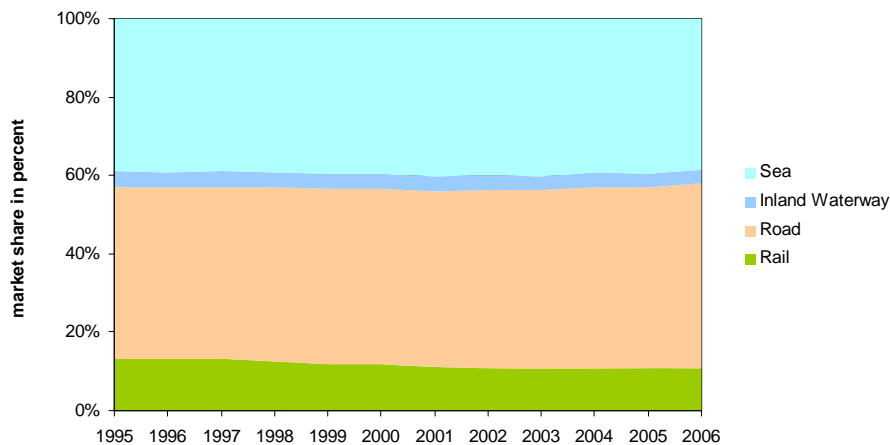


Figure 1.1: Performance (Data: EU-DG TREN / Eurostat, 2007)

However, seen in a global perspective the situation in Europe is still characterized by relatively low market shares for rail and high market shares for road (see fig.1.3). There are, of course, many explanations for the high market share in other parts of the world, however, the fact that rail has a much higher market share in many different parts of the world with widely varying geographical conditions, traffic patterns and organizational and political frameworks indicate that there still is a considerable unexploited market potential for rail in Europe.

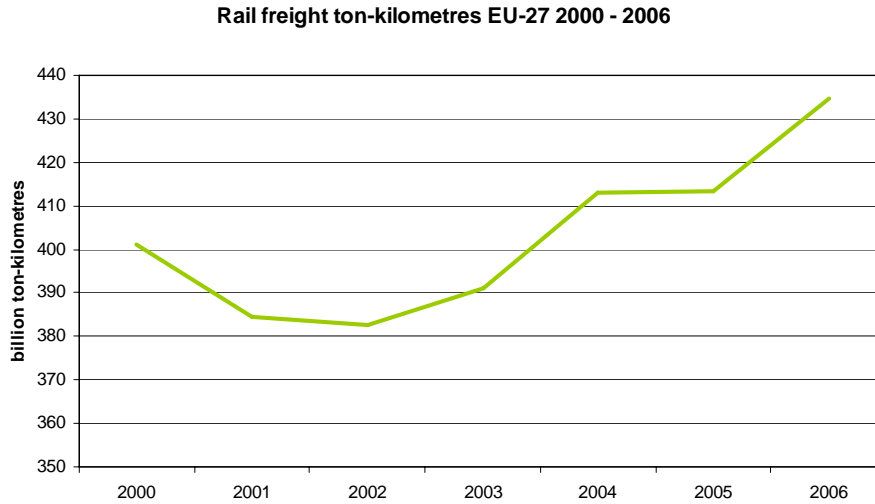


Figure 1.2: Development of rail freight ton-kilometres 2000-2006 in EU-27. (Data source: EU-DG TREN / Eurostat, 2007)

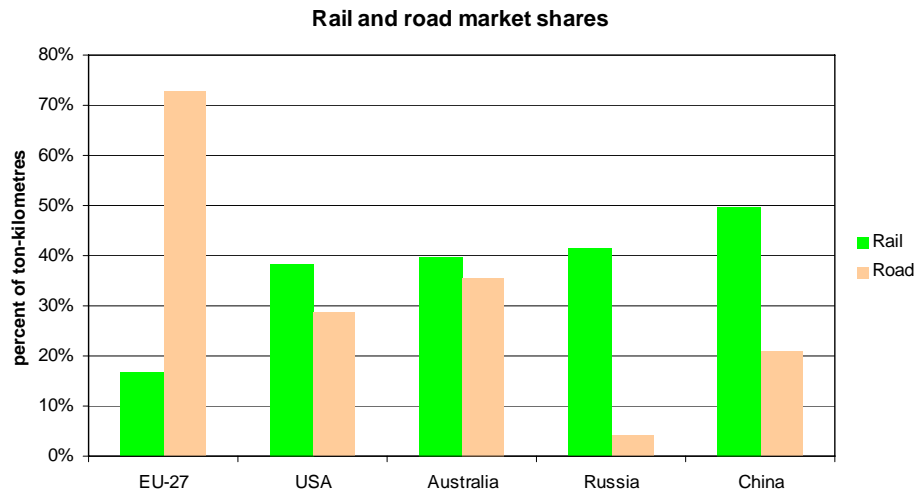


Figure 1.3: Rail and road market share in different world regions, total market comprises rail, road, internal waterways and pipelines, for Australia even coastl shipping (EU, Russia: 2006; USA, Australia, China: 2005) (Data source: ALLIANZ FÜR SCHIENE, 2008)

A strategy to break a negative trend for rail or to strengthen the foundation for a sustainable turnaround has to address both the supply and the demand side of rail freight. The services offered by the railway companies have to meet today's customer requirements and the services have to be produced efficiently to make them cost-competitive. Higher productivity combined with greater attractiveness can improve profitability for rail freight.

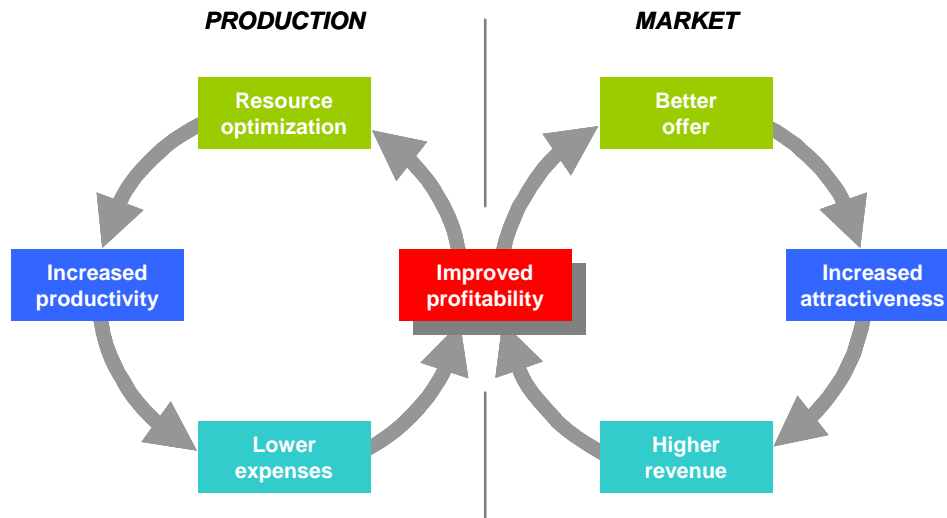


Figure 1.4: A strategy for profitability (Source: Sparmann 1997, in German)

The challenge is to fill the strategy above with concrete content and to identify suitable measures. There is no lack of ideas for improving rail freight's prospects. Two approaches can be distinguished, based on the perception that the railway market is surrounded – and limited – by both technical and economic restrictions (which to some degree are interdependent), and recognition of the fact that the market price can scarcely be influenced to any larger extent by the railways, since it is set in practice by its competitors, in most cases road haulage. The approaches must therefore focus on the cost side. One approach is to reduce the unit costs of production resources by both taking advantage of increased competition on the resource side and implementing new production methods; another is to achieve economies of scale by (re-)moving technical restrictions in the form of loading gauges, axle and metre loads, train lengths, etc. (fig. 1.5).

Approaches to enlarge the railfreight market and improve profitability

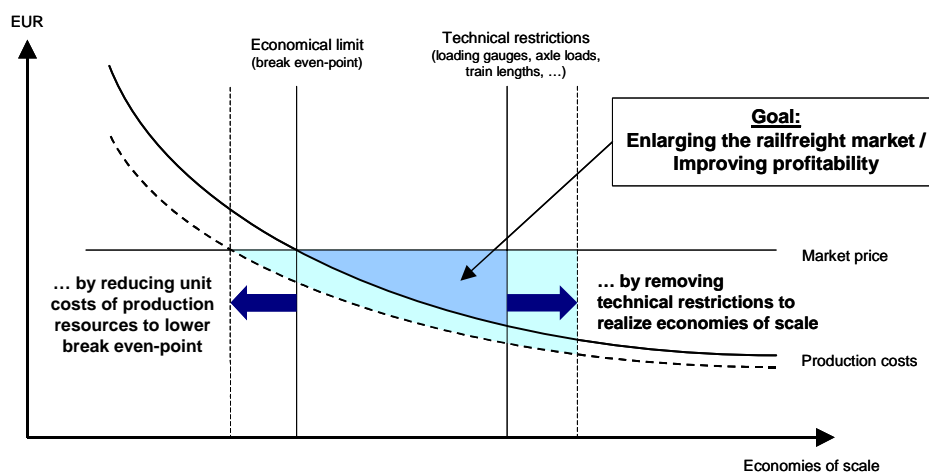


Fig. 1.5: Approaches to enlarge the rail freight market and improve profitability. (Gerhard Troche)

This study focuses on the cost effects of technical and operational improvements in the railway system, thereby not underestimating the necessity of measures on the organizational and political level. Measures on the technical/operational level and those on an organizational/political level are often to some extent interconnected with each other. The latter are important when it comes to implementing technical and operational measures.

Technical improvements refer to changes in the physical resources in the form of wagons, locomotives, etc. A certain locomotive class may for example be replaced by a new, “better” locomotive with different technical characteristics. *Operational improvements* refer to *how* the physical resources are deployed, for example how the trains run (routes, speeds, train formation, train lengths, stopping pattern, etc.).

In general, it can be said that operational changes can be implemented faster and can consequently give quicker economic effects – within 1-2 years but often within weeks. Technical improvements often take longer

to implement, typically from one year up to several years. They also often entail higher investments.

There has been a tradition in the railway sector to analyse technical improvements in the first place from a technical point of view, i.e. to look at the technical feasibility and performance, while many times disregarding economic aspects.

However, in an increasingly liberalized and competitive freight transport market – and growing in ability and reluctance on the part of states to cover financial holes in the budgets of their railway companies – it is natural that the railway companies are paying increasing attention to the economic effects of their decisions. The need to adopt an integrated approach when looking at certain measures – taking into account both technical and economic aspects – is today widely accepted. This of course also holds true for the new private entrants in the rail freight market. They are forced to adopt clear business-oriented perspectives from the very outset.

1.2 The need for information on railway costs

From the trend to run railways as a business on a commercial basis arises the need for detailed information about costs in the rail freight system. An understanding of costs and knowledge about cost-drivers are becoming essential in business and policy decisions. They are a key factor for the successful management of a railway company. This is especially true since railways are faced with the need to modernize their production systems in order to meet today's and tomorrow's customer requirements, something which often requires substantial (initial) investments.

There is thus a need for a tool that can predict the economic effects of technical and operational improvements in the railway system.

Cost information and understanding is needed ¹

- to identify money makers or money losers
- to take resource allocation decisions
- to plan and control operations and activities
- to find economic break-even points
- to compare different options
- to discover opportunities for cost improvement
- to prepare and actualize business plans
- to improve strategic decisions making

Potential users of a cost model for rail freight and/or its results can be found in a number of different target groups (see even fig. 1.6):

- Train operating companies
- Government and public administrations
- Shippers
- Infrastructure Managers
- Scientific researchers

Table 1.1 below contains a list of fields in which these groups may use the model as a decision-support tool.

¹ BERRY, L.E. (2005), completed

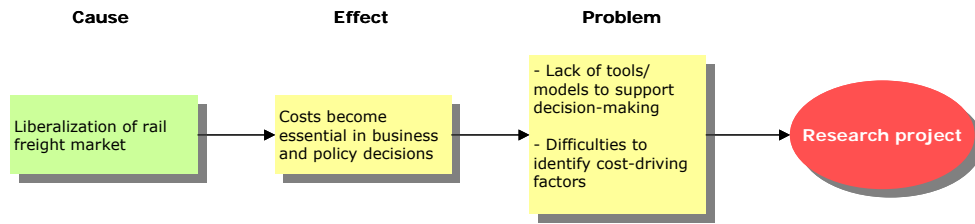


Figure 1.6: Justification and positioning of project (G.Troche)

Train operating companies	Government and public administrations	Shippers	Infrastructure Managers	Scientific researchers
Pricing Investments Operations Business strategies	Legislation Transport infrastructure development Subsidies Policy strategies	Choice of transport mode Logistical planning	Socio-economic analysis Infrastructure investments Policy strategies	Model development (demand forecast) Evaluation of transport systems Cost understanding

Table 1.1: Users of rail freight cost information and fields in which they may use the model as a decision-support tool.(G.Troche)

Forecast models for freight transport often comprise some form of sub-model for calculation of transport costs. However, these models are only to a very limited extent useful as a decision-support tool, especially when it becomes necessary to depict changes in the rail freight system with major system-wide impact on costs and cost structures. A fundamental problem with these models is that much of the data used in them

- is often not calculated within the model, but put in as primary input data, and/or
- is quantified on the basis of often quite uncertain assumptions.

There is thus a great risk that this data will either become very "conservative", in the sense that it is based on a status quo assumption or alternatively on a trend extrapolation of development hitherto; or that major changes are assumed, but on relatively inexact grounds, allowing the results to appear to be a "what would happen if..." scenario, rather

than answering the question "why would it happen?" – or, by extension, "how likely is this scenario?"

Consequently, in order to describe the railways' opportunities in a dynamic perspective, i.e. taking into account more extensive changes in the rail supply as a result of new production methods, improved technical solutions and operational performance, etc, *it is necessary to have cost information about both different current and possible future rail freight production systems.*

Today, there is no such information – or tool which could produce this information – publicly available, which would make it possible to systematically analyse and compare transport costs in different rail freight production systems or in transport chains where rail cooperates with other transport modes.

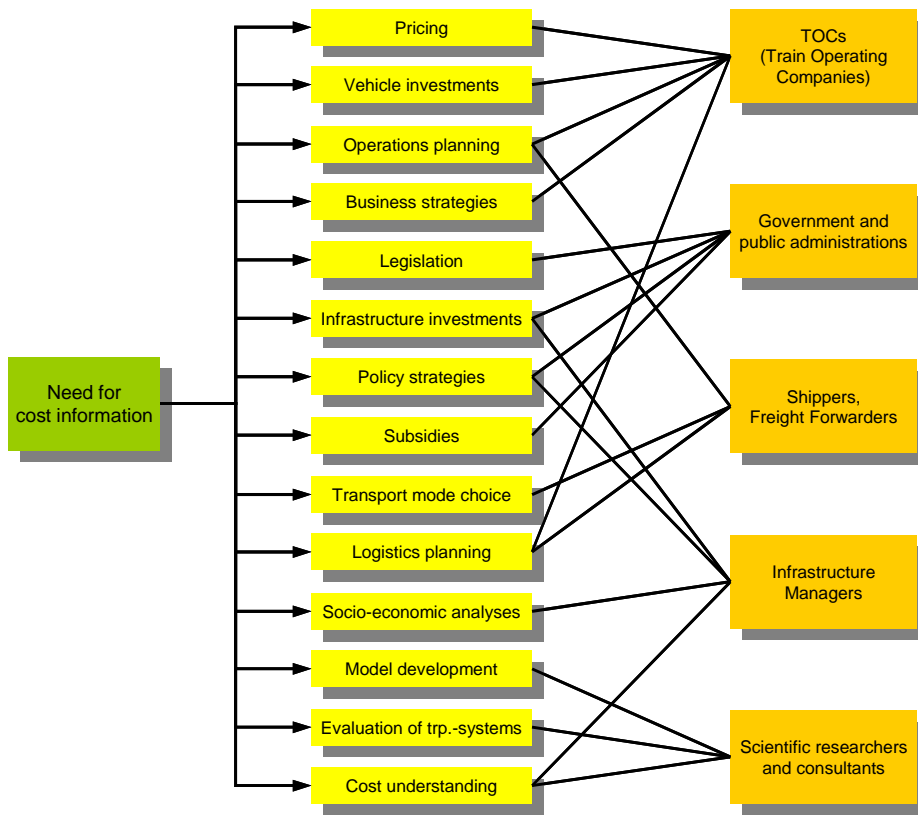


Fig. 1.7: Fields in which cost information on rail freight is required and its main users (G. Troche)

1.3 Goals and purpose

In the previous chapter a need for cost information was identified. This need can be addressed by a cost model. The advantage of a model, in contrast to benchmarking (case) studies for example, is that it can be designed in a way, which makes it generally applicable to rail freight. It can satisfy the demands of different users and has the advantage of showing a connection between input and output.

The *goal* of this work is thus to develop a model, which makes it possible to enhance the understanding of costs in rail freight and to analyse possible ways to improve the profitability and/or cost competitiveness of the rail freight system.

The model to be developed has been given the working name *EvaRail* – standing for *Model for Economic evaluation of rail freight services*.

The model aims to describe the supply side of freight transportation by rail on a detailed level. The model should deliver cost data for door-to-door transportation of specific (single or recurrent) shipments. At the same time, the model has to satisfy a requirement to be general and to be able to depict transportation in (almost) every production system, both those used today and potential future production systems.

The *purpose* of the project is to address the need for information of the different actors as they are identified in the previous chapter, 1.2. This purpose can be concretized as follows:

- For scientific researchers and consultants working with modelling and forecasting, the primary purpose of the model is to deliver input data for transport choice and freight forecasting models.
- For train operators, government and public administrations, and infrastructure managers, the main purpose of the model will most likely be to evaluate the economic effects of technical or operational measures that aim to improve the performance of the railway system. This can also be relevant for scientific researchers working with more applied research.

Finally, the model may also serve as an instrument to calculate transport costs for alternative transport solutions, which addresses the needs of shippers.

In this project there was no hypothesis to be verified or disproved. The aim was rather to create a tool – in the form of a supply and cost model – which in its turn can be used to test hypotheses, for example about the efficiency of measures to improve the rail freight production system.

1.4 Delimitations

EvaRail is a business-economic, activity-based cost model calculating costs *from the view of a train operator*. Under the reasonable assumption that there exists a connection between production costs in rail freight and the prices charged to the customers, EvaRail, by adding a profit margin, is also able to calculate transport costs from a shipper's point of view.

The scope of a business-economic model is influenced by the organizational structure of the sector. In the railway industry – as well as in other industries – this structure has changed over time, and is still changing, and there also exist considerable differences between different countries and railway companies. The liberalization of rail freight in Europe has led to the creation of new private railway companies with a variety of different business models. At the same time the earlier state railways have reorganized themselves and adopted business goals, management methods and organizational structures from the private sector. In addition, a general trend towards outsourcing has increased the variety of organizational models in the rail freight sector. There is no homogeneous structure within the sector and *that* typical train operating company does not exist. EvaRail is designed in such a way that it to a certain degree can adapt to different organizational models. How the organizational structure affects the depiction of the rail freight production system is dealt with in more detail in chapter 4.3.

No external costs or effects are included in the model, as long as they are not internalized in monetary form, i.e. charged to the train operator. It is not necessary to include external costs since they do not affect the train operators' pricing and consequently not the customers' transport costs either. Since business-economic costs are also part of a socio-economic calculation it is, however, highly conceivable that EvaRail can deliver input data for a socio-economic calculation. It could also be included as a sub-model in a socio-economic model. The creation of such a socio-economic model, however, lies outside the scope and intention of this project.

In EvaRail, emphasis has been put on a detailed depiction and calculation of rail transport and multimodal road/rail transport chains. The model calculates transport costs on a flow level. Calculations can be made of one or several specific flows. It is possible to calculate the costs for a whole production system, if *all* flows in a system are known and specified

in detail by the user. This, however, requires comprehensive information on a large number of flows. Exceptions are large-volume regular flows (system flows), for which dedicated systems can be established – normally trainload services.

A production method, which is not yet possible to properly depict in the model is a combination of passenger and freight transport on the same train. It would be possible to adapt the model without too big efforts to cover even this situation, if any need should arise (which, however, is rather unlikely). In this context it can be mentioned, that – *if* this should be done – the model then, in principle, would be able to calculate production cost in pure rail passenger system as well, including complex production system with direct wagons.

It should also be emphasized again that this project deals with the cost side of rail freight. Costs represent only one side of the economic effects of measures taken to improve the rail freight system. The other side comprises revenues. These are not part of this project and are consequently not calculated in the model. A costing model is thus only *one* tool for decision-making; it should be complemented by a revenue model depicting willingness to pay for certain improvements. In the long term it would be desirable to integrate these models.

2 Literature review

2.1 Introductory remarks

The literature review comprises two parts: In the first part (chapter 2.2) a number of transport cost models for rail freight are presented. In the second part (chapter 2.3) the categorization of costs and typical problems encountered in the development of cost models are discussed. In this way, the literature review both gives a reference frame for the new model and identifies problems, which have to be dealt with in the development of the new model.

When it comes to the first part – the presentation of cost models for rail freight – the number of pure rail freight (or multi-mode) cost models is quite limited. Cost models are often integrated in mode choice models, which in their turn can form part of transport prognosis models. The reason for this is that costs/prices are an important criterion for the choice behaviour of shippers. For this reason alone, almost every transport choice model has necessarily to comprise some form of transport cost calculation.

However, this does not mean that all transport choice models are included in this overview. Many transport choice models only contain a very simple and rough calculation of transport costs. Even a simple multiplication of transport distance with a net-tonne-kilometre cost – maybe the most rudimentary calculation of transport costs, which is possible – in a transport choice model, can in a strict formal meaning be considered as a “cost model”. However, in the following overview only models are included which comprise a slightly more sophisticated transport cost calculation and where the transport cost calculation itself is an important aim of the model. The model (or its cost module) should be able to calculate the effects of changes in the rail freight production system. This requires that the production system is depicted in the model, at least roughly.

A complication in this part of the work has been that most cost models – irrespective of whether they form part of transport choice or demand

forecast models or are free-standing cost models – for natural reasons contain confidential data. Furthermore, many cost models are only intended for internal use, for example within railway companies. Thus their existence is sometimes not even known to a broader public nor within academic circles. Other models have been developed for commercial use by consulting companies. Even these are for understandable reasons not too interested in revealing all too detailed information about their models. For these reasons it has been difficult to obtain more detailed information about many of the models – this difficulty not only concerns the input-data, but also the model structure and the calculation principles.

2.2 General theory of costs and cost calculation

2.2.1 Cost concepts and categorizations

Costs and cost structures can be described in different ways. In the following a number of categorizations, which can be found in literature are presented. Many of these categorizations show similarities and in many cases the differences are rather in terminology than in definitions. The purpose of this overview is to help the reader to relate different terminology used in different contexts to each other.

The categorization of costs used in this dissertation follows – as far as is applicable – the one presented in figure 2.1.

Direct and Indirect Costs

A common way to is to distinguish between *Direct costs* and *Indirect costs*. The latter can in their turn be divided into *Joint costs* and *Common costs* (see figure 2.1).²

Direct costs can be allocated directly to the production of a certain product. Allocation of direct costs is consequently “simple” since it is not necessary to share them between different products.

However, in many cases – and this is especially true in the case of railway services – many activities are shared between different products. Exactly what are direct cost and what are indirect costs depends not only on the price of the activities concerned and the characteristics of the rail service, but also on what is considered to be the “product”. If for example a shuttle train service between two container terminals is considered *one* product (and the rolling stock and the rolling stock deployed in this train service is not used for any other duties), then the capital cost of the rolling stock are direct costs. If, however, the “product” is the transport of goods in one specific goods flow – of several goods flows using the train – these have to be regarded as indirect costs.

² Comp. e.g.: ANIANDER, BLOMGREN, ENGWALL (1998)

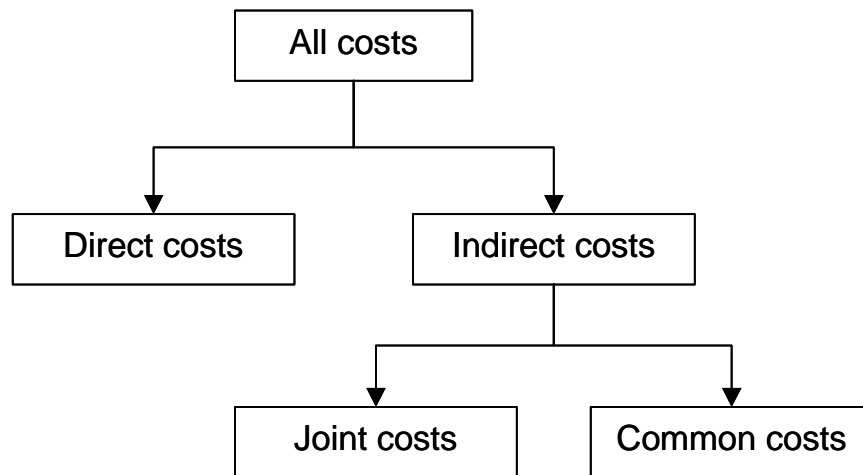


Figure 2.1: Systematization of certain cost terms according to OXERA (2005). (Graphic: G.Troche)

Common costs – as one type of indirect costs – arise when an activity is shared voluntarily between two or more products. This means that the producer *chooses* to share these activities, normally because it is economically advantageous. By doing so he may for example achieve positive scale effects or synergy effects.

Joint costs arise when activities *have* to be shared in the delivery of a product, i.e. when they are inseparable. This means that the producer *cannot choose* whether or not to share these costs.

An example may serve to illustrate the difference between joint and common costs: “A train carries commuters into the city early in the morning and returns nearly empty for a second trip. The seats in the first and second class carriages share common costs: the carriages have been linked together for convenience. However, the seats on the upward and downward journeys share joint costs: the delivery of upward and downward services is inseparable from another - the train has to travel in both directions.”³

Translated to freight this means that different wagons in a (wagonload) train share common costs, while the wagons’ return trip entails joint costs.

³ OXERA(2005), p.7

The same source also deals with the question of allocating common and joint costs. Generally it is easier to allocate common costs than joint costs. In the case of common costs, the underlying activities, their costs and the cost drivers would be identified and allocated to each product according to their consumption. In the example above the costs for traction power and the working time of on-board personnel would be shared between first and second class passengers accordingly.

The allocation of Joint costs he considers far more problematic, which is exemplified in OXERA(2005): “A work-study would indicate that the cost of the upward and downward journeys are similar (the only difference between a full and empty train being the trivial cost of issuing tickets). Yet the train only runs for the benefit of commuters, so the principle of causality would suggest that this group should bear almost the full cost and the return journey be treated as a by-product and bear the negligible incremental cost. But should this principle hold in the evening when the commuters return and theatre-goers undertake expeditions in the opposite direction? The latter would use the train and should therefore share the costs of its operation, lowering the costs for the home-bound commuters.”⁴

It should be mentioned that the problem of empty trains is highly relevant in the case of freight traffic: While inbound and outbound commuter train services certainly show varying load factors, trains are seldom completely empty. There are normally at least some passengers to which costs could be allocated. In freight, however, there is often no load at all for the return run; wagons – and in the case of unit-trains even whole trainsets – run almost always empty for a part of a turnaround. It shows also that cost allocation principles are not necessarily straightforwardly transferable between passenger and freight.

The Baumol-Willig rule⁵ states that the allocated costs should be no greater than the stand-alone cost and no less than the incremental cost. Otherwise joint production would not continue and the benefits of the economy of scope will be lost; the same effect would arise if the allocated costs exceed the revenue from a particular product.

KAPLAN even suggests using Ramsey pricing, meaning that indirect costs should be allocated to products in inverse proportion to their price

⁴ OXERA(2005), p.7

⁵ ERGAS, H., RALPH, E.: Pricing Network Interconnection: Is the Baumol-Willig rule the right answer?, 1996

elasticity - or – as he expresses it in common parlance: “Load the costs onto those who have little choice but to pay”.⁶

Fixed and Variable Costs

Characteristic of railways is that many resources are indivisible or – within certain limits – fixed. This is true even if we do not consider infrastructure. A high portion of costs is therefore fixed and independent of transport quantity.

The figure below illustrates a classification of fixed and variable costs. Of the cost categorizations presented in this chapter this appears to be the most complete one. For this reason this categorization and its terminology has also been used in this dissertation.

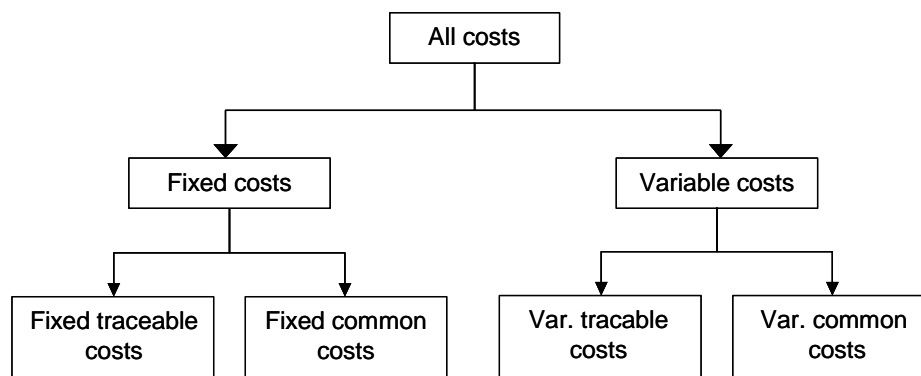


Fig. 2.2: Systematization of Fixed and Variable costs.^{7,8}

The marginal costs for rail traffic can be calculated with different time horizons – from adding one ton of freight when loading a wagon, to investing in new rolling stock with up to more than a year of realization. The costs for adding one ton of freight – given that the transport capacity of a wagon is not already reached – is close to zero.

The next step is to add a wagon, which already exists, to an already scheduled train. This can be done with a horizon of some days. The

⁶ KAPLAN (2001)

⁷ NN (2007)

⁸ CRUM, R.L., GOLDBERG, I. (1998), p. 94

marginal costs would be energy costs, infrastructure fees and maintenance.

After this the next step would be to arrange a new train departure with already existing rolling stock. This is possible with a horizon of some weeks to months. In addition to the costs mentioned above costs for personnel (man-hours) have to be added to calculate the marginal costs (assuming that personnel costs are considered to be variable!).

With a time horizon of more than a year, new rolling stock could be acquired. This may also result in a necessity to invest in new maintenance facilities and administration. In this case the marginal costs of a train operating company are almost 100%. When the time horizon is extended still further – from several years up to decades - a need may also arise for the infrastructure manager to invest in new infrastructure, e.g. yards and terminals, or – in an extreme case – new railway lines. In this case, the marginal costs of the railway system as a whole are approaching 100%.

A further step is taken if terminal costs are affected, which is conceivable over a period of at least six months. The change is then of such a magnitude that more personnel need to be taken on for shunting and switching.

The problem of low short-run marginal costs is especially critical in pricing decisions. A train operating company that always sets its prices according to its short-run marginal costs would never be able to cover its total costs even in the long run. Marginal cost pricing should therefore be used very carefully and only selectively by train operating companies; it is only viable if there are market segments where a price higher than total costs can be achieved.

Specific and Unit costs

The Regulatory Costing Model of the Canadian Transportation Agency distinguishes between Specific and Unit costs. Both are Variable costs, as can be seen from the figure below, which shows the cost categorization used in this model.

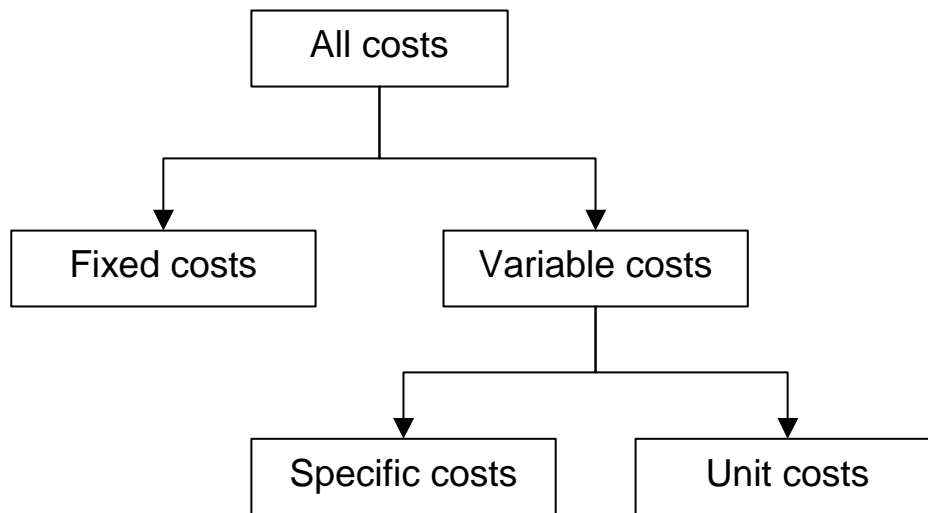


Figure 2.3: Systematization of costs according to the Regulatory Costing Model of the Canadian Transportation Agency. (Source: CANADIAN TRANSPORT AGENCY)

The differences between specific and unit costs are explained as follows:

“*Specific costs* are those costs which can be directly attributed to the traffic or service for which costs are to be determined (for example, crew wages).”⁹ In the CTA-model (see chapter 2.3.7) Specific costs are used whenever:

- costs are 100% variable;
- the expense is directly related to the traffic movement or service for which costs are being determined; and
- the collection of expense data permits the cost to be identified to specific segments of the rail operation.

“*Unit costs* are costs, which are common to all railway traffic and services. [...] A unit cost represents a mathematical relationship between two variables: railway expenses (dependent variables) and levels of output (independent variables). System-wide unit costs are used to assign common costs to services.

Unit costs are developed through one of two techniques. If the common cost is deemed to be 100% variable with the system workload statistics to

⁹ CTA CANADIAN TRANSPORT AGENCY (2006)

be used for cost allocation, the unit cost is developed from the direct relationship between expenses and workloads. This is called *direct analysis*. If the common cost is deemed to be less than 100% variable with the associated workload statistic or is dependent on two or more workload statistics, *regression analysis (simple or multiple)* is normally used. [...] A geographical cross-section of costing data input is required in order to ensure that costs are truly representative of the railway's system in total. Regression analysis, be it simple or multiple, is the most widely-used tool to estimate the fixed and variable costs and to separate the causal effects of different workloads on grouped expenses (cost complexes)."¹⁰

Figure 2.4 gives a further overview of different cost terms and cost classification principles.¹¹ All three categorization principles cover the total costs and can be used in parallel. Consequently the cost terms are overlapping.

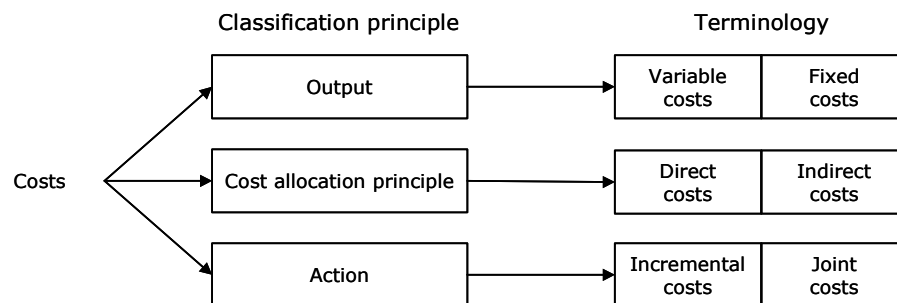


Figure 2.4: Three principles for classification of total costs (Source: ANIANDER, BLOMGREN, ENGWALL, et.al.. (1998), p. 153)

2.2.2 Principles of cost calculation

Top-down versus bottom-up approach

There are two principally different approaches to calculate the costs for a certain activity:

- a top-down approach and
- a bottom-up approach

¹⁰ CTA CANADIAN TRANSPORT AGENCY (2006)

¹¹ ANIANDER, BLOMGREN, ENGWALL, et al. (1998)

To clarify these terms two examples may be given:

Example I: When using the top-down approach to calculate the staff costs for the traction, they would be calculated by dividing the total costs for driver wages in a railway company by the number of driving hours of all drivers in that company.

A bottom-up approach would be to multiply the number of driver working-hours for a certain activity by the gross salary per driver-hour.

Example II: When using the top-down approach to calculate the energy costs for a certain activity, the total traction-related energy costs in a railway company would be divided by the total train-kilometres (or gross ton-kilometres or whatever unit of measurement is considered suitable) this railway company produces during a given period, giving the energy cost per train-kilometre.

A bottom-up approach would be to calculate the energy consumption for that activity using a suitable formula which takes into account running resistance, air resistance, losses, etc. and then multiplying the calculated energy consumption, suitably expressed in kWh, by the actual working price per kWh.

Which of the approaches is used in the model depends partly on what data are available.

Generally a bottom-up approach is preferable for the following reason: In the top-down approach, there is no longer any direct connection to the factors causing and determining the costs; instead, the total costs are simply distributed over some measurement units (train-kilometres, working hours, tons, etc), although no linear connection necessarily exists at all.

For example, when calculating infrastructure charges for a train, these can of course, easily be calculated by dividing a railway company's total annual infrastructure charges by the total train-kilometres, although in reality they might be charged per gross-ton-kilometre or vice versa.

This means that values obtained through a top-down approach are valid only for the current production of rail freight, and that they are correct only for an "average" transport, i.e. average train size, average speed, average rolling stock productivity, average driver utilization, etc. It is therefore not, or at least not to the same extent and with the same precision, possible to quantify effects of differences or changes in the

relevant factors, as the starting point in the top-down approach is the total costs and not the cost-determining factors.

A bottom-up approach makes it easier to take into consideration specific characteristics of a transport, as well as changes in the relevant cost-determining factors, as the following examples illustrate:

When calculating energy costs for example, a bottom-up approach makes it possible to take into account the weight of the train and if it is running at high or low speed, while the top-down approach normally only calculates the costs on the basis of the average energy consumption per train-kilometre, irrespective of the speed and weight.

Another example would be infrastructure charges. In some countries these are different on different lines. A bottom-up approach makes it possible to calculate these costs in a way that takes into account whether the train is running on a line with low charges or on an "expensive" route.

However, there are also problems connected to the bottom-up approach, mainly practical ones:

- The bottom-up approach demands much more and more detailed input data, which may not be available. This also applies in principle to the top-down approach, but there is normally less data and it is consequently less likely that they will not be available.
- The amount of data necessary for a calculation increases and might make the model less user-friendly.

In spite of these problems, the bottom-up approach has been applied as far as reasonably possible.

Input data and compatibility of data

So far this chapter has presented a number of different cost categorizations and cost terms. A cost model uses much input cost data which belong to one of the categories presented above. Knowing which category certain cost data belong may help to improve understanding of the model, but for the quality of the model results it is at least as important to know the exact definition of each piece of cost data information. The important difference between defining cost *categories* and defining specific *cost data information* is that the developer or user of a

model is quite free in his definition of cost categories – and can thus follow scientifically accepted definitions more or less without any problem – while he is totally dependent on the definition of primary cost data information as it is given in the sources he uses. Apart from the problem that the exact definition in these – mostly non-scientific – sources is not always given, he also has to take into account, since he will normally use information from different sources, the fact that the exact definition of “same” data information may vary slightly between different sources.

For this reason the quality, and not least the compatibility, of primary input data deserves special attention.

UNESCAP notes in a report¹² on the development prospects of South-East Asian Railways, whose findings and conclusions certainly – at least in those parts that are relevant here – are also applicable to Europe, that many railway companies have introduced computer based traffic costing models, but that the base data for these models come from accounting systems designed to fulfil the legal reporting requirements at a macro level. These models can certainly improve the capabilities to achieve certain corporate financial goals, but are “not suited to providing disaggregated cost data to the level of individual services and specific operating resources”. The models “do not generally have a ‘job or activity costing’ orientation”¹³. “This disability is often compounded by the lack of any direct link between physical operating records, which provide the necessary dissection of activities and the accounting systems, which do not”. Difficulties in updating the models with recent cost data also have their origin in this problem.

Another aspect the UNESCAP report takes up is the incompatibility of costing systems and methodologies used by railway organizations of different countries, which represents an obstacle when railway companies in neighbouring countries want to develop business opportunities in cross-border traffic. (The ESCAP Railway Marketing project therefore aimed to develop a computer based cost model for freight and/or passenger services which relies on a consistent basis throughout the region).

¹² UNITED NATIONS, ESCAP (1998)

¹³ UNITED NATIONS, ESCAP (1998), p. 65/66

Interestingly, the same problem has been recognized by the European Union¹⁴, when it comes to infrastructure charging by the railways Infrastructure Managers in Europe. Though the calculation of the infrastructure costs themselves is outside the scope of this thesis – since infrastructure and operation in Europe are separated and the cost model to be developed here is for a train operating company, not for an infrastructure manager – the consequences are actually the same here and find their expression in the widely varying track charges in Europe.

BROWN and SIBLEY state: “One of the everyday regulatory problems in countries where public enterprises must break even is to allocate costs to services for rate-making purposes. This is not a straightforward task and is the source of many of the most muddled, lengthy and unsatisfactory proceedings in regulatory history.”¹⁵

2.2.3 Costs or prices ?

The terms ‘cost’ and ‘price’ are often used without making a clear differentiation between them. For a better understanding of them – and how they relate to each other – it is necessary to start with their definitions:

Costs can be seen as the sum of all expenses a certain actor has to produce a certain output.

A *price* is the monetary amount for which the actor offers this output (product) on the market.

With these definitions there is – in a strict sense – no direct relation between costs and prices, i.e. there is no (mathematical) formula, which would allow the price for an output (product) to be derived directly from the costs for this output.

In the real world there *is* a relation between both; however, this relation is complex, due to the fact that costs are only *one* of the determinants for the price. The two other determinants are the competitive situation – giving a market price – and tactical/strategic decisions underpinning the undertaking. For this reason the EvaRail model *cannot be* a pricing model, since it depicts neither the competitive situation nor the decision-making processes of an undertaking (here a railway undertaking). The EvaRail

¹⁴ EURAILPRESS (2006)

¹⁵ BROWN, SIBLEY (1986), p.44

model, however, delivers (important) input for pricing decisions, and, as will become clear in the following, there is – at least in the long term – a clearer relation between cost and prices in any case.

The difference between the price and the costs for an output is the profit margin. In the *long term* an undertaking has to strive for a price higher than costs, i.e. a positive profit margin must. This is necessary to ensure the survival of the undertaking. It also requires that the undertaking is able to produce at lower costs than the market price. If this is not possible in the long term, the product will disappear from the market.

However, in the *short term* an undertaking can even choose to accept a negative profit margin. This may be the case in two situations:

- (1) When a negative profit margin avoids an even bigger loss. This can happen if the undertaking has fixed costs for a certain product (which it normally has). In this case the undertaking will even accept/offer a price which just covers the variable costs. However, as has been pointed out before, distinguishing fixed and variable costs can be a challenging task in itself, and depends largely on the time perspective.
- (2) When the undertaking intends to enter into a market it may be prepared to initially offer a price below costs. In this case it may even be below the variable costs of a product. The negative profit margin can be considered as the price for buying market share.

A third reason to offer a price below cost could be to limit competition, by trying to force competitors, which do not have the financial strength to accept a negative profit margin for the same duration, out of the market. However, this would mean breaking legislative rules.

In any case, it is important to underline that a price below costs can only be offered temporarily. Both costs and (market) prices can vary over time and do not necessarily co-vary in the short term. However, in the long term, the profit margin must *always* be positive. Normally undertakings strive to achieve a profit margin of around 10%.

As can be concluded from the aforementioned, it also depends on the perspective whether a certain monetary amount represents a cost or price: A price from the seller's point of view becomes a cost from the buyer's point of view. If a railway undertaking sells a certain transport service for a certain amount of money, it is a price (transport price) from the railway's perspective, but a cost (transport cost) from the transport

customer's perspective. In the same way, the costs which the railway undertaking has in order to carry out the transport, are costs from the railway's point of view, but prices from its supplier's point of view.

In this thesis only the term 'cost' or 'costs' is used but the reader should be aware that the term can also refer to prices, depending on the perspective.

2.2.4 Activity-Based Costing

A model can be seen as a simplified depiction of a more or less complex phenomenon in reality. According to HICKS a cost model (or economic model, which is the term he uses) can be used to understand the cost behaviour taking place in a company in the real world. Depending on the type of business it can take different forms. A model suitable for one kind of business, or even one company, may be totally inappropriate for another.¹⁶

This already indicates that a cost model for example developed for road transport may not be applicable to rail transport. Even within rail freight the variety of different production systems – and the high complexity of most of them – may render a cost model for a specific production system totally useless for other kinds of production systems. Limitations like this have already been identified for a number of the models presented in chapter 2.1.

GRIFUL-MIQUELA states that the usefulness of a model depends on its capacity to generate the right information to make the right managerial decisions.¹⁷ To this may be added the availability of input data factor, a factor which can have considerable impact on the structure of a model.

The essential task of a cost model is to determine costs. ROZTOCKI lists four different methodological approaches for determining costs¹⁸:

- intuition
- educated guessing
- Traditional Cost Accounting (TCA)
- Activity Based Costing (ABC)

¹⁶ HICKS, S.T. (1999)

¹⁷ GRIFUL-MIQUELA, C. (2001)

¹⁸ ROZTOCKI, N. (1998), p.9

For more reliable cost calculations the first two options should be avoided whenever possible. Consequently the choice stands between Traditional Cost Accounting (TCA) and Activity Based Costing (ABC).

GRANOF, PLATT and VAYSMAN present a comparison of TCA and ABC, which summarizes well the characteristics of both methodologies (table 2.1).

In the comparison of TCA versus ABC, it becomes clear that the latter has advantages both when it comes to the accuracy of the results, as well as the possibility to analyze obtained data, since ABC creates a more direct connection between costs and cost drivers.

Though KAPLAN and BRUNS, who started proposing ABC in the end of the 1980-ies, originally focused on the manufacturing industry¹⁹, where a trend towards increased automation reduced human labour and replaced direct costs by indirect, ABC is – for the same reason – suitable for the service sector, to which rail freight belongs.

¹⁹ KAPLAN, R.S., BRUNS, W.J. (1988)

Activity-Based Rail Freight Costing

	ABC Costing	Traditional Costing
Cost Pools	ABC systems accumulate costs into <i>activity</i> cost pools. These are designed to correspond to the major activities or business processes. By design, the costs in each cost pool are largely caused by a single factor – the <i>cost driver</i> .	Traditional costing systems accumulate costs into facility-wide or departmental cost pools. The costs in each cost pool are heterogeneous – they are costs of many major processes and generally are not caused by a single factor.
Allocation Bases	ABC systems allocate costs to products, services, and other cost objects from the activity cost pools using allocation bases corresponding to cost drivers of activity costs.	Traditional systems allocate costs to products using volume-based allocation bases: units, direct labour input, machine hours, revenue dollars.
Hierarchy of costs	Allows for non-linearity of costs within the organization by explicitly recognizing that some costs are not caused by the number of units produced.	Generally estimates all of the costs of an organization as being driven by the volume of product or service delivered.
Cost Objects	Focuses on estimating the costs of many cost objects of interest: units, batches, product lines, business processes, customers, and suppliers.	Focuses on estimating the cost of a single cost object – unit of product or service.
Decision Support	Because of the ability to align allocation bases with cost drivers, provides more accurate information to support managerial decisions.	Because of the inability to align allocation bases with cost drivers, leads to <i>overcosting</i> and <i>undercosting</i> problems.
Cost Control	By providing summary costs of organizational activities, ABC allows for prioritization of cost-management efforts.	Cost control is viewed as a departmental exercise rather than a cross-functional effort.
Cost	Relatively expensive to implement and maintain.	Inexpensive to implement and maintain.

Table 2.1: Comparison between Activity-Based Costing and Traditional Costing (Source: GRANOF, M.H., PLATT, D.E., VAYSMAN, I., 2000, p.9)

ROZTOCKI summarizes the advantages of ABC as follows:

- ABC is a more accurate methodology
- ABC focuses on indirect costs
- ABC traces rather than allocates each expense category to the particular cost object (which is in line with the bottom-up approach, see below)
- ABC makes “indirect” expenses “direct”

In a comparison between TCA and ABC ROZTOCKI goes so far as to state that TCA “is unable to calculate the ‘true’ cost of a product”²⁰

He also recommends the use of ABC when (1) overhead costs are high, (2) products are diverse, i.e. characterized by high complexity, volume and amount of direct labour, (3) when cost errors are high and (4) competition is stiff.²¹ All these factors are fulfilled in the rail freight business.

For the reasons mentioned above ABC has been chosen in this work as a suitable methodology for a transport cost model for rail freight.

However, not even ABC is a methodology without problems. GRANOF, PLATT and VAYSMAN already mention the relatively high costs to implement and maintain an ABC model as a shortcoming (see table 2.1 above). Behind this argument lies the significant effort needed to collect all the required input data and to ensure that the data are of sufficient quality.

BRUGGEMAN, EVERAERT, ANDERSON and LEVANT realized this problem, too, and present as a solution *Time-Driven Activity-Based Costing*. This concept, originally developed by Steven Anderson in 1997, requires only two parameters to estimate: The *unit cost* of the supplying resources and the *time* required by an activity of this resource group.²² The costs for an activity in Time-Driven ABC are thus time-dependent rather than volume-dependent.

²⁰ ROZTOCKI, N. (1998), p.24

²¹ ROZTOCKI, N. (1998), p.14

²² BRUGGEMAN, W., EVERAERT, P., ANDERSON, S.R., LEVANT, Y. (2005), p.10

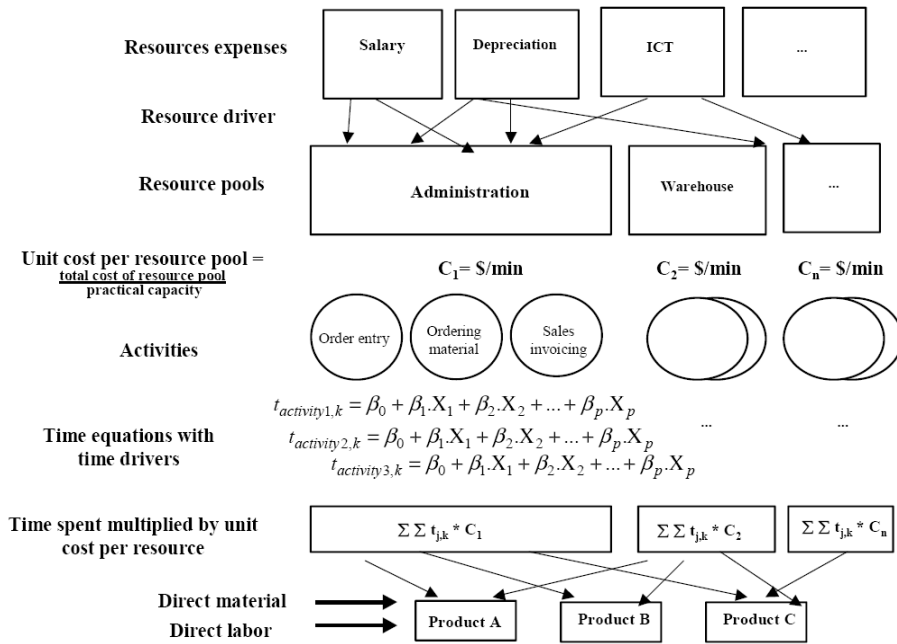


Fig. 2.5: Time-Driven Activity-Based Cost Systems trace costs of resource pools to objects, based on the outcomes of the time equations per activity, in contrast to Traditional Activity-Based Cost Systems, which trace resource expenses to activities and use activity cost drivers for tracing activity costs to objects (Source: BRUGGEMAN, W., EVERAERT, P., ANDERSON, S.R., LEVANT, Y. (2005), p.38)

The model developed in this work incorporates to a high degree the principles of Time-Driven Activity-Based Costing. The benefits were only been that the effort required to collect input data, though still substantial, could be reduced, but also that Time-driven ABC depicts reality more correctly since most costs in rail freight are time-dependent, not volume-dependent. A shunting operation for example will cost (almost) the same, irrespective of whether two wagons or ten wagons are moved.

Another problem with ABC, according to HANSSON and OTTOSSON, is the loss of customer focus, since ABC may have the result that “management only focuses on the costs and does not consider the implication a cost reduction might have on customer service”.²³

²³ HANSSON, M., OTTOSSON, P. (2003), p.28

However, this is an argument, which could be raised against cost models in general and not specifically against ABC. Furthermore, though this risk of course exists, it should rather be seen as a problem in using and interpreting results than a problem with ABC itself. In order to also include the effects on customer service – or rather revenues, which are more important from an economic point of view – it is necessary to also include the demand side in the model. It is therefore proposed to link the transport cost model developed in this work to a demand model at a later stage.

2.3 Transport cost models for rail freight

2.3.1 Cost model by Nelldal (1980)

In 1980, as part of his dissertation at the Royal Institute of Technology, Bo-Lennart Nelldal developed a transport cost model for rail freight (NELLDAL, 1981). His model is able to calculate transport costs for a specific single transport assignment. It consists of three parts:

A supply function describing the means of production required for an assignment

A utilization function describing how these means of production are utilized

A cost function describing how much it costs to utilize the means of production stated in point 1, at the rate stated in point 2.

The cost function contains a part-cost model and a total-cost model. In the latter the supply function (i.e. the production system) is given, while the utilization function can be varied. In the part-cost model the supply function can also be varied.

The model structure describing the railway's cost structure is shown in the figure below. The cost for a specific single transport is calculated according to the following formula:

$$K_{\text{trp}} = \left(1 + \frac{\text{emp}}{\text{load}} \right) * A_{\text{rö}} \left[\sum_{i=1}^n \frac{T_i(d, t)}{v(d, t)} + v(l) \right]$$

emp = share of empty wagons
 load = share of loaded wagons
 V (d, t) = average number of axles per load status/traintype

Figure 2.6: Formula for calculation of transport costs for a specific single transport assignment in Nelldal's model (Source: NELLDAL, B.-L. (1981), p.52)

Nelldal's model is based on a comprehensive description and in-depth analysis of the Swedish rail freight system and its costs and cost structure. His work can be considered as the most important contribution since the Financial Analysis of Sweden's Railways from 1942. This also means,

however, that the model is first and foremost of use for calculating transport costs within the (then) existing production system for rail freight in Sweden.

To some degree it would be possible to calculate transport costs in today's – or possible future – production systems with the model by updating input data. However, changes in the organizational framework of the railway sector as well as new production systems for rail freight would require a more or less comprehensive adaptation of the model's *structure* in order to correctly depict today's situation. In some cases this even opens for a simplification; for example, due to the then integrated structure of the railway, Nelldal had to deal with the problem of quantifying and allocating the (full) right-of-way costs to a certain assignment. Today, this problem is no longer relevant for a train-operating company since these costs have been replaced by (for the train operating company) easy-to-calculate infrastructure user fees. Nelldal also had to deal with the problem of joint use of locomotives for both passenger and freight services, a practice which has almost disappeared today.

On the other hand, Nelldal's model takes into account only trainload and wagonload services. The model is not adapted at all to intermodal transports, probably since Combined Traffic at that time was still quite a marginal phenomenon on the railways. This has changed radically today. It should also be noted that Nelldal to a large extent applied a top-down approach when calculating transport costs, i.e. the total costs within SJ for a certain function are broken down to a certain unit (e.g. train-km, wagon-axle-km) by applying a suitable allocation key. This has the advantage of correctly depicting SJ's cost situation at the time. Nelldal also benefited from access to relatively detailed (and at that time publicly available) records on railway operations. The disadvantage, however, is that the transport costs for a specific assignment are calculated on the basis of *average* utilization data (for example of rolling stock), although utilization of wagons assigned to a specific flow may deviate considerably from the average, although this could also have been calculated if a bottom-up approach had been applied

Nelldal's model is one of the most well documented business-economic cost models for rail freight and has been a great help in developing the model in this project. Due to the limitations mentioned above it has not been chosen as a basis for the new model. Nelldal's model has, however,

served as a guideline in the development of the new model, especially when it comes to finding allocation principles for joint and common costs.

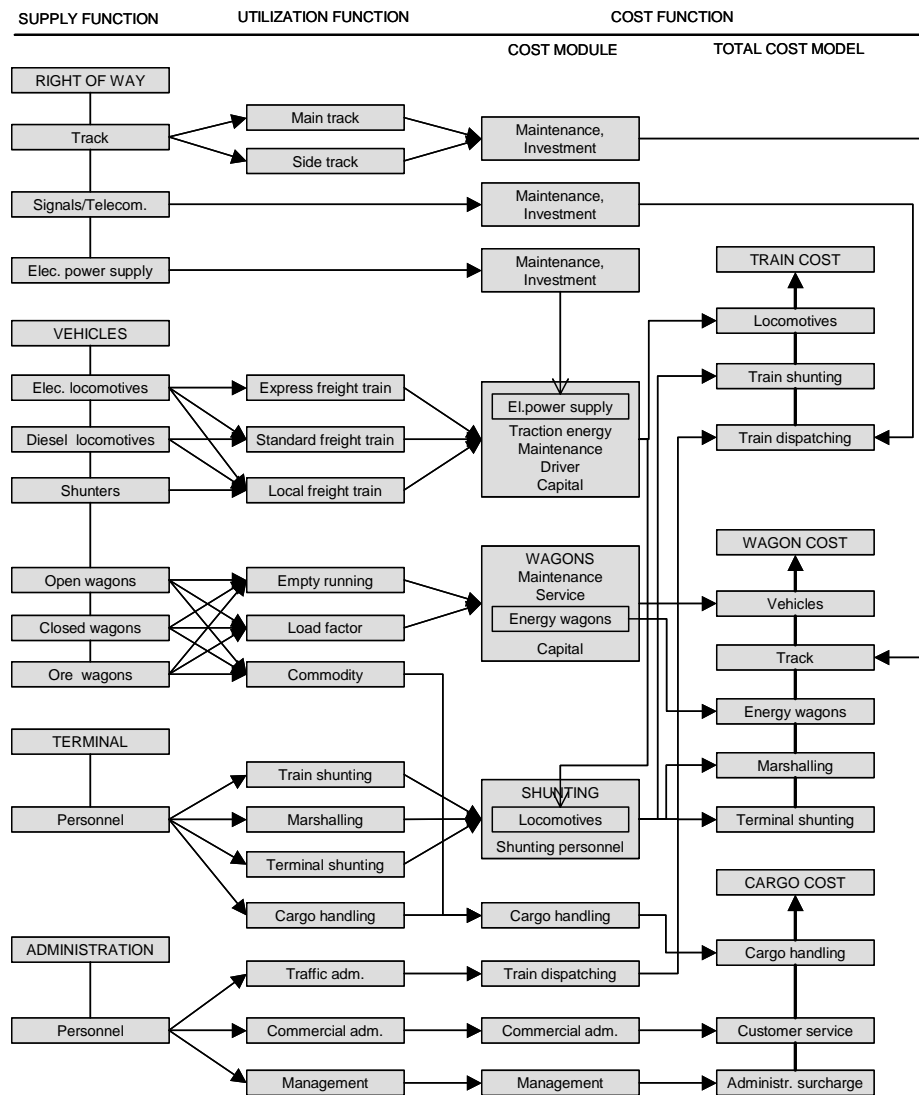


Figure 2.7: Nelldal's model describing the cost structure for Swedish rail freight (NELLDAL, B.-L. (1981), p.53; translated and redrawn by G.Troche)

2.3.2 Cost model for Combined transport by Jensen (1990)

Arne Jensen (JENSEN 1990) presents a cost model for calculating incremental costs for Combined Traffic in the Swedish railway system. In addition to business economic costs his model also covers socio-economic costs. In his work he also calculates cost savings in the transport system resulting from a switch to combined transport. The figure below shows the cost functions included in the model.

Jensen's model calculates costs for a fixed network of relations served by combined traffic in Sweden. He has put much effort into collecting input cost and utilization data. Some of these data, collected or calculated, are route or location-specific and directly connected to the way the Combined Traffic offer was produced at the time of writing. This is on the one hand a clear strength of the model, giving highly reliable results; on the other hand it also means that the model cannot be considered to be "general", since it cannot depict production systems that differ from the one which was in operation at the time of writing. Nor does it cover the train operating principle of liner trains, which could be relevant to study for future combined traffic.

However, though Jensen's model certainly cannot be used "out of the box" in this work, it has served as a valuable guideline for the model developed in this work. To some extent the design principles in his model are also applicable to non-CT production systems.

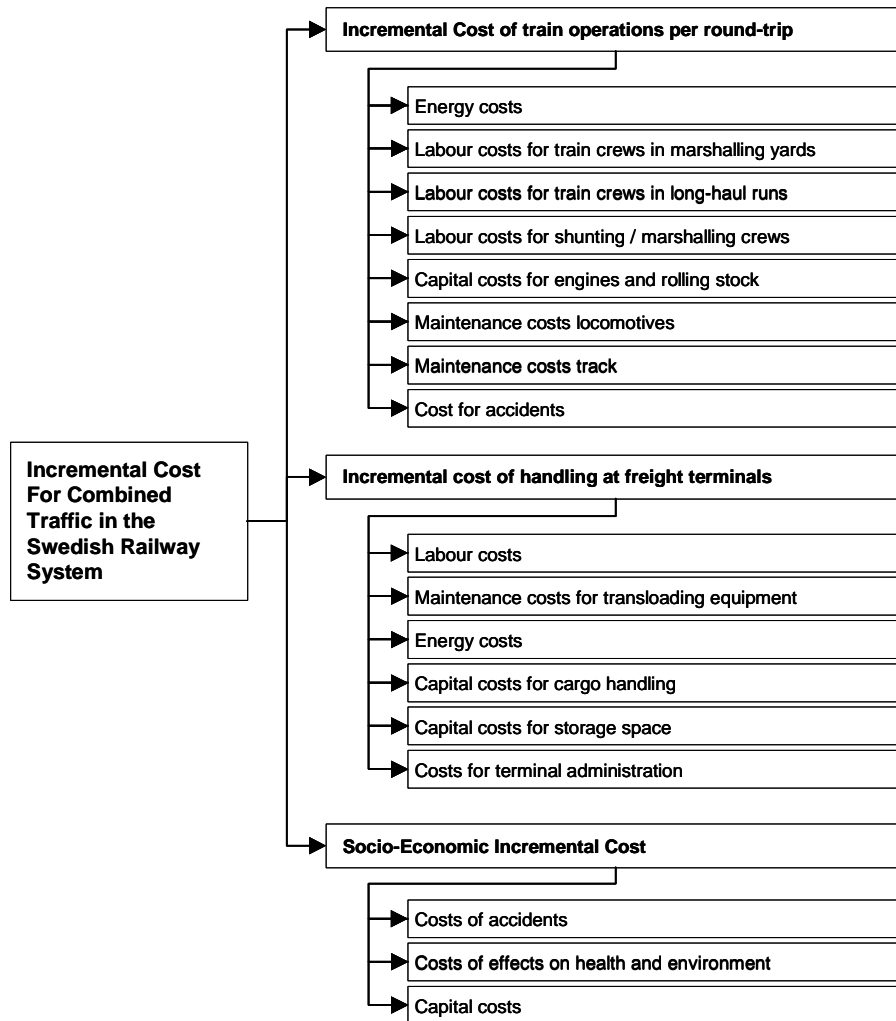


Fig. 2.8: Jensen's cost model for combined traffic. The figure shows the cost functions included in the model (figure: G.Troche)

2.3.3 HIT model (2007)

The Heuristics Intermodal Transport model – HIT model for short – was developed by Jonas Flodén at the School of Business, Economics and Law at the University of Gothenburg (FLODEN, 2007). It is a general, large-scale model of intermodal transport between road and rail in Sweden and its competitive situation towards all-road transport. The model is intended to be used as a strategic decision support tool, quantifying the theoretical potential of intermodal transport. This is done by analyzing how well intermodal transport performs compared to all-road transport.

For a given transport demand the model determines the most appropriate modal split, sets train timetables and calculates the type and number of trains and specifies trains consists and train occupation.

Both business-economic and socio-economic costs are calculated, as well as environmental effects. Different system layouts, both of large-scale national systems and smaller individual transport systems, can be compared; effects of the intermodal system on specific factors, e.g. tax changes, regulations or infrastructure investments can be studied as well.

For each demand occurrence the output from the modal comprises:

- modal choice
- departure and arrival time
- train departure used
- position on train
- type and number of lorries
- business-economic costs
- socio-economic costs
- environmental impact (emissions, energy consumption and monetary estimation)

A strength of the HIT model is that it contains a mode-choice function, based primarily on (business-economic) cost and time performance of intermodal transport and that it can easily be applied even on large-scale intermodal networks. However, the HIT model only covers intermodal transport and does not comprise a route choice model (which may be acceptable for traditional intermodal traffic with a high share of direct

trains, but would probably be necessary for larger wagonload systems and/or new production systems in intermodal transport)

The HIT model will be further developed by its originator and there is also an ambition to create an interface between the HIT and the EvaRail models so that both can be used in combination.

2.3.4 GBFM – Great Britain Freight Model

GBFM is a computer-based model to analyse freight traffic flows in Great Britain (MDS TRANSMODAL, 2008, and DFT, 2008). The model forms part of the Department for Transport's National Transport Model suite and arose out of the STEMM project, a European Framework Research Project into strategic European multi-modal modelling. It is a freight demand and mode choice model and uses county-to-county trip matrices by commodity. Since it contains a more detailed cost module, able to handle both technical and operational changes in the rail freight production system, it is of interest in this context.

In the GBFM model the mode choice for a particular type of cargo is a function of rail costs, cost of competing modes, cost of access to the rail network, network density, reliability of service and user perception.

The model is currently adapted to British conditions, with four modules corresponding to different cargo types and used separately to build up costs:

- UK-Continental traffic via the Channel Tunnel or ports
- Other traffic to/from ports (including deep sea container ports)
- UK domestic bulk including port traffic as relevant
- UK general cargo for domestic traffic

The cargo types are thus defined by the type of relations they are moving in rather than by commodities. Obviously this approach builds on the assumption/premise that there is some affinity between the characteristics of many commodities and the relations they are moving in.

The model can be constructed to calculate the effects on mode choice of for example

- tax changes
- changes in track access charges

- changes in Channel Tunnel usage charge
- freight grants
- new rail freight terminals
- higher speeds
- longer trains
- greater reliability
- higher locomotive productivity
- better quality of service
- better rail connectivity

As far as is appropriate corresponding changes can be made for the other modes, such as increased fuel taxes, higher weight limits for trucks, etc.

The model has been used, among others, by DETR to calculate the impact of Sustainable Distribution policies, by the Strategic Rail Authority (SRA) for the development of the Ten Year Plan and its Freight Strategy, by Railtrack for the validation of policy scenarios, and by McKinsey for the 2000 Network Management Statement.

2.3.5 CostLine, Rail Cost Analysis Model – USA

Reebie's CO\$TLINE Rail Cost Analysis Model (GLOBAL INSIGHT, 2009) provides shippers with an informed view of what it costs to transport shipments by rail. The model offers the user the following benefits:

- Faster, more informed rate negotiations for shippers and logistics providers
- Forecasting, budgeting, and planning of transportation expenses and costs
- Fast, easy benchmarking rate quotations and validations
- Analysis of transport cost components based on researched data and accepted methodologies
- Based on actual, carrier-specific, North American transport systems

Special features of the model are:

- Accepts origin, destination, payload weight, car type, commodity, and routing inputs

- Produces detailed and summarized per shipment cost reports
- Standard and customizable cost routines
- Detailed view of costs and rate components
- Windows point-and-click interface
- Based on Reebie's comprehensive rail cost and mileage database

The figure below gives an example of the analyses which can be carried out with the CostLine model. It illustrates the components of rail carload shipping rates. The various components vary with the shipments' parameters, such as weight, distance, routing, and car type. The results can for example be used to benchmark transport customer's rates and offer a possibility to develop surrogate rates without contacting a carrier. The carrier data files used in the CostLine model are updated on a quarterly basis, so that the data is current with fuel prices and wage increases, among other input price changes.

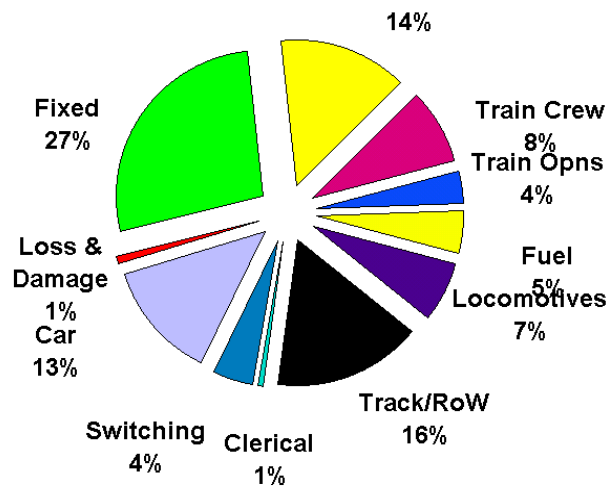


Figure 2.9: Example of analysis in the CostLine model. The pie-chart shows the cost components of a carload rate. (Source: Reebie)

2.3.6 Commonwealth Rail Costing System CRCS

The Commonwealth Rail Costing System, CRCS, consists of three costing models: QuickCost, BasicCost and ProCost. In this order each requires more information, but provides greater accuracy in return. This means that CRCS takes into account the fact that the quantity and quality of input data varies and allows the user to adapt a suitable model depending on the availability of input data. Transport assignments analyzed with QuickCost may be moved to the BasicCost or ProCost level through a Data Manager, eliminating the need to re-enter all of the variables.

CRCS is a Windows-based program that allows shippers to analyze the railway's variable cost of service and price mark-up for a given origin destination pair. It uses the most recent available railway unit costs from the Surface Transportation Board.

The main characteristics of the three models are as follows.

The Quick Cost Model

As its name implies, this model allows the user to quickly assess revenue to variable cost ratios and other pertinent information for a large number of flows in a short amount of time. Quick Cost requires the user to input as few as six flow parameters. The Product Code, Freight Car Type, and Rail Carrier may be chosen from lookup tables.

Required input is:

- product code
- freight wagon type (hopper, tank, etc.)
- wagon ownership (private or railway)
- wagon rental rate
- rail rate
- rail carrier for each segment
- mileage for each segment

The Basic Cost Model

Basic Cost allows the user to input up to twenty-five flow characteristics. The primary advantages over Quick Cost are that the user can specify:

- wagons per waybill

- switch charges
- wagon rental rate
- tare weights
- loss and damage costs
- switch engine minutes at origin
- switch engine minutes at destination

Basic Cost is the preferred module for calculating flows in wagon groups or unit trains, full mileage freight rate contracts, or that have local switching carriers.

The ProCost Model

ProCost provides the capability of entering variables for as many as thirty-three parameters. Again, flow input using BasicCost may be moved to the ProCost model for further analysis with no data loss. The results from this model, given accurate inputs, provide a degree of accuracy heretofore available only through the expenditure of tens of thousands of dollars in consulting fees per flow.

2.3.7 Regulatory Costing Model of the Canadian Transportation Agency

This model has evolved over the last two decades and has been the basis for paying transportation subsidies. While the subsidy programmes were abolished later, the basic costing model remained intact, although it has been streamlined to reduce the regulatory burden on the railways. The model is updated annually for the two national freight carriers, Canadian National and Canadian Pacific. The following description corresponds largely to those given by the Canadian Transport Agency (CTA, 2006).

The basic approach of cost development in the model is to trace costs to their cause. The costing methodology takes all the railway expenses identified in the UCA Manual (UCA = Uniform Classification of Accounts and Related Railway Records), together with the costs of depreciation and ownership of capital, and determines how these are caused by the traffic handled by the railways (i.e. establish a relationship between railway expense and traffic), recognizing that some of these expenses do not vary freely with traffic and are therefore fixed costs. The UCA Manual identifies over 160 separate expense accounts. Although

some of the larger expense accounts are analysed individually for costing purposes, a great many are aggregated and treated as a group, called a *Cost Complex*.

Once the expense groupings are determined, output units are associated with each Cost Complex in order to determine the causality. In general, the output measures used to explain various cost complexes are chosen, in the first place, on the basis of general knowledge of railway operations. The precise form of relationship can sometimes be determined on operations knowledge, sometimes on the basis of engineering studies, and often with the final selection on the basis of statistical evidence from *regression analysis*.

The railways' *Costing Manuals* document the causal relationships between expenses and operating statistics. A railway is required to prepare and file with the Agency a Costing Manual containing complete descriptions of the costing methods and procedures it follows in its cost calculations. The manuals identify the grouping of the expenses for cost analysis purposes (*dependent variable expenses*), the causal factors (the *independent variables*), the level of aggregation (region, system or geographic cost centre), the years of analysis and the method of cost development (direct assignment, direct analysis, regression analysis).

In order to determine the costs incurred by the railway for the movement of traffic, the determined unit cost values and specific costs are combined in a *cost deck* or *listing*. The listing is a set of a railway's unit cost values and specific cost items that have been verified and determined by Agency staff. Over 700 CN and 500 CP unit cost values (representing approximately 60 CN and 50 CP individual expense files) are reviewed and determined by Agency staff annually. The type of traffic movement for cost determination establishes the number of specific costs that are determined by Agency staff. The structure of the cost deck also allows the determination of costs that are dependent on other costs (overheads) rather than system workload statistics. Cost decks containing the unit cost values and lines for specific cost items are recommended annually for approval by the Agency Members.

Service units are used in conjunction with unit costs to determine the appropriate costs associated with a traffic movement or service. In order to properly assign common costs, the long-run variable costs of traffic are: (1) determined on a system-wide basis; (2) expressed as a cost per unit of work output (*unit cost*); and, (3) assigned to traffic by means of

applying the workload of the traffic to be costed (service unit) against the unit costs.

Service units (or output units) are units of production and are, in essence, a sub-set of the operating statistics previously identified. Whereas operating statistics represent the total workloads for the railway's entire system, the related service unit will only represent the proportion of that total system workload that is applicable to the traffic movement or service for which costs are being determined. Service units are derived from various *workload tables* (train performance, car cycles and empty return ratios - ERR) or through special studies (e.g., yard switching).

Automated main frame computer programs have been developed by the railways and adapted over the years by staff for personal computer use in order to determine the total costs incurred by a railway in its movement of traffic. The *Agency's Regulatory Costing Model* marries the applicable unit cost values in the cost decks/listings to the appropriate service units, adds the specific cost values and computes the overhead costs. The end result is a total cost figure that is an estimate of the costs incurred by the railway in the movement of some specified traffic or provision of a particular service.

Under the new *Canada Transportation Act*, cost determinations are made in order to establish Interswitching and Competitive Line Rates (known as CLRs) and to resolve disputes on rate complaint cases. In addition, the legislated review of the *Canada Transportation Act* as well as Transport Canada have required determinations of railway costs in order to assist in the development of railway transportation policy and any corresponding legislative changes.

2.3.8 Cost model for intermodal transport in the RECORDIT project

Within the RECORDIT project, which aimed to provide a framework for policy intervention in the field of Intermodal Freight Transportation in Europe, a model of cost formation and price formation on intermodal transport routes has been developed (RECORDIT, 2001). One requirement was that the model should be responsive to different tax regimes and other policy instruments in order to predict the demand effects of such interventions on Intermodal Transport.

The model consists of three sub-models:

- A set of cost functions referring to different locations, distinguishing between internal and external costs, and identifying the (marginal) cost impact of changes in demand; these functions must refer to all relevant modes including road
- A set of price formation functions describing how prices are related to internal costs, taxes and variables such as the competitive environment and user demand; these functions must refer to all relevant modes including road
- A set of demand functions that describe the impact of price and other quality variables on the demand for intermodal transport

Costs and prices are calculated for door-to-door journeys. The figure below shows how total costs break down into their cost components. The model distinguishes clearly between price and cost. It is also possible to distinguish between costs (prices) of traction and train providers for example.

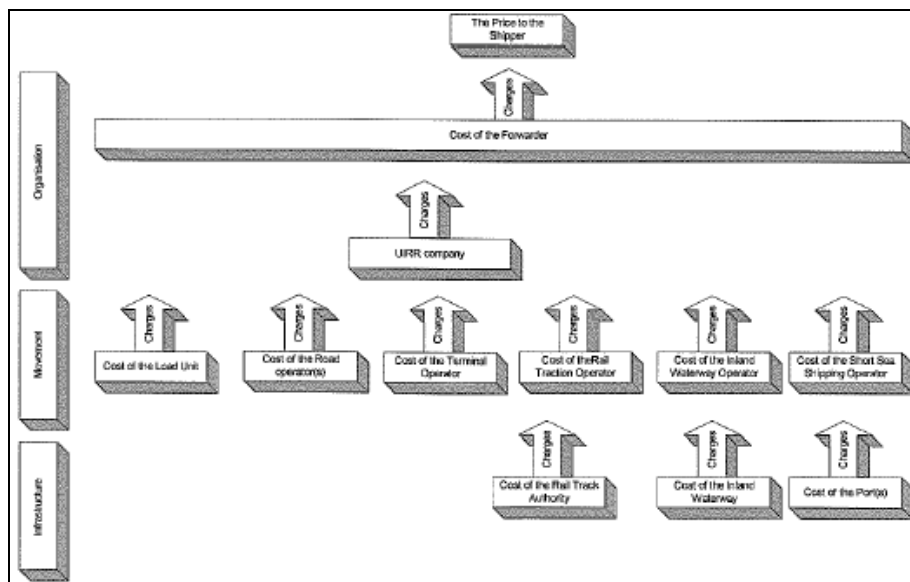


Figure 2.10: Model for formation of costs and charges in intermodal transport as developed in the RECORDI project. (Source: RECORDIT, 2001, p.35)

2.3.9 SAMGODS/STAN model

The SAMGODS model is a comprehensive traffic forecasting model used jointly by the Swedish infrastructure managers Banverket (rail) and Vägverket (roads) for traffic forecasting and by the Swedish Institute for Communications Analysis (SIKA). The last is also responsible for its development.

The models consists of several sub-models of which one, the STAN model, contains a transport cost module that covers all transport modes. Figure 2.11 gives an overview of the architecture of the SAMGODS model.

In the STAN implementation used in the SAMGODS model, transport costs are divided into link costs and node costs. Link and node costs are in turn divided into Operating costs (OC) and Quality-related costs (QC).

OC on a link consist of distant-dependent costs, time-dependent costs, special costs on certain links and starting costs. OC in a transfer node are loading, transloading and unloading costs.

QC on a link are costs for risk of delay, plus value of time and a frequency-related cost. QC in a transfer node are costs for risk of delay, plus value of time and a frequency-related cost when reloading

For cost calculation outside Sweden the cost functions can be slightly different.

The output of STAN consists of tonne-kilometres, generalized costs, transport costs and transport times.

One problem with the transport cost calculation in SAMGODS is that it does not depict the railway system with any great accuracy. The railway cost calculation is today the least-developed part of the model. The rail freight offer is only defined on an O/D basis, not on a link basis in a network model. The model divides rail freight into unit trains, wagonload trains and combined traffic, which are considered to be three independent production systems without any connections. It does not depict different train-operating principles within each group. All calculations are based on average values for train weight, speed, wagon capacity and utilization, etc. In combined traffic, cost data are for example the same as for container traffic, swap-body traffic and trailer

traffic, though in reality the costs and cost structure vary considerably between them.

The transport cost model in SAMGODS/STAN reveals clearly the problems that are encountered when trying to adapt a model which was not originally designed for rail freight, but for road and sea transport, to the much more complex rail freight system.

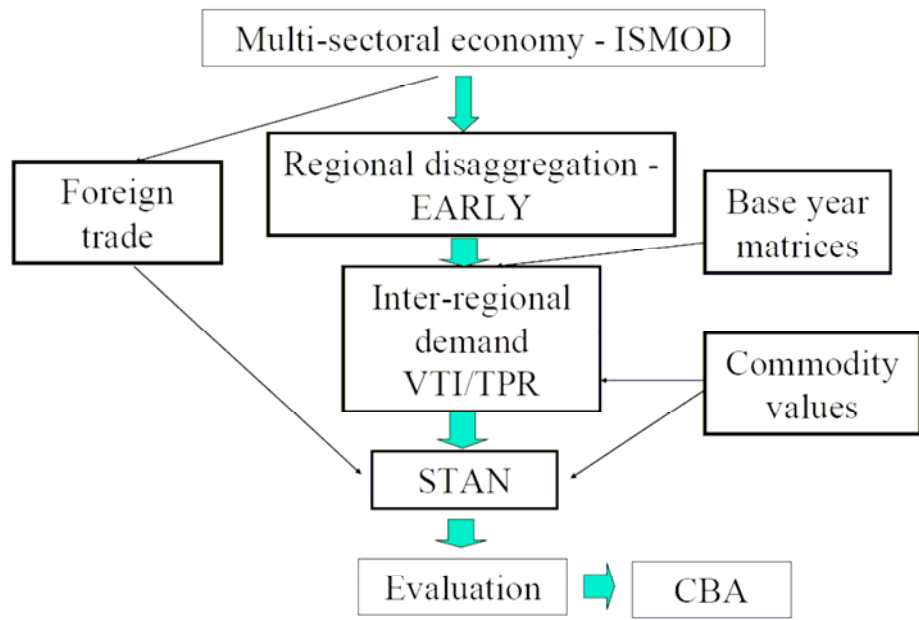


Fig. 2.11: Model architecture of the SAMGODS model. The STAN sub-model contains the transport cost module. (Source: SWAHN, 2001)

3 Methodology

3.1 Research approach

In order to develop the model a number of research questions were formulated at the start of the project:

- 1) Which rail freight infrastructure is to be depicted and how?
- 2) Which rail freight production systems are to be depicted and how?
- 3) Which activities are to be depicted and how?
- 4) How can total costs be assigned to specific flows/consignments?
- 5) How can the model be designed to adapt to different organizational models?

The project was carried out in six main steps, each consisting of a number of “sub-steps” (fig. 3.1):

The *first step* was a literature analysis, in its turn consisting of two parts. The first part focused on cost theory and cost classifications and especially to develop an understanding of cost behaviour and cost-drivers. This has been seen as valuable input to create a framework and starting point for the creation of the model structure for EvaRail. The second part focused on the costing models themselves and contains an overview of models that exist today, including an analysis of their strength and shortcomings.

In the *second step* an inventory of production systems for rail freight was made and a selection made as to which should be included in the model. This step included an investigation of systems that might possibly emerge in the future. The final selection was generous, i.e. most production systems were included; only production systems based on a joint production of freight and passenger transport were excluded. Such systems are nowadays extremely rare and can not be expected to play any major role in the future.

In the *third step* an analysis needed to be made of which activities occur in the production systems, what resources are needed and the cost of these resources. Activities might for example include shunting, marshalling, transloading of loading units, coupling, etc. Resources are locomotives, wagons, loading units, drivers, etc. In the model the activities and resources are specified more exactly, i.e. instead of the resource "locomotive" several classes of locomotives are specified and instead of "transloading of loading units" several transloading techniques are specified.

The fact that the model is activity-based facilitates the depiction of a large number of production systems, since it is not necessary to depict each single production system as such, which in practice would have meant a separate (sub)model for each production system. Instead, costs are allocated to different activities and resources, irrespective of the production system in which they occur or are deployed. Some activities and resources are common to several or all production systems, others occur in only one production system. This approach allows the user to design his or her "own" production system(s) according to his or her specific needs. It also avoids the need to exactly define different specific production systems.

The *fourth step* consisted of constructing the model itself, by far the most time-consuming part of the project. The model is computer-based and written in Visual Basic Applications (VBA) for Excel. This was considered appropriate since data can easily be stored and saved directly in Excel worksheets and, if desired, used for further "manual" analysis or processing. In order to run the model, maintain the databases, and display the results, it is not necessary to open any worksheet. For these tasks the model has a graphical user interface consisting of VB user forms, which considerably facilitates the use of the quite complex model. It also helps to avoid unintentional misapplication of the model. All calculations are carried out in programming code; worksheets are only used for storing input and output data.

The *fifth step* comprised the definition of the cost allocation principles to be used in the model to tackle the problem of joint and common costs. This step is to a great extent based on a literature review with regard to cost allocation in general and other transport cost models in particular.

In the *sixth step* the model was validated and calibrated. Input data was taken from

- a) the inventory of production systems and methods drawn up in step two
- b) contacts with experts from the rail freight industry (train operators, rail authorities, rolling stock suppliers)
- c) a survey of scientific publications and trade journals and contacts with other researchers.

By comparing model results with known costs and cost structures for freight transport, the model was able to be validated and calibrated. To some extent, restriction to a plausibility judgement was unavoidable. Either the model itself needed to be corrected, or the input data overviewed and if necessary corrected.

After validation and calibration, the model was applied in order to:

- a) to test the technical functionality of the model
- b) to identify cost driving factors in rail freight
- c) to economically evaluate operational and technical measures to improve rail freight in an economic perspective

Typical transport chains in different production systems addressing different markets and market needs were calculated and analysed. In concrete trainload traffic, wagonload traffic, intermodal traffic and high-speed freight traffic have been analysed.

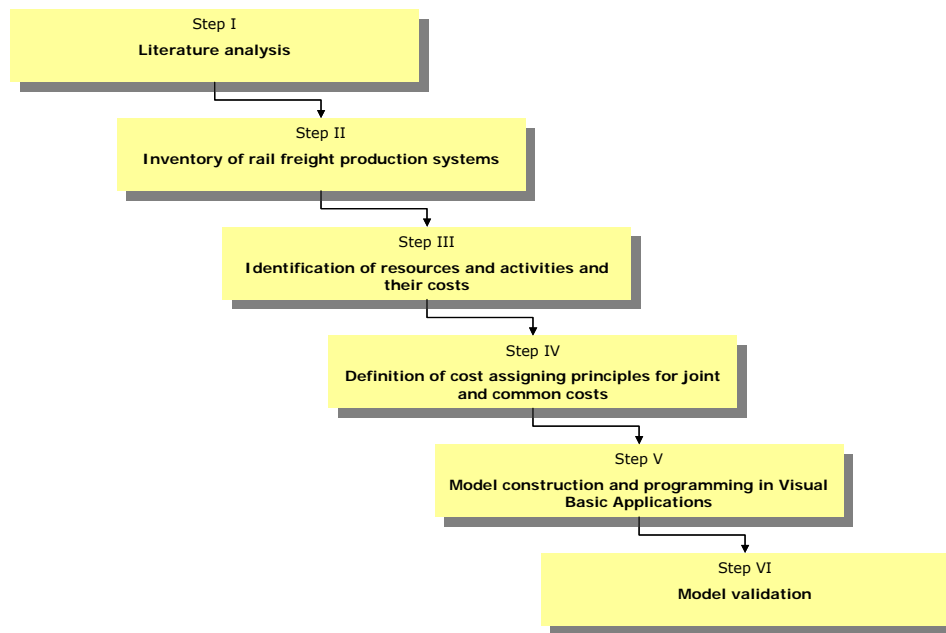


Figure 3.1: The six main steps in the project

3.2 Selection of activities and cost items to be depicted

The selection of the activities that should be depicted in the model and the decision as to the degree of detail with which they should be depicted, i.e. the cost items which the models should contain, was conducted in three phases:

- 1) Analysis of the different functions within the company
- 2) Break- down of the processes into activities
- 3) Identification of the resources consumed when performing the different activities

These phases correspond to the first three steps in ABC modelling as they are presented in LIN, COLLINS and SU.²⁴

The following aspects were considered during the process:

- Importance/share of the activity/cost item of total costs; separately for different production systems. If a cost item/activity is important in only one production system, it has been included in the model
- Variability of the cost of the activity/cost item with output
- Expected future changes in the input costs (e.g. energy, infrastructure user fees)

By enabling the model to take into account future changes in input costs for certain activities/cost items the model developed in this work also addresses the criticism that ABC only gives a “moment’s glance at previous occurrences”²⁵. GERDIN says that an ABC model should therefore also reflect future costs.²⁶

Another factor which has been taken into account is that the cost allocated to cost items in the model reflect a sufficiently large share of the total costs. This means that not too large a share of the total cost is included in the model only as percentage surcharges. According to

²⁴ LIN, B., COLLINS, J., SU, R. (2001)

²⁵ HANSSON, M., OTTOSSON, P. (2003), p.27

²⁶ GERDIN, J. (1995), p.87

JENSEN, it is sufficient when 75-80% of a company's resources are allocated to the right cost items.²⁷

It is obvious that some of the necessary information is information that the model is expected to *deliver*. For this reason an iterative approach was chosen, where the model is refined during the process. In the first step the selection had to be based on state-of-the-art information from experts and – as far as it was available – literature. Then the model results were analysed and on the basis of these results decisions were taken as to which parts of the model needed to be refined.

The methodological approach used to identify costs and cost drivers can thus be illustrated as shown in the figure below.

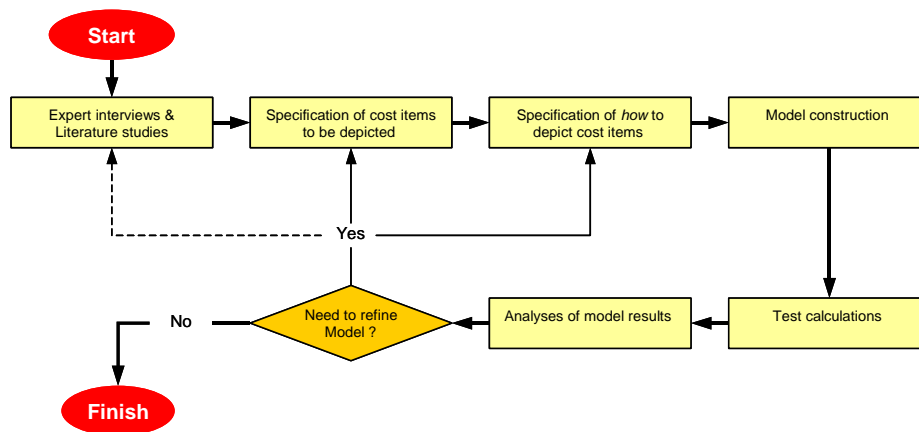


Figure 3.2: Methodological approach for selection of cost items to be depicted (Figure: G.Troche)

²⁷ JENSEN, M. (1994)

As a result of the selection process the following cost items have been included in the model:

Cost item	Cost driver / determinant
1 Capital costs, wagons	Depreciation period, acquisition value, residual value, interest rate
2 Maintenance & service costs, wagons	Time, distance, number of loading runs
3 Rental costs, wagons	Time
4 Capital costs, locomotives	Depreciation period, acquisition value, residual value, interest rate
5 Maintenance & service costs, locomotives	Time, distance
6 Rental costs, locomotives	Time, distance
7 Capital costs, loading units	Depreciation period, acquisition value, residual value, interest rate
8 Maintenance & service costs, loading units	Time, distance, number of loading runs
9 Driver	Time
10 Shunting	
- Locomotive	(see 1 + 2)
- Driver	Time
- Shunter	Time
11 Marshalling	Per occurrence and wagon
12 Transloading (intermodal terminal)	Per occurrence and loading unit
12 Infrastructure user fees (here: Banverket)	
- Track fee	Distance, weight
- Accident fee	Distance
- Marshalling fee	Per occurrence and wagon
14 Energy	Distance, weight, speed

Table 3.1: Cost items and main determinants

The following functions have been added as percentage surcharges:

- | |
|-----------------------------------|
| 1 Administration & planning costs |
| 2 Overhead costs |
| 3 Risk costs |
| 4 Insurance costs |
| 5 Profit margin |

Table 3.2: Cost items as percentage surcharges.

3.3 Model validation

Validating a model is a demanding task. The validation process for a computer model comprises three steps (FLODÉN, J, 2007, p 113):

- I. Validation of the underlying conceptual model
- II. Validation of the translation of the conceptual model into a computer model
- III. Validation of the actual computer model

Steps I and II have been carried out by studying and developing concrete transport solutions from/for the real world and trying to depict these in the model. Doing so ensured that the model could depict transport chains of varying character and complexity correctly. The calculations were carried out partly within other research projects at the Railway Group KTH, especially the 'Efficient Train Systems for Freight Transport' (NELLDAL(ed.), 2005), as well as consultancy projects (TROCHE, 2007/1; TROCHE, 2007/2). The transport chains studied covered different production systems, as unit-trains, wagonload and intermodal traffic.

In addition, the model has been continuously discussed with my thesis supervisor, Bo-Lennart Nelldal, who has very long experience of transport modelling and especially railway cost modelling (see also ch. 2.3.1). The model's input and output have also been extensively discussed with experts in the field, principally Lars Ahlstedt, who has been working for different railway undertakings in Sweden and abroad for a long time and has run a railway company independently for several years. This experience gives him in-depth and up-to-date expert knowledge about railway costs.

Steps I and II of the validation could be carried out successfully without requiring any major corrections in the model, thanks to the careful analysis of the rail freight production system that preceded the actual work of designing the model, and the bottom-up approach on which the design of the model is based. This ensured that the rail freight production system was depicted on a fairly detailed level, giving it from the outset a high degree of flexibility in order to depict a wide variety of situations.

The final step, the validation of the actual computer model, in its turn can be divided into three sub-steps (BANKS, et al., 2001, PEGDEN, et al., 1995):

- a. Verification
- b. Validation
- c. Evaluation

In the verification step the computer program is debugged. The goal of verification is to ensure that a model operates correctly in the sense that it produces all output data and that it produces these data in the intended way. Verification does not involve any checking to determine whether the output data are in line with the real world. Verification can be considered a form of “technical testing” of the program code. Verification was carried out continuously as part of the programming phase to ensure full functionality after each programming step.

Validation means testing the agreement of a model with the real world. In the validation step the model is tested for continuity, consistency, degeneracy and absurd conditions (FLODÉN, J, 2007, p.47):

- | | |
|---------------------|--|
| - Continuity | checks that small changes in the input data result in equally small and appropriate changes in the output data |
| - Consistency | checks that essentially similar model runs should produce essentially similar results |
| - Degeneracy | checks that the model responds to removed or unused features of a model in an appropriate way |
| - Absurd conditions | checks that absurd conditions do not occur during a model run, e.g. negative transport times or train lengths below zero |

All steps are closely related to the verification of the model so that they could be carried out together with the verification. The evaluation is often an iterative process as illustrated by figure 3.3.

The evaluation is performed to ensure that the final model meets the model requirements and that the model can be used in the intended way and fulfils its purpose. The key purpose of the model is to carry out detailed rail transport cost calculations in order to assess transport solutions and to obtain input data to other models. The successful application of the model in various projects showed that the model meets expectations and is able to answer the questions it is expected to answer.

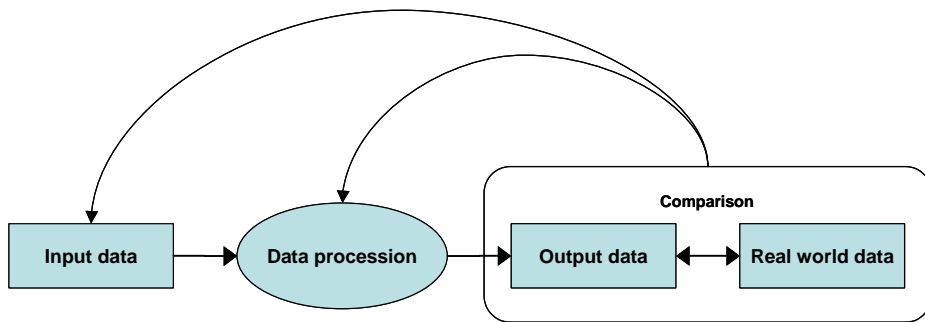


Figure 3.3: The validation of a model as an iterative process (figure: G.Troche)

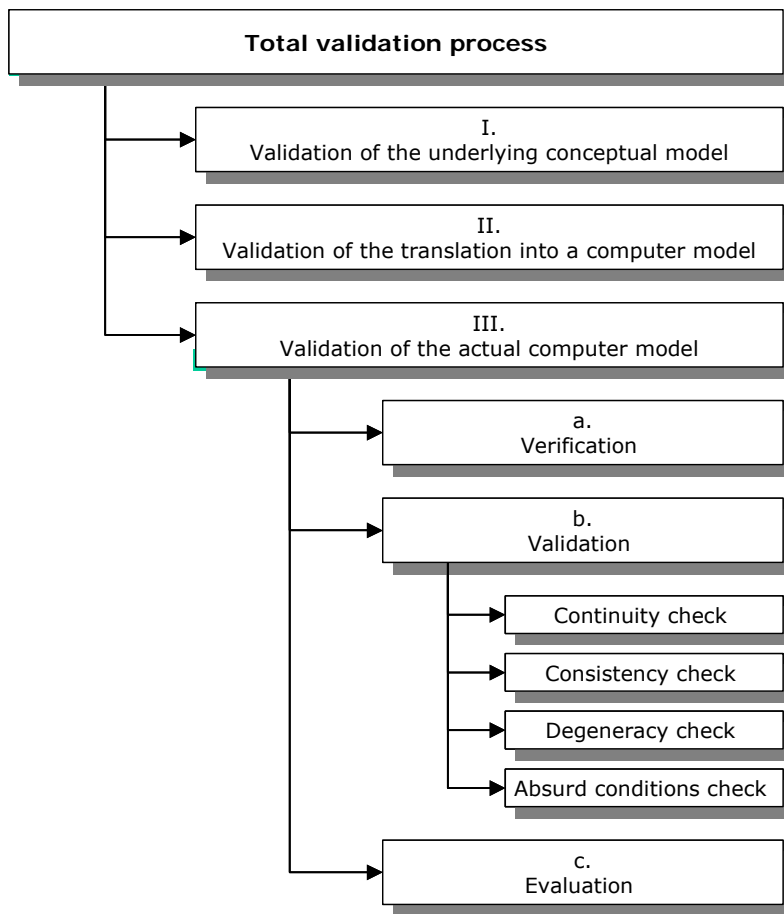


Figure 3.4: Validation process for the EvaRail-model (G.Troche)

3.4 Methods of data collection

3.4.1 Data sources

The availability of input data determines to a large extent the design of a model. A problem specific to (business-economic) cost models is that input data often (1) cannot be found in public statistics, (2) nor be gathered in test series and (3) nor be collected by means of questionnaires to end consumers. A large part of the input data is information used internally within a company and subject to confidentiality. Consequently, the collection of the input data needed for the model requires a great deal of cooperation from actors in the railway sector.

Principally there are three sources of input data:

- 1) Train operating companies (TOCs) and other actors involved in the production of the transport service (infrastructure managers, etc.)
- 2) Independent experts in the railway sector (consultants, researchers)
- 3) Earlier studies and news magazines in the railway sector

In this project cooperation with TOCs could only be achieved to a limited extent. Not least increased intramodal competition diminishes railway companies willingness to reveal detailed cost data.

Even earlier studies are only useful to a certain extent. One problem with them is that data are often not disclosed in detail – if at all. Another problem is that data often are old and do not reflect current cost levels. A third problem is that the cost items are not always exactly identical to those used in the EvaRail model. An exception are the project deliverables from the RECORDIT project, from which at least some input data could be used for the model.

Some information on the purchase cost of rolling stock could be obtained from railway sector trade journals.

3.4.2 Collection methods

Four different methods of data collection can be distinguished:

- 1) Analysis of statistics and other publications
- 2) Mail surveys (by physical mail or e-mail)
- 3) Telephone interviews
- 4) Personal interviews

Of these four methods, 1, 3 and 4 were used in this study, albeit – for reasons mentioned above – with a strong focus on the fourth method, personal interviews. Telephone interviews were used only in very rare cases, and then mostly to follow up earlier personal interviews.

Personal interviews were thus an important part of the data collection – and at a later stage of validation and calibration as well. The main reasons for choosing personal interviews as the main source of data lie in the nature of the data required for the cost model:

- Much data is confidential or at least sensitive. Consequently, people are often not willing to divulge such information in a – rather anonymous – survey. Furthermore, the necessity to write down information gives it a more “official” character, which people may wish to avoid when it comes to information of this kind. Personal interviews allow the interviewer to build up a closer relation to the interviewed person and create an atmosphere of mutual trust, which considerably increases the interviewee’s willingness to give specific information.
- Some data may require additional information and can be understood only within a broader context. To foresee all the possible information which might be required and design a survey to cover all thinkable situations would require a considerable amount of work on the data collectors’ part and would most likely result in a quite long, complex and scarcely respondent-friendly survey.
- In some cases it is not known in advance by the data collector exactly which information a specific respondent is able to contribute. In any survey perhaps only a few questions are relevant for a specific respondent. If a respondent has to go through a large number of questions, all of which are irrelevant

for him/her, before finding a relevant question, he or she may give up before reaching any relevant question(s).

The questions put to the respondents in this study often require quantitative answers, e.g. certain costs. However, the interviews are more of a qualitative nature, since the answers are not used to carry out any statistical evaluations. VALENZUELA, SHRIVASTA (N.D.) discern four different types of qualitative interviews:

- 1) *“Informal, conversational interview* – no predetermined questions are asked in order to remain as open and adaptable as possible to the interviewee’s nature and priorities; during the interview the interviewer ‘goes with the flow’
- 2) *General interview guide approach* – the guide approach is intended to ensure that the same general areas of information are collected from each interviewee; this provides more focus than the conversational approach, but still allows a degree of freedom and adaptability in getting the information from the interviewee
- 3) *Standardized, open-ended interview* – the same open-ended questions are asked to all interviewees; this approach facilitates faster interviews that can be more easily analyzed and compared.
- 4) *Closed, fixed-response interview* – where all interviewees are asked the same questions and asked to choose answers from among the same set of alternatives [...]” (VALENZUELA, SHRIVASTAVA (S.D), pp 4,5)

The type of interview applied in this work was a combination of the first and second types described above. It differs from type 2 insofar as it was not necessarily intended to collect data for the same areas of information from all respondents, nor were the interviews completely without predetermined questions as in type 1. Another important aspect of the interviews was that the respondents in all cases were experts.

The interviews conducted can thus best be characterized as *structured, conversational expert interviews*. They contained certain predetermined questions but allowed for additional free questions. The interview was allowed to develop in a certain direction, which also means that not all predetermined questions necessarily had to be put to all respondents. The fact that the respondents were experts in their field not only required experience in carrying out interviews – which is always a prerequisite for personal interviews, even non-expert interviews – but also a high degree

of in-depth background knowledge in the fields concerned on the interviewer's side, ranging from the ability to use a specific terminology to being up-to-date on sector-specific news.

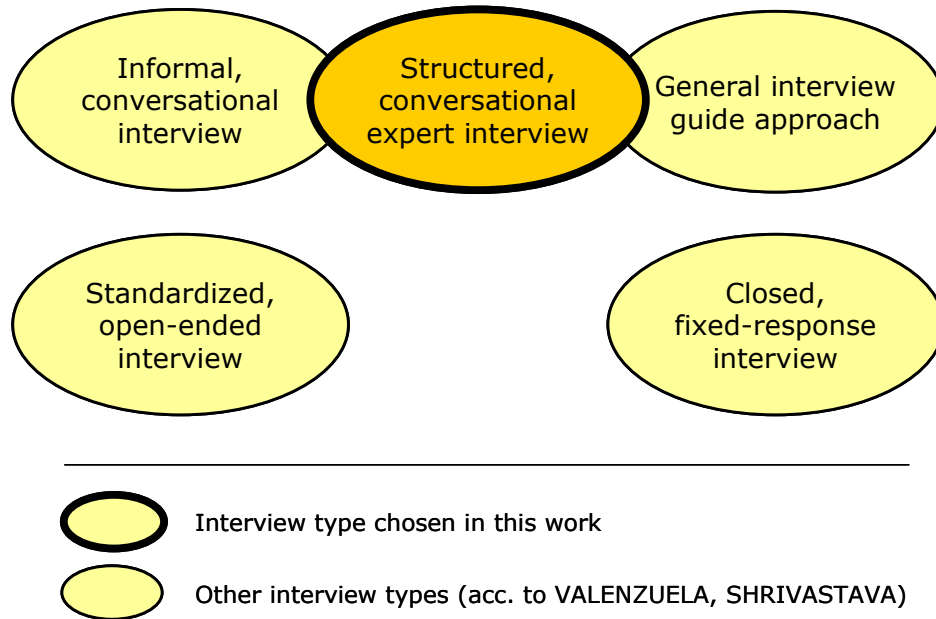


Figure 3.5: Types of personal interviews (G.Troche)

4 Structuring the rail freight system

4.1 Products and production systems

4.1.1 Introduction

The terms “products” and “production systems” in the context of rail freight are frequently used but often without a clear demarcation and definition. The figure below illustrates how these terms should be understood in the context of this work.

A *production system* is the sum of all resources – material and immaterial – which are necessary to carry out a certain task, in this case to move goods on the rail network. The main resources are:

- rolling stock
- personnel
- infrastructure
- energy
- train operating principles
- organizational structures

Four different production systems can be distinguished:

- Trainload
- Wagonload
- Combined Traffic
- High-speed rail freight

They can be distinguished from each other by the specific combination of different types of in first hand train operating principles and rolling stock, and to some degree by which parts of the infrastructure they use. There are parts of the infrastructure, that are specific for certain production

systems (see below). Sometimes even the organizational structure can be a distinctive attribute for a certain production system. However, even here a strict demarcation is not always possible and production systems to some degree certainly overlap each other. A container train, for example, will in most cases belong to the production system of Combined Traffic, whereas if the train operates for a single customer in a regular flow in a fixed relation, it may very well also belong to a trainload system.

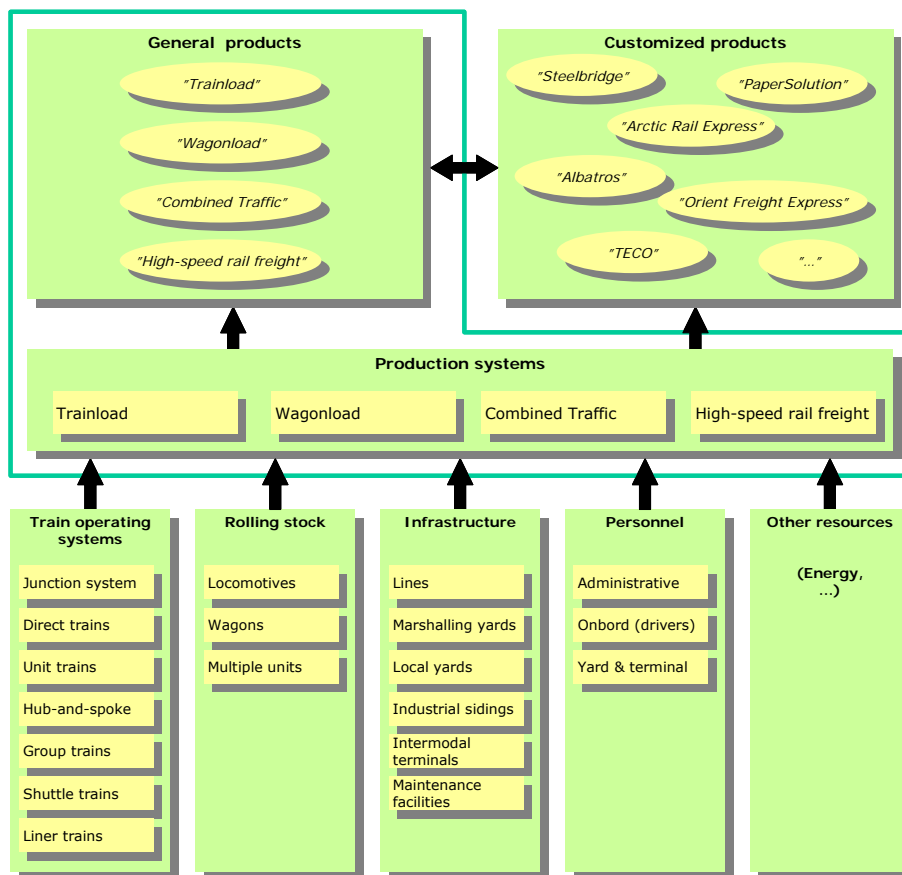


Figure 4.1: Clarification of the terms “products” and “production systems” (Gerhard Troche)

Not all resources need to be assigned to only one specific production system; in many cases resources will be shared by different production systems (for example locomotives). This is especially true of

infrastructure. The railway network – or at least most parts of it – is used by all rail freight production systems and not only these but also by passenger traffic. By contrast, the so called capillary infrastructure is often dedicated to freight and may very well be specific for a certain production system.

4.1.2 General and Customized products

A *product* is a (transport) service offered to the customers and is based on one or a combination of different production systems. Its attributes largely depend on the characteristics of the production system(s) it is based on. A production system as a whole can be marketed as a product. This is for example often the case with wagonload and Combined Traffic production systems.

In this case one can speak of a *general product*. This is open to all customers and its geographical coverage coincides with the whole area covered by a production system (traditionally, but no longer necessarily, corresponding to the area of a country). No formal limitations are imposed on general products when it comes to commodities, relations, etc. as long as they do not result from the production system’s characteristics themselves.

Production system	Product
A <i>production system</i> for rail freight comprises – in a wide sense – all resources necessary to offer a certain rail freight service.	A <i>product</i> is the (transport) service offered to the customer(s) and is based on one or a combination of different production systems. Its attributes largely depend on the characteristics of the production system(s) the product in question is based on. A production system as a whole <i>can</i> be marketed as a product.

Table 4.1: The definitions of ‘production system’ and ‘product’ in the context of rail freight (Gerhard Troche).

Wagonload traffic is the oldest product and in most countries still forms the core of rail freight. Principally, it meets the base market’s need to transport raw materials and semi-manufactured goods. It comprises the

transportation of whole wagons that are loaded and unloaded by the customers at industrial sidings or loading platforms. Wagonload traffic may be either single wagons or groups of wagons. The wagons are often shunted twice or more during their journey. Where the freight's consigner and/or consignee has no rail connection of their own, the transportation by rail is often combined with road haulage at one or both ends. Wagonload traffic principally carries freight in the base market.

Unit trains are freight trains that form part of logistics systems where the railways function as conveyor belts for industry for the transportation of bulk freight and basic commodities. Each unit train is operated for a specific customer with dedicated wagons and according to the customers' own timetable. Unit trains use basically the same techniques as wagonload traffic, but unit trains allow the railway's advantages of scale to be exploited to the full. The largest and oldest unit train system in Sweden is the Laponian Ore Line. Typical loads of unit trains are iron ore, raw timber, steel, wood chips, peat, oil and oil products, and paper.

Intermodal traffic is the transportation of single load carriers, principally containers, swap-bodies, and semi-trailers between specially designed terminals on special railway wagons. It addresses in first hand the product market. The wagons travel (mostly) directly between intermodal terminals or – nowadays more seldom - as groups of wagons in direct wagonload trains. Feeder traffic is by road. Intermodal terminals exist in 13 locations in Sweden today, some of them in ports. Container traffic to ports and trailer traffic in connection with ferry services is extensive.

High-speed freight trains generally transport mail and parcels in the service market. Transportation is generally overnight with late departures and early arrivals so that collection and sorting can be done at the terminals before departure and sorting and distribution upon arrival. Some trains make scheduled stops along the way for loading and unloading. Modified passenger train equipment is used and the trains' maximum speed is 160 km/h. The fastest high-speed freight trains are the TGV mail trains in France with a maximum speed of 270 km/h.

Customized products: In addition to the general products railway companies often offer *customized products*. These are dedicated to large customers, certain industrial branches, certain types of traffic or certain geographical relations/corridors. The table on the next page contains a selection of Customized products offered by railway companies in Europe.

The following table gives an overview of the general products in rail freight and the market segments which they address. The table below gives examples for customized products.

Product	Market segment	Typical transport time	Frequency
Trainload	Bulk goods - raw materials	Less than one day	Continuously
Wagonload	Base market - raw materials - semi-finished products	National: Day 0-1 International: Day 1-4	National: Daily International: Several/week
Combined Traffic	Product market - semi-finished products - finished products	Overnight 17:00 – 07:00	Daily
High-speed rail freight	Service market - Mail - Express freight	Overnight, Same-day	Daily Several/day

Table 4.2: Markets, customer requirements and rail freight products

Type of customization	Product		Operator
Large customers			
	Steelbridge Avesta – Göteborg (– Sheffield)	Avesta Polarit	Green Cargo
	Kopparpendeln Piteå – Helsingborg	Boliden	Green Cargo
	Stålpilen Luleå – Borlänge	SSAB	Green Cargo
Certain Industrial branches			
	Paper Solution	Paper industry	Railion
	Chem Solution	Chemical Industry	Railion
Certain types of traffic			
	Albatross network	Port-hinterland traffic	Railion
Certain geographical relations			
	Orient Freight Express	Köln – Istanbul	Transfesa
	Ostwind/Westwind	Berlin – Moscow	Railion/RZD

Table 4.3: Examples of customized products offered by European railway companies

4.1.3 Classification of products in the modelling context

The traditional classification of rail freight services into Trainload and Wagonload Traffic is mainly based on the shipment size. Combined Traffic, though not in its denomination expressly relating to the shipment size, can in many cases be included into this logic as well (figure 4.2), since intermodal loading units are even smaller than wagons.

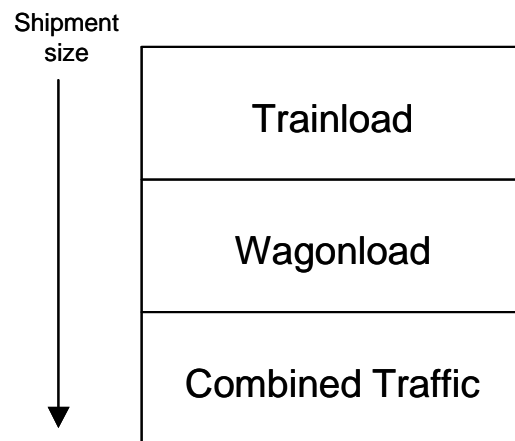


Figure 4.2: *Traditional classification of rail freight services (Gerhard Troche)*

From a modelling point of view, however, this very rough classification may not be the most suitable, especially since the wagonload segment contains many types of assignment of which some show characteristics typical of trainload services. This becomes obvious when the frequency of the transports is added as a classification parameter in addition to the shipment size.

For a better understanding in the context of modelling it therefore appears meaningful to choose a somewhat finer classification of rail freight products, splitting up the large group of wagonloads into single wagons and wagon groups, and adding the frequency of transport (system transports, one-off shipments) as a further classification parameter. Figure 4.3 shows an attempt to make such a finer classification.

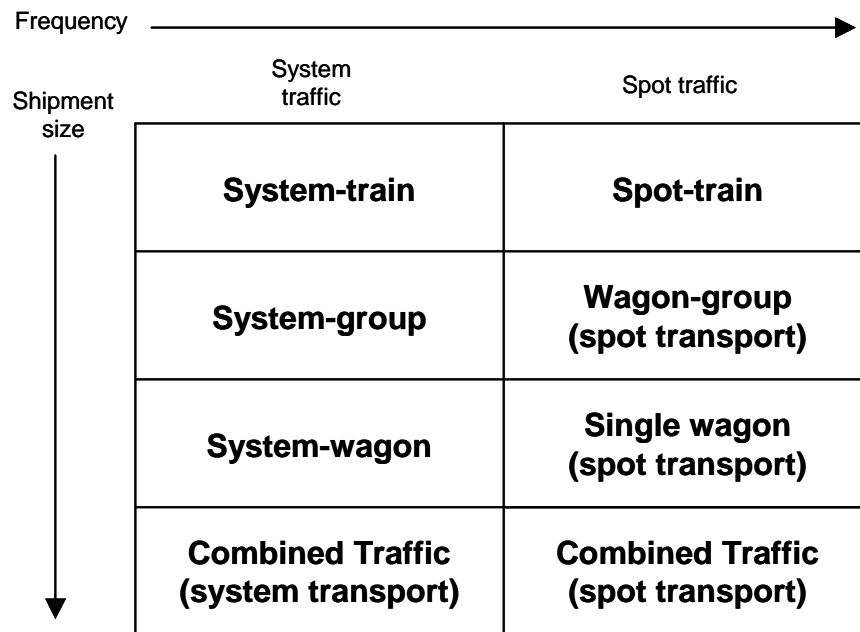


Figure 4.3: *Finer classification of rail freight services, taking into account both shipment size and frequency/regularity (Gerhard Troche).*

4.2 Operating principles for freight trains

Railways apply a variety of different operating principles for freight trains. Figure 4.4 illustrates schematically a number of different principles, both common ones and more seldom applied ones. It should be mentioned that there are no 'official' exact definitions of operating principles; some terms overlap and sometimes different terms are used for those principles shown below.

4.2.1 Junction system with intermediate marshalling

The junction system is a hierarchical system and forms the basis of conventional wagonload traffic.

Terminal yards and marshalling yards form the nodes (junctions) in this system. While marshalling yards represent an internal production resource for the railway, terminal yards connect to interfaces between the railway system and the "rest of the world" in form of e.g. team tracks, and industrial spurs.

Freight wagons from the shippers are collected in the terminal yards and combined to form local freight trains bound for the next marshalling yard. In the marshalling yard long distance trains are formed to run to other marshalling yards. Sometimes a freight wagons has to pass several marshalling yards until it arrives in the destination region. This often occurs in international traffic. From the last marshalling yard wagons are again moved to terminals yards where they are unloaded on team tracks or distributed to industrial sidings.

Each terminal yard is assigned to (normally) one marshalling yard. The terminal yards assigned to a certain marshalling yard define the catchment area of the latter.

The extensive handling in marshalling yards when transport distances are long implies many time-consuming and costly activities as well as constituting a potential source of disruptions in the transport chain. On the other hand, the junction system gives a high geographical coverage since each train connection between two classification yards serves a large number of relations.

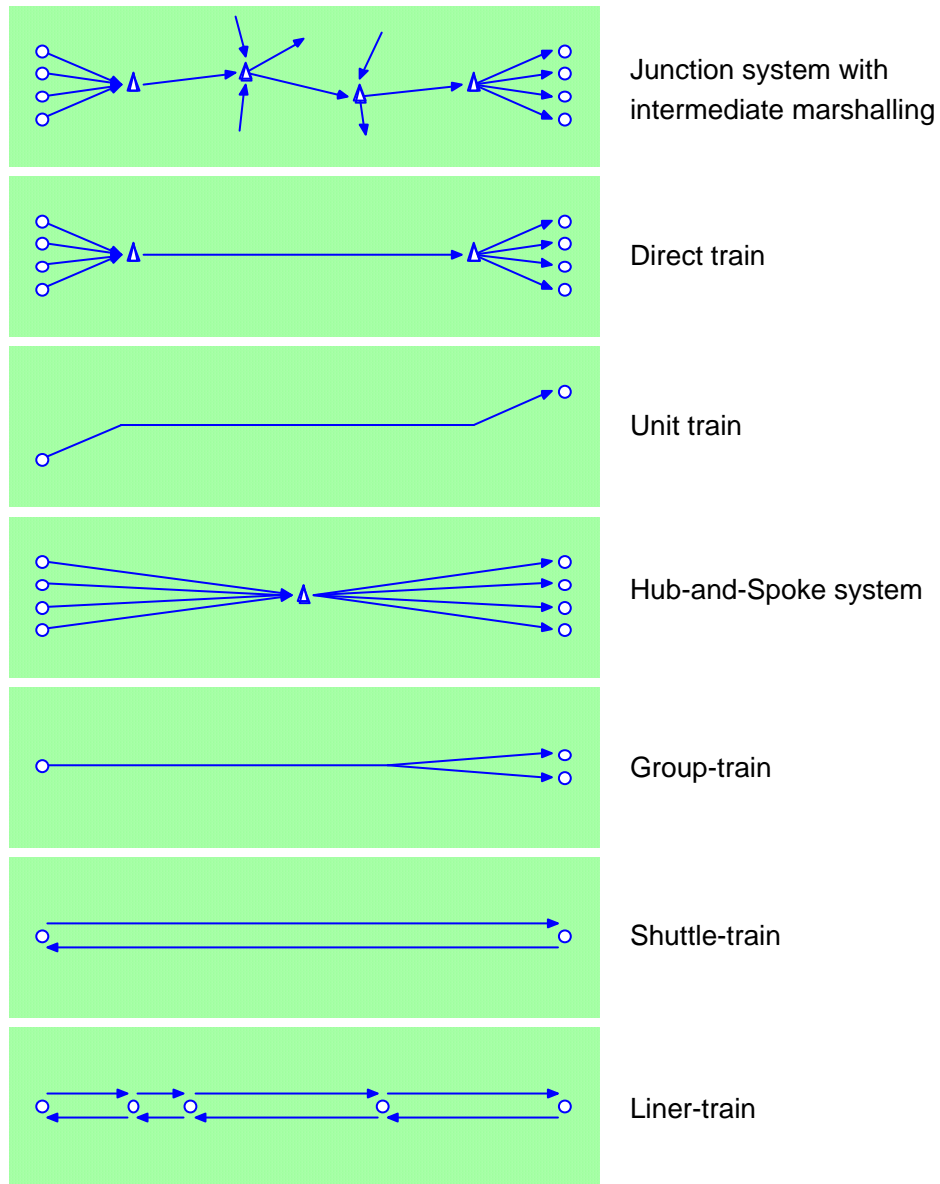


Figure 4.4: Operating principles for rail freight. (Gerhard Troche)

Today railways tend to operate direct trains even between marshalling yards situated far away from each other in order to shorten transit times and improve quality (cf the next section, about direct trains). However, it is unlikely that direct trains will completely eliminate the need for intermediate marshalling, since the traffic base is not in all relations

sufficient to bear direct trains with an acceptable service level (= frequency). This underlines the importance of cost- and time-efficient marshalling yards.

4.2.2 Direct trains

Direct trains are trains in the wagonload system, which operate without intermediate marshalling between their originating and destination regions. The wagons are thus marshalled (in ideal cases) only twice between consigner and consignee: In the marshalling yards in whose catchment areas the consigner and consignee are located. The trains pass by intermediate marshalling yards with considerable time gains and less sensitivity to disruptions. If the traffic base is large enough, direct trains also run to and/or from terminal yards.

Green Cargo's (and previously SJ Cargo Group's) international transportation systems are to a large extent based on direct trains. Between 1987 and 1997 the number of direct trains in Swedish international traffic increased from 350 to more than 6,500 a year. Much intermediate marshalling has been eliminated in this way and transportation times in many international relations have been considerably reduced at the same time as quality has improved.

It should be pointed out, however, that the term *direct trains* is by railway companies often used in a wider sense than the definition above. The marshalling yards where the trains stop function as gateways, suitably located with good connections to and from other regions in a certain country. The marshalling yards that constitute the direct train's departure and destination stations can often only contribute traffic to the direct train connection to a limited extent. For traffic between Sweden and France, for example, Woippy in north-eastern France functions as a gateway. From here, many wagons are sent in French domestic long-haul freight trains to other marshalling yards in France before they arrive at their final destination.

Direct trains thus often link only two countries with each other "directly", rather than two marshalling yards' catchment areas. That there are few "real" direct trains is partly due to the fact that a relatively large traffic base is needed to be bear a train; for daily traffic 5 days a week at least about 100,000 tons/year in each direction. The number of relations that can be provided for using direct trains is thus limited and the traffic base from a marshalling yard's catchment area is often not sufficient to

fill a whole train. The number of direct train connections and the frequency of each connection must also be weighed against each other.

It should, however, be emphasized that the establishment of direct train connections, not least in international traffic, has increased the railways' competitiveness in the relations concerned and the positive market effects in the form of retained market share over long distances often compensate for the drawbacks and perhaps reduced market share in non-standard relations.

4.2.3 Unit trains

Unit trains are freight trains that form part of dedicated logistics systems where the railways function as conveyor belts for industry. Each unit train is operated for a specific customer and is tailored to this customer's needs runs, when it comes to timetables, rolling stock, etc. As a rule, the trains contain only one type of wagon, which often is specialized for a certain commodity. The trains often run from factory to factory or from factory to port and vice versa.

Unit train traffic makes maximum use of the railways' economies of scale. There are approximately 20 unit trains systems in Sweden in operation today. The oldest – and the one with the largest volume – is the Laponian Ore Line. The others have been built up gradually in recent decades, e.g. the “Steel Arrow” between Luleå and Borlänge, the “Copper Shuttle” between Rönnskärsverken in Skellefteå and the SCA train (forestry products) between Munksund and Skövde. Unit train traffic is dominated by transportation for base industries. Typical freight carried includes iron ore, steel, copper, raw timber, wood chips, peat, oil and oil products, gas and paper.

4.2.4 Hub-and-Spoke systems

A hub-and-spoke system is a system where trains from different places meet in a more or less centrally situated hub to change single wagons, wagon groups and/or load units. Hub-and-spoke systems can be found in both intermodal traffic and wagonload traffic. The advantage of hub-and-spoke systems is that they allow relations to be covered that on their own do not have sufficient volumes to justify daily direct train connections. By bundling several flows, block trains with a high utilization can be operated to and from the hub, where the wagons

and/or load units are changed in order to continue towards their final destinations as new block trains.

Two of the drawbacks to such systems are that the freight in some relations has to be transported via long detours and that the hubs must be dimensioned for very high throughput in narrow time-windows. Their capacity is utilized for only very short periods during the day. To avoid too long detours in relations with large demand, hub-and-spoke systems are often supplemented by and combined with other production systems.



Figur 4.5: *Intercontainer-Interfrigo's Qualitynet is an example of a hub-and-spoke system for intermodal traffic. In this concept, Metz functions as a hub in a European intermodal traffic concept covering 12 countries. The system is supplemented by direct connections that lie outside the configuration (and that are not shown on the map). Map: ICF..*

One example of a hub-and-spoke system for intermodal traffic was IntercontainerInterfrigo's (ICF) so-called Qualitynet (figure 4.5). This system covered 12 European countries. Six days a week, one or several block trains left different intermodal terminals in Europe and converge in a hub in Metz in the east of France. Here, new trains were formed from the incoming block trains that then continue on towards their final destinations. There were 60 trains circulating in the whole system every day. In relations with a sufficiently large traffic base to fill single trains, ICF's Qualitynet is supplemented by block and shuttle train connections that run directly from origin to destination, especially along the Rhine-axis between the North Sea ports and the Alpine Region and Northern Italy.

4.2.5 Group trains

Group trains can be found in both wagonload traffic, intermodal traffic and (sometimes) unit train traffic. As the name implies, these trains consist of two or more train sections with different destinations. This means that the wagons must be sorted by destination already during train formation, which puts high demands on the marshalling procedures. As the trains leave the outbound stations already grouped, they do not need to be marshalled when the wagons for the different destinations are separated; the train sections can simply be connected at any intermediate station without any great loss of time.

The advantage of group trains is that they can build trains with a high capacity utilization on long shared sections without all wagons needing to have the same destination. The stations should, however, lie in roughly the same direction/region. The larger the proportion of the total transport distance that the train sections travel together, the larger the synergy effects. Among the drawbacks with group trains can be mentioned that the timetables for the different train sections cannot be drawn up independently of each other. Forming group trains requires relatively long train lengths if the train sections should not become extremely short – and probably unprofitable – on the sections where they run separated.

The Group train concept is similar to the Train Coupling and Sharing concept. The difference between the two is that in TCS traffic, complete trains are coupled together, including locomotives; in Group trains only the wagons are coupled together. If a Group train is split, a new

locomotive must be coupled to the decoupled train section in order to continue the journey. Since the TCS-concept requires the possibility of remote control of the traction vehicles coupled to the train, it has hitherto not been used to any great extent, but ongoing technological development will probably enable a breakthrough for the concept.

4.2.6 Shuttle trains

Shuttle trains are mainly used in intermodal traffic. Shuttle trains travel regularly between intermodal terminals and always keep their configuration, i.e. wagons are not normally attached or detached to the trains. Shuttle train traffic is thus very cheap to produce but has relatively low flexibility. The trains' capacity can not be adapted to variations in demand over time or direction, nor can the train configuration be adapted to varying market requirements, e.g. different numbers of trailer and container wagons. Shuttle trains are thus primarily suited to relations with strong, stable balanced flows.

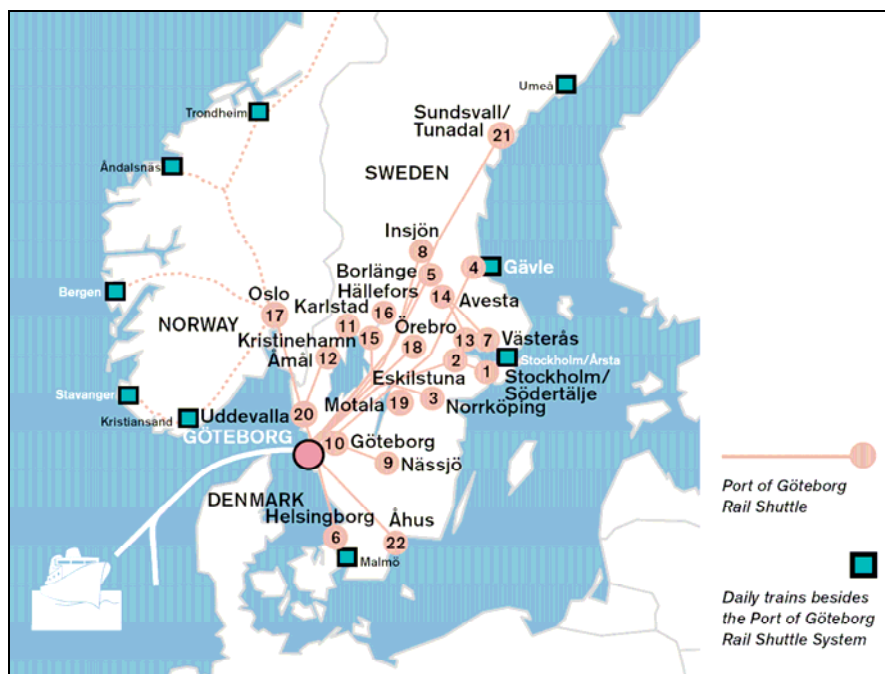


Figure 4.6: Shuttle trains are common in port-hinterland traffic. The map shows shuttle trains to and from the Port of Göteborg. However, not all trains shown are shuttle trains in a strict sense. (Map: PORT OF GÖTEBORG, 2004, p.6).

4.2.7 Liner trains

Unlike conventional production systems for freight traffic, where it is normally not possible to load or unload freight along the way, liner trains make short intermediate stops for loading and unloading at intermediate stations – in the same way as passenger trains make stops for passenger exchange at intermediate stations. Liner trains thus allow much greater geographical market coverage than traditional production systems since, in addition to the end-point market, they can also capture the intermediate markets. More terminals mean that feeder transportation distances are shorter and that feeder transportation against the direction of transport in many cases can be avoided.

Time- and cost-efficient loading and unloading techniques that are also suitable for small volumes are a prerequisite for liner trains. The terminals should be connected to the main lines at both ends in order to avoid time-consuming shunting operations.

Intermodal Liner trains are since many years in operation in Japan, but are a relatively new phenomenon in Europe. In Sweden Liner trains were tested on a commercial basis for some years starting in 1997. Other countries have – or had – more or less advanced plans to introduce Liner trains. The concept, though, has not seen any breakthrough yet, mainly due to the lack of fast cheap transloading methods. However, the concept may well be developed further for both unit train and intermodal transportation and become in a longer perspective an important complement to other train operating principles.



Figur 4.7: Light Combi, LC, a traffic concept with liner trains.

4.2.8 Train operating principles in different production systems - overview

The table below shows how common different train operating principles are in different production systems.

	Trainload	Wagonload	Combined Traffic	High-speed rail freight
Junction system with intermediate marshalling	-	++	o	-
Direct trains in junction system	-	++	o	-
Unit trains	++	-	-	+
Hub-and-spoke system	-	+	++	+
Group trains	-	++	+	o
Shuttle trains	-	-	++	++
Liner trains	-	+	++	++

++ Very common or suitable
 + Common or suitable
 o Possible
 - Not possible

Table 4.4: Train operating principles in different production systems

4.3 Changing organizational structures in the railway sector

Since the intention was to develop a business-economic model from a train operator's perspective organizational structures in the railway sector had implications for the model structure. It was natural that the starting point had to be to model processes which can be directly influenced by a train operator, i.e. processes where the train operator can decide himself how to design them and with which resources.

This simple approach is, however, complicated by the fact that there is today no longer *the* train operator. The rapidly changing organizational structures in the railway sector over the last decade and a half has had a great impact on the roles of different actors in the sector – and the processes and resources they control.

While the organizational structure of the railway sector in Sweden had been stable for a quite long time until the end of the 1980s – there have been virtually no further fundamental changes since nationalization, which was largely completed during the first half of the 1950s – the railway sector has since then undergone massive reorganization in conjunction with, and as a result of, the liberalization process of the railways in Europe.

One important phenomenon of the process was a far-reaching outsourcing of resources and functions, as illustrated in figures 4.8-4.10. Earlier, almost the entire railway system was managed by a national railway company. One problem arising from this situation was that no market prices were available for many activities or resources necessary for the production of transport services. This was because many services were produced within a railway company. There was an internal price setting, which did not necessarily reflect any market value or “true” costs. This problem was not unique to the railway sector, but it was without doubt much more widespread there, as the railway business had traditionally been organizationally much more integrated.

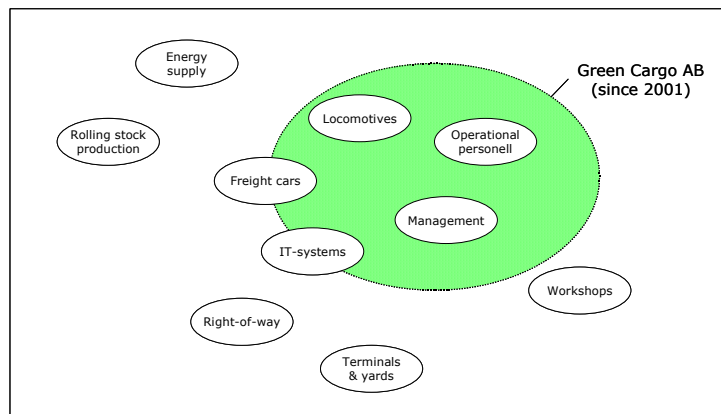
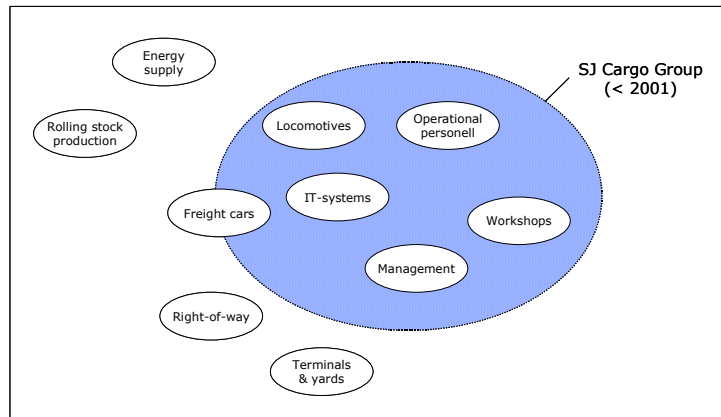
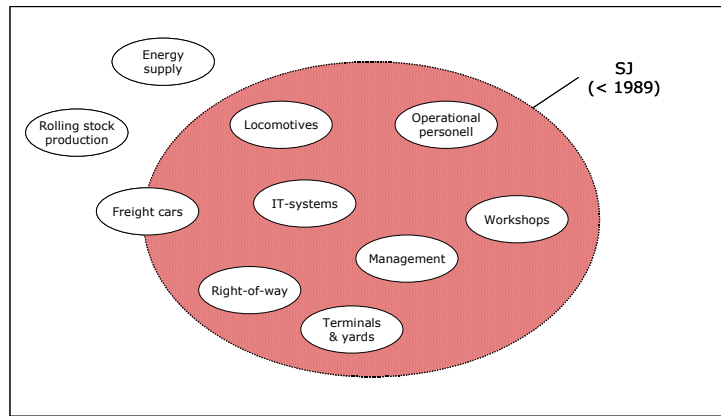
Outsourcing was and is driven by both political decisions – for example the separation of infrastructure and operations was seen as a prerequisite for the liberalization model adopted by the EC and the Swedish government – and market forces. Often it was even a combination of both. As can be seen from figure 4.10 today's train operators keep much

fewer resources (and processes) in-house than their predecessors just a little more than one decade ago.

To make the situation (from a modelling point of view) even more complicated, new (private) train-operating companies have emerged where the degree of outsourcing is already much higher from the start. Today there exist train-operating companies, which do not consist of much more than a small management – all other resources, from locomotives to personnel and IT systems, are hired or leased. But it is also clear that the earlier state railways will be important players on the rail freight market for the foreseeable future and thus serve as an important reference when it comes to the delimitation of a “railway company” in a modelling context.

EvaRail has been designed so that it can adapt to a wide range of organizational structures, for example by including lease rates for locomotives or personnel. The general conclusions from the model will also to a high degree be generally applicable, since the prices charged by external suppliers will be largely based on basically similar cost calculations as if these processes were carried out in-house. The fact alone that there are alternative suppliers of resources and services means that even train-operators who still keep these functions in-house will be forced to adopt cost-based internal pricing and to produce these functions at a competitive, i.e. roughly similar, price as external suppliers. Otherwise these functions will sooner or later be outsourced.

As a consequence of the ongoing deregulation process in the railway sector further changes can be expected in the future. It is therefore necessary to follow the development and, if necessary, adapt the EvaRail-model to the changing organizational structures in the sector.



Figures 4.8-4.10: Schematic and simplified illustration of changes in the organizational reach of a railway undertaking over selected resources/functions, here Swedish SJ/Green Cargo. The figures illustrate the outsourcing process which has taken place as a result of the liberalization of the rail freight in Europe. The development in other countries may differ to some degree from the Swedish case presented in this figure but the general trend is the same in all European countries. (Fig.: G. Troche)

5 Cost allocation in the rail freight system

5.1 Allocating costs in a specific transport system

5.1.1 Trainload

In a trainload system a high portion of variables can be calculated within the model, since most resources required are assigned to one recurrent freight flow. As illustrated in figure 5.1 the train consist of the entire train used for that flow is known since the train conveys only wagons for that flow. The annual utilization of the wagons can be calculated on the basis of the data for the flow in question and – if even the locomotives are exclusively allocated to this flow – their utilization as well. Costs for empty runs do not need to be shared with any other flows.

5.1.2 Wagonload

When it comes to a wagonload system, things get more complicated. Wagonload trains normally convey wagons assigned to a number of different flows. Freight wagons can also be assigned to different freight flows at different times.

However, if all flows within a wagonload system over the whole calculation period (in EvaRail one year) are known, the consist of each train for each departure as well as the utilization of each wagon individual can be calculated within the model (fig. 5.2), like with a trainload system. Both can be considered closed systems, the only difference being that the trainload system is a one-flow system while the wagonload system is a multi-flow system. In order to be able to handle a multi-flow system the model has to be much more complex since it must be able to assign freight cars to different flows and trains over time, and different freight wagons to a trains.

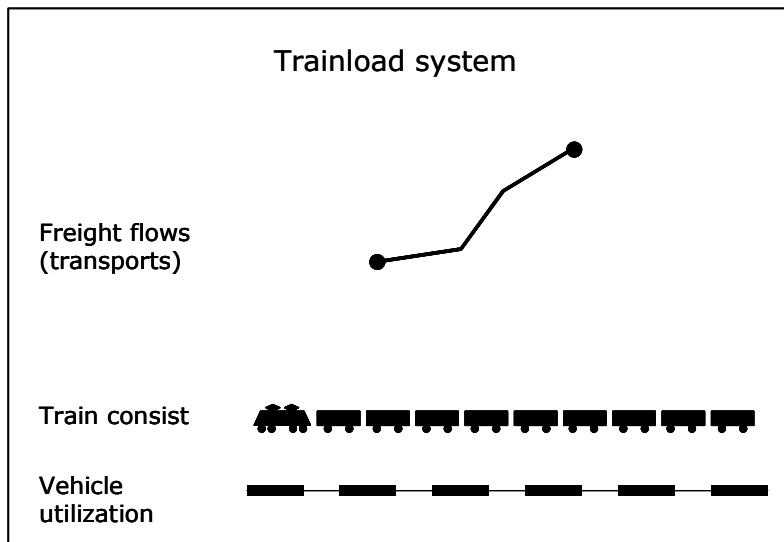


Figure 5.1: In a Trainload system both train consist and vehicle utilization can be calculated since all wagons are exclusively assigned to one particular flow and the train conveys exclusively wagons assigned to that flow (G.Troche)

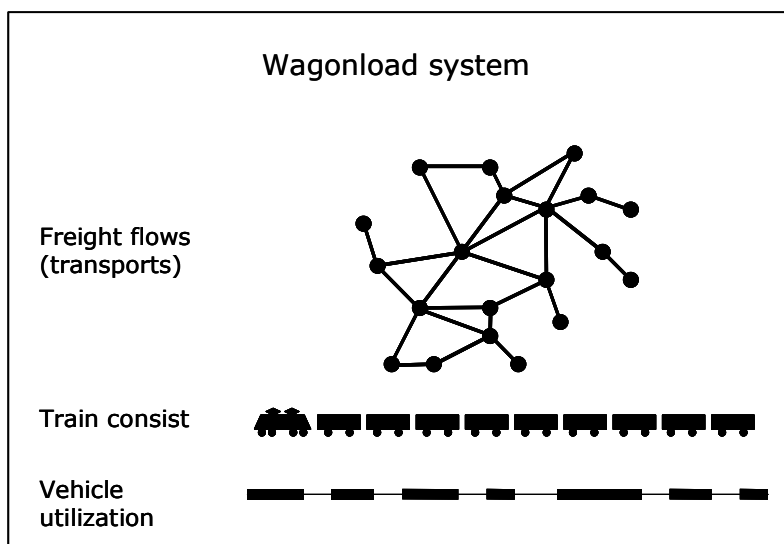


Figure 5.2: If all freight flows within a wagonload system are known, both train consists and vehicle utilization can be calculated (G.Troche)

Often not all freight flows within a wagonload system are known, at least not with the same level of detail. In this case it is consequently not possible to calculate the train consist within the model. This situation is handled in EvaRail by letting the user specify the value of variables which otherwise would be calculated within the model, such as the train's gross weight and length, and which are required for example for allocation of train-related costs to certain wagons (= specific flows) in a train consist. In this case endogenous variables are becoming exogenous. If only one flow within a wagonload system is concerned, only part of the whole system is depicted in the model in detail.

Concerning the calculation of the utilization of freight wagons two cases can be distinguished. First, a regular (recurrent) wagonload flow, where specific freight wagon individuals are assigned to the flow in question for the whole calculation period. In this respect there is a similarity to a trainload system, where all wagons are also assigned to a one specific flow – the difference is that in the case of the trainload transport the wagons are moved in a dedicated train while in the wagonload transport the wagons have to share the train with (an unknown number and kind of) other wagons assigned to (unknown) other transports. The case of a regular wagonload flow is illustrated in figure 5.3. Here the wagon utilization can be calculated within the model.

If a flow consists only of a one-off transport (spot transport), the wagon utilization cannot be calculated within the model, see figure 5.4. In this case, the user consequently not only has to specify certain train data as exogenous variables but also the (annual) utilization of the freight wagon(s) used for that transport.

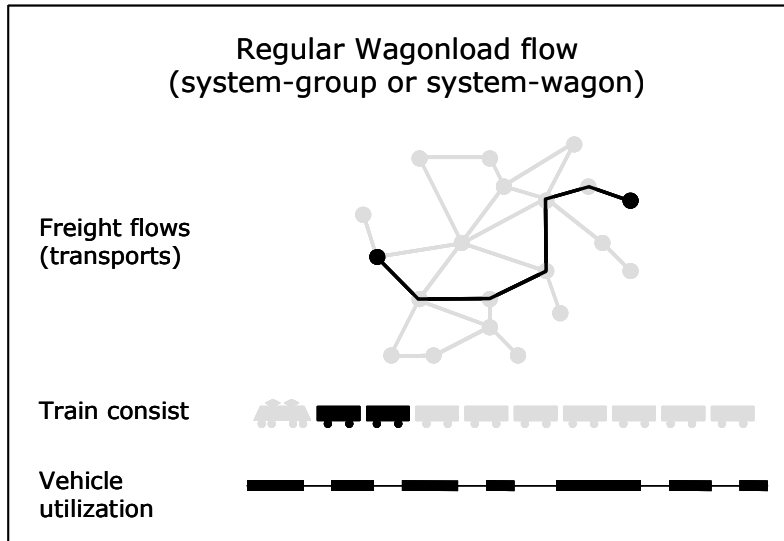


Figure 5.3: If freight wagons are assigned to a regular transport their utilization can be calculated within the model based on information for that flow. Train data, however, cannot be calculated based on information for only one flow. (G.Troche)

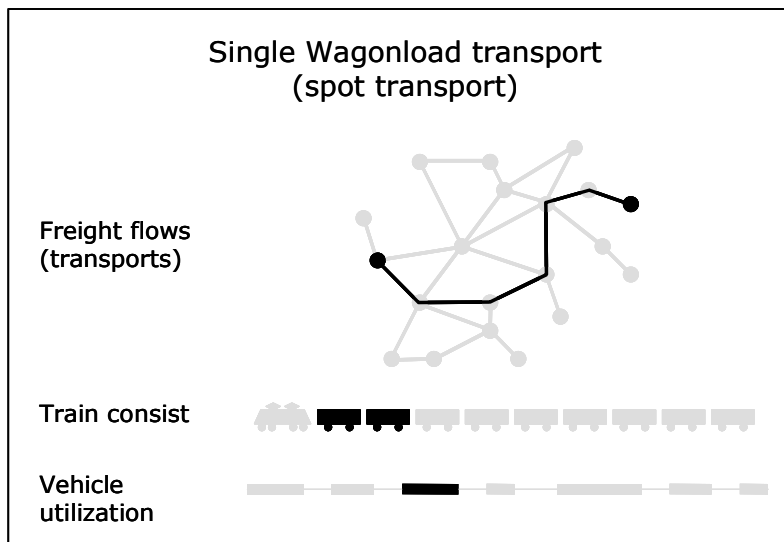


Figure 5.4: In the case of a single wagonload transport, neither train consist nor vehicle utilization can be calculated within the model and both have to be entered as exogenous variables. (G.Troche)

5.1.3 Intermodal Traffic

In Intermodal Traffic the situation is even more complicated due to the fact that the equipment containing the goods is not identical with the vehicle(s) carrying the goods. Thus, the turnarounds of the loading units (which contains the goods) are independent of those of the vehicles. The turnarounds of the wagons are consequently not directly linked to the freight flows but to the flows of loading units. The utilization of loading units and wagons can consequently differ.

A new system level, load units, has to be introduced between the freight flow level and the wagon level, increasing the complexity of the model. The model also has to be able to handle not only two load statuses of a wagon – loaded and empty – but three: (1) *loaded* with a *loaded* load unit, (2) *loaded* with an *empty* load unit and (3) *empty*.

The problems encountered in wagonload traffic with the calculation of the utilization of wagons are valid in Intermodal Traffic for both the wagons *and* the load units. The additional system level of load units also adds to the problem of joint and common costs.

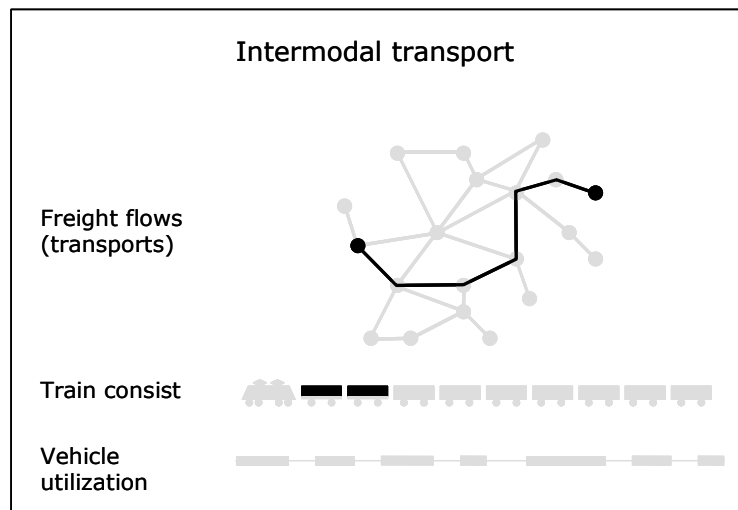


Figure 5.5: *In the case of an intermodal transport, neither the train consist nor vehicle utilization can be calculated within the model on the basis of information for only one flow, even if it should be a regular (recurrent) flow.(G.Troche)*

5.2 Handling the joint and common cost problem

The rail freight system is characterized by a large portion of common and joint costs.

The train transport costs, excluding loading/unloading and train formation costs, can be allocated to three levels:

- the train level
- the vehicle level (wagons or locomotives)
- the loading unit level

5.2.1 Trainload traffic

In trainload traffic it is relatively easy to allocate costs, since costs do not need to be allocated to different vehicles or loading units in order to calculate the final transport costs for a certain flow. Consequently, the existence of joint and common costs does not present a problem in the particular case of trainload.

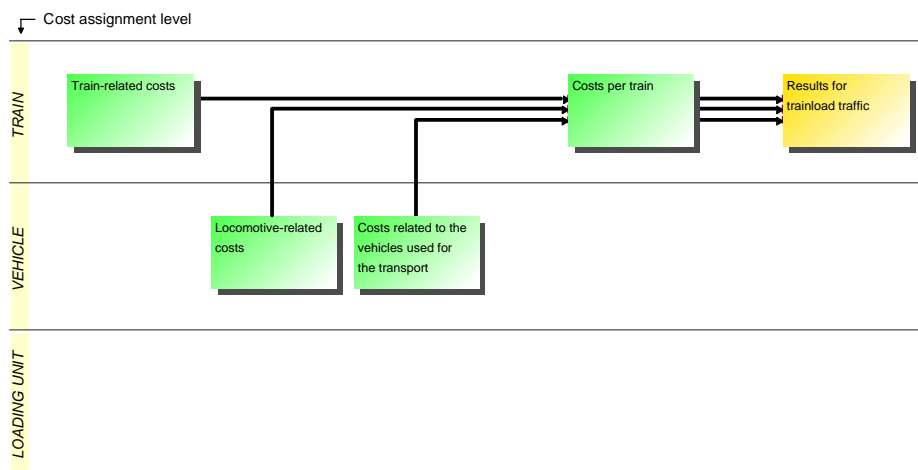


Figure 5.6: In trainload traffic, joint and common costs do not present a problem for the calculation of final transport costs since these only need to be calculated on the “highest” level, i.e. the train level. (G.Troche)

5.2.2 Wagonload traffic

In Wagonload traffic the situation is different: Here, trains convey wagons for different customers and wagon types often vary widely. In order to calculate transport costs for a specific flow, costs must be allocated to wagon individuals on the train level. This is also true for locomotive-related costs. Although these can be related to a specific vehicle – the locomotive – the costs have to be treated in the same way as costs incurred on the train level since the locomotive is fulfilling a joint function for all other vehicles (wagons) in the train.

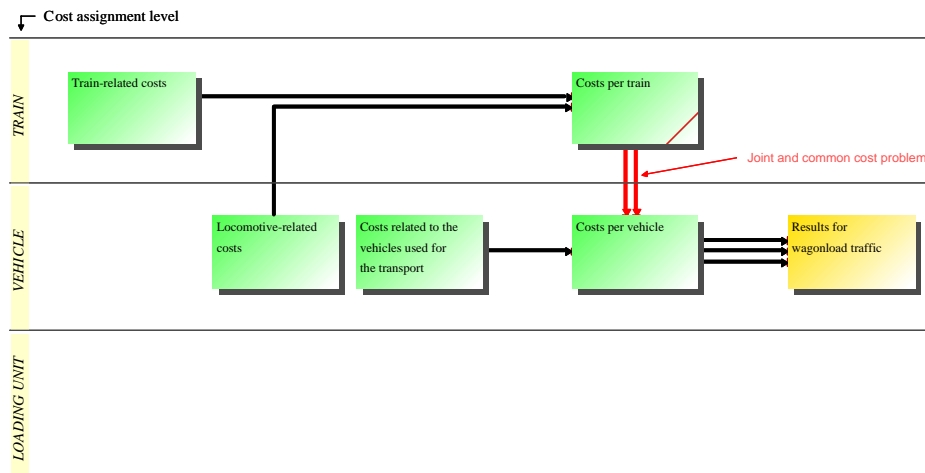


Figure 5.7: In wagonload traffic, a joint and common cost problem arises for the allocation of costs on the train level to the vehicle level. This also includes costs on the vehicle level related to the locomotive(s), since this/these is/are fulfilling a joint function for all other vehicles in the train. (G.Troche)

5.2.3 Intermodal Traffic

In Intermodal Traffic, a further cost level is added and consequently another cost allocation step. In addition to costs on the train level, which have to be allocated to the vehicle level, all costs on the vehicle level also need to be allocated to loading units. This is necessary, since a wagon may carry load units assigned to different flows (and the load units need not necessarily be of the same type, but can vary in weight, dimensions and load status). Costs for these wagons therefore have to be shared.

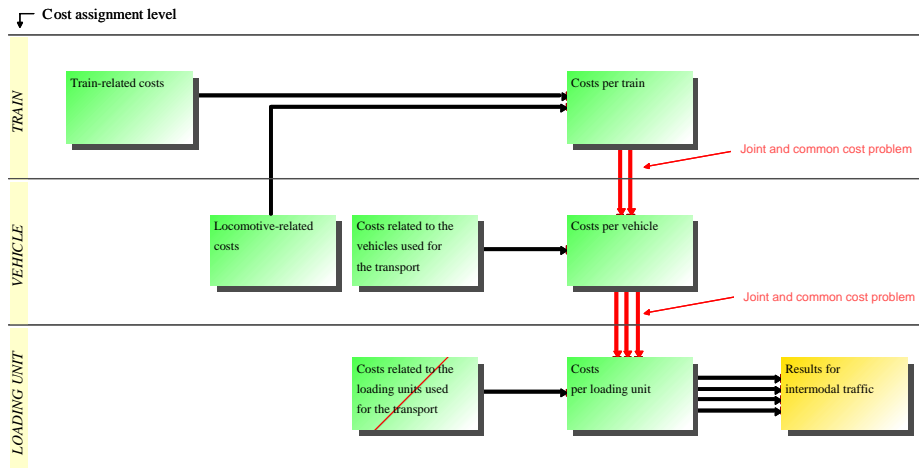


Figure 5.8: *In Intermodal Traffic, a joint and common cost problem arises both between the train and vehicle level and between the vehicle and load unit level. This is because a wagon may carry load units assigned to different flows and all wagon costs consequently need to be shared among the load units on the wagon.*

5.3 The Empty Wagon Problem

Though it is the ambition of every railway company to minimize the extent of empty wagon runs, these can never be eliminated completely. From a modelling point of view empty runs have to be dealt with, because they incur costs, but not any direct revenue. The costs for empty runs therefore have to be allocated to the load runs.

Three types of empty movements can be distinguished:

- empty movements for repositioning of wagons between load runs
- empty movements in connection with transport-related wagon service
- empty movements to and from workshops in connection with maintenance

The last-mentioned can be ignored when designing wagon turnarounds for cost calculating purposes, since the costs for hauling wagons to and from workshops can be considered as maintenance-related and should therefore be included as a specific cost item in the maintenance cost calculation.²⁸

Empty movements in connection with transport-related wagon service occur only in very specific cases and mainly concern tank wagons for chemicals. Depending on the chemicals transported, tank wagons in some cases have to be cleaned at certain intervals or between load runs. This cannot always be carried out at the point or origin or destination of a load run and in such cases the wagons have to be moved to places where the special equipment is available. The wagon service is thus directly related to the transport of a certain type of cargo, i.e. a specific flow. From a modelling point of view, these empty movements to and from the service points should be treated in the same way as maintenance-related movements. Consequently a specific cost item, transport-related wagon service costs, has been included in the model, under which the costs for empty movements to and from the service points can also be covered.

²⁸ However, it is necessary to allow for a sufficient number of free days for maintenance – including the empty hauls from and to the workshop – when allocating wagons to transport tasks.

By far the largest part of all empty movements are related to the repositioning of wagons between load runs. Two sub-cases can be distinguished for this type of empty movement:

- Wagons allocated to *one* flow during a turnaround
- Wagons allocated to *two or more* flows during a turnaround

In the first case, the wagons return after the load run from the point of destination to the point of origin. The empty haulage share of the total turnaround is consequently in most cases exactly 50%, since the wagons have to go back the same distance as they run loaded (case A in figure below). All the costs for the empty run can be allocated to one specific flow. Almost all unit trains fall in this group, but many wagonload transports also belong to this group, especially “system wagons”.

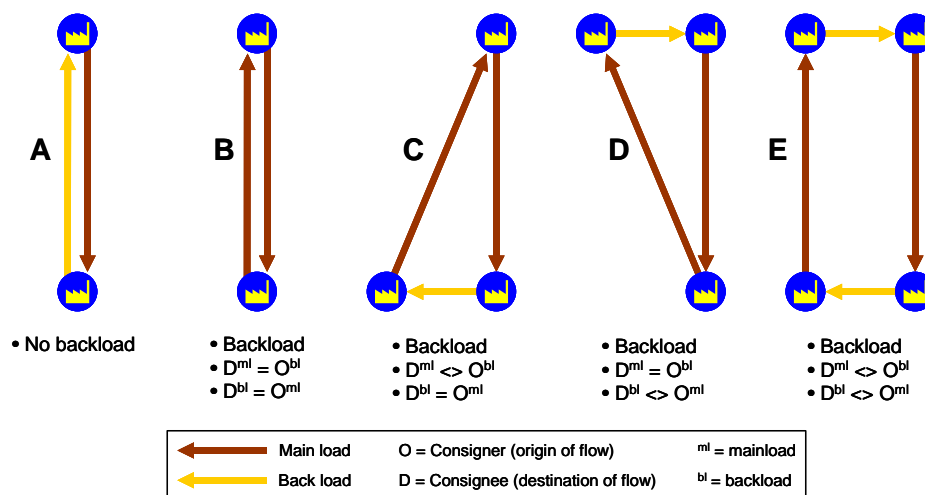


Figure 5.9: Wagon turnarounds – different cases

In order to reduce empty haulage, train operators try to find *backloads* for the empty wagons. This means the wagons are allocated to two – or even more – different flows during a turnaround. In the best case, the second flow is in the same relation as the first flow; this means the wagons are loaded again at the point of destination of the first flow and return loaded to the first point of origin. In this, ideal, case empty movements are eliminated completely – and consequently also the need to allocate empty hauling costs to different flows. However, in reality this ideal situation can be found only in extremely rare cases. In most cases a repositioning of

wagons is necessary at one (case C and D in figure 5.9) or both ends (case E) of a flow to capture a backload.

From an economic point of view assigning wagons to several flows during a turnaround is a way to both reduce costs for empty haulage and to share these costs between different flows, thus reducing the transport costs for both flows. However, here it has to be taken into account that the repositioning of wagons between two different flows normally prolongs the total turnaround and consequently also the total costs of a turnaround. These not only depend on the distance over which the wagons have to be repositioned, but also on the time. This time consists of the time to move the wagon to the new point for loading, the waiting time until loading can start, the loading time itself and waiting time until departure. Depending on the costs the savings from reducing empty haulage can partly – or in the worst case completely – be eaten up. Only if, theoretically, the waiting and repositioning cost were 0 (zero), the transport costs (for both flows) could be halved (see figure 5.10).

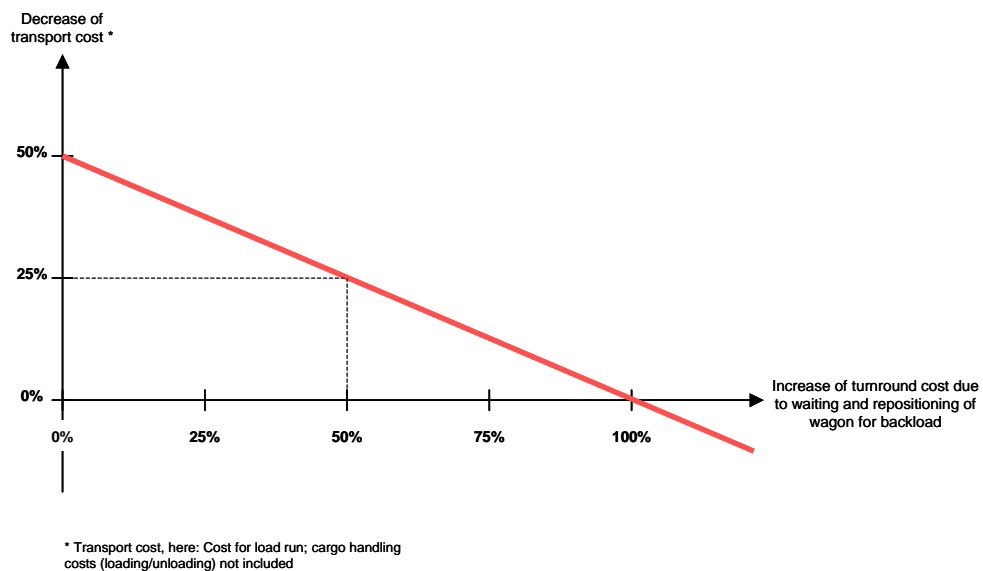


Figure 5.10: Effect on transport cost savings of increases in turnaround cost due to waiting and repositioning of wagon(s) for backloads. The cost changes on both axes are related to the total turnaround cost for a wagon or wagon-group. (Gerhard Troche)

As can be seen from the aforementioned in the modelling approach chosen here the cost for empty haulage, which is allocated to a certain flow, is not dependent on the number of empty wagons in the train(s) in which the wagons, which are assigned to a certain flow are conveyed, but of the empty haulage share in the turnround of the wagons, which are used in this flow (in EvaRail the average of all wagons of the same class).

The same principle is also applied when it comes to Intermodal Transport: If an intermodal wagon can carry more than one loading unit, a loading unit is only charged with the costs for a part of the wagon, irrespective of whether the rest of the wagon capacity is used or not. In the model it is also taken into account that the transport capacity of a CT-wagon is not fixed, but can vary depending on the type and weight of the loading units.

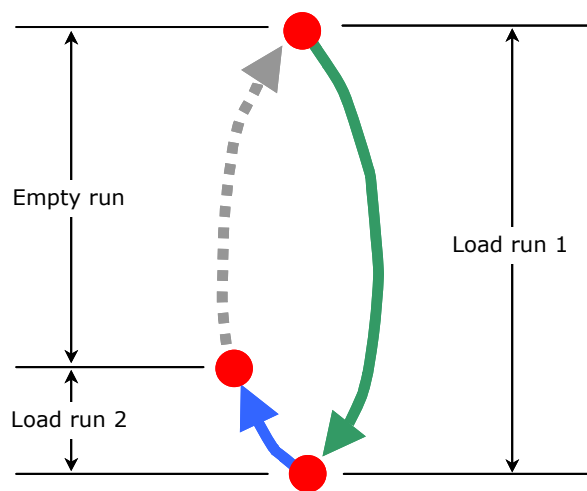


Figure 5.11: Wagon turnaround comprising two load runs and one empty run. The cost of the empty run is allocated to the load runs according to each load runs share of the total distance and time of load runs (Gerhard Troche)

6 General structure of the model

6.1 Overview

The rail freight system is in the model depicted by three main "levels", which are interconnected with each other:

- the infrastructure
- the train services (on the infrastructure)
- the freight flows (carried in/on the trains)

The infrastructure in the form of the rail network constitutes the lowest level. The rail network is depicted as nodes and links, where the nodes represent stations (or terminals, industrial spur, etc.) and the links the stretches of track between them. The next level is the train service level, containing detailed information on the train services offered on the network. The infrastructure and train service levels together represent the supply side in rail freight. On the third level the freight flows are specified, i.e. this level represents the demand side.

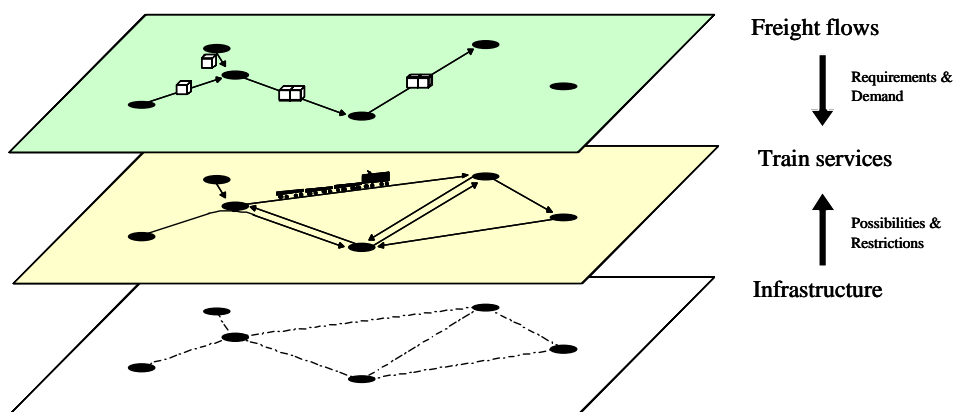


Figure 6.1: A way to structure the rail freight system, as used in this work. (G.Troche)

Since it is the purpose of the model to identify possible ways to improve the profitability and/or cost competitiveness of the rail freight system the user will – after having specified the demand – mainly deal with the train service level and to some degree with the infrastructure level, since these represent the cost side in rail freight. On the train service level he/she can create different scenarios reflecting short-term changes, while scenarios on the infrastructure level would reflect long-term changes in the rail freight system.

The Infrastructure level sets the “frame” for the user when specifying different train service scenarios, while the Freight flow level reflects market opportunities and customer requirements regarding the train services.

In the following the different levels are dealt with in more detail. In chapter 6.2 the infrastructure level is described, chapters 6.3 and 6.4 deal with the train service level and the freight flow level. Chapter 6.5 treats the utilization model used in EvaRail.

The following figures illustrate some of the terms used in this project and also improves understanding of the model’s structure.

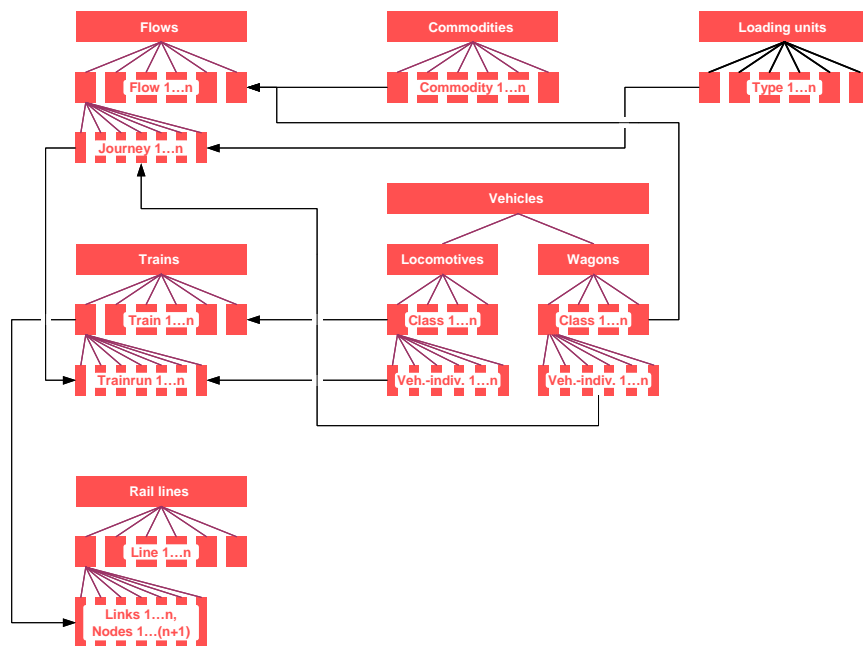


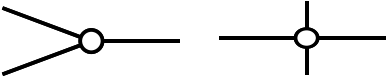


Figure 6.2: Objects in EvaRail and how they are related. (G.Troche)

6.2 The infrastructure level

The rail freight infrastructure is described and modelled as a network of *nodes* and *links*. The nodes in the model represent physical places in a railway network, while the links represent railway lines or tracks connecting them. Each link always connects two nodes and each node connects with at least one link.

There exist different kinds of nodes:

- End nodes 
- Intermediate nodes 
- Junction nodes 

A node always has to be inserted when (1) a place, where an activity should take place, (2) at junctions and (3) where one or more parameters of the adjacent links change.

For nodes connecting to more than two links it is also necessary to specify how these are connected to each other, i.e. in which relations trains can pass the node without changing direction and in which a change of direction is necessary.

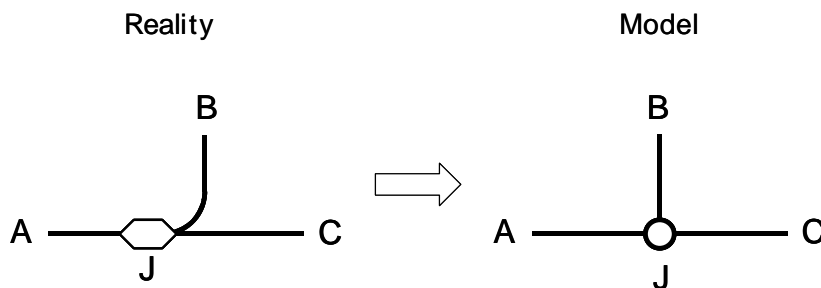


Figure 6.3: For nodes connecting with more than two links it is necessary to specify in which relations trains have to change direction. In the example above this is the case in relation C-J-B and vice versa; in all other relations trains can pass J without changing direction. (Gerhard Troche)

One or several of the following activities *can* be assigned to the nodes depending on their function in the network:

- loading/unloading of freight
- loading/unloading of intermodal loading units
- attaching/detaching of wagons
- shunting
- marshalling
- locomotive change
- locomotive runaround

The table below gives an overview of which activities normally have to be assigned to a node in order to represent a certain facility in the real infrastructure.

The first three facilities are places where goods can enter and leave the rail freight system, i.e. in the model the corresponding nodes can be origin or destination points of freight flows.

The table should only be seen as a list of examples; it is possible to assign all activities to a certain node.

Facility in real rail freight system	Activities typically assigned to corresponding model nodes
Freeload terminal	Loading/unloading of goods Flat shunting
Intermodal terminal	Loading/unloading of intermodal load units Flat Shunting
Intermodal liner train terminal	Loading/unloading of intermodal load units
Industrial siding	Loading/unloading of goods
Terminal yard	Flat shunting
Marshalling yard	Marshalling
Junction	Locomotive runaround, Locomotive change
Border station	Locomotive change

Table 6.1: Facilities in the rail freight system and activities typically assigned to corresponding nodes in the model network (Gerhard Troche)

Depending on the activities assigned to a node, further parameters have to be specified for these:

For nodes allowing goods to enter and leave the rail freight system, i.e. with the activities “Loading/unloading of goods” or “Loading/unloading of intermodal load units” assigned to them, the user must specify the following parameters:

- permitted weekdays and time window for arrival
- permitted weekdays and and time window for departure
- permitted weekdays and time window for loading/unloading
- type of load units, which can be handled
- commodities, which can be handled
- cost for loading/unloading per unit (t, m³, item, or intermodal load unit)

The first three parameters are used to reflect the fact that not all of the facilities allow operations at any time. Different costs can be specified for different types of load units or different commodities.

For nodes with the activity “Shunting” or “Marshalling” assigned to them, the following parameters have to be specified:

- permitted weekdays and time window for operation
- minimum dwell time
- cost per wagon handled

The first parameter reflects the fact that not all marshalling or terminal yards are open for operation 24 hours a day seven days a week. Smaller yards in particular often close during weekends or for part of the day.

The minimum dwell time is the shortest time required between an arriving train and a departing train in order to make a connection.

The cost per wagon is the cost to the train operating company for handling the wagon in the yard, excluding possible infrastructure user charges (which are calculated separately).

For nodes with the activities ‘Locomotive change’ or ‘Locomotive runaround’ assigned to them, only the cost per event need be specified. The cost is per event, not per locomotive, i.e. the cost is the same irrespective of whether one locomotive or two locomotives (for example when the train is double-headed) make the runaround or are changed.

The costs reflect in first hand expenses for yard personal, since the capital costs for the locomotive(s) and personnel costs for the driver during the runaround are calculated separately.

Parameters assigned to links are:

- length
- electrified/non-electrified
- maximum (average) line speed
- maximum allowed train length
- allowed direction of traffic (bi-directional or unidirectional)

6.3 The train service level

The train services are in EvaRail described for the period of one year (as are the freight flows). Starting point for the description of a train service is the timetable for a train path and the traffic periods and traffic days of the train (or more exactly: of that train path). One can imagine a train path as a train consisting only of a locomotive (or several locomotives), but without any wagons. Wagons are assigned to the train path (= attached to the locomotive(s)) by EvaRail, if it identifies the train path as suitable to use to carry out a transport.

The traffic periods are weeks (1-52) and the traffic days weekdays (1-7). Up to to five different traffic periods with different traffic days can be defined.

The timetable contains the exact departure and arrival times at starting station, final station and all intermediate station. For technical reasons a train path cannot stretch over a period longer than 24 hours. However, in order to depict trainruns longer than 24 hours, it is possible to create a connection between two subsequent train paths.

For each stop of the train it is also specified, whether it is allowed to attach wagons, detach wagons, load on load units and/or load off load units. In this way it is possible to avoid that EvaRail attaches or detaches wagons during purely operational stops, e.g. for change of locomotives.

It is also possible to indicate whether certain wagon types are excluded to be conveyed in a train. By doing so it possible to avoid that conventional wagons get attached to an intermodal train and vice versa. Furthermore it is possible to block certain flows to use a train path, or to give priority to certain certain flows. This is useful, if a train path is exclusively or primarily intended to be used by a certain flow in a specific trainload service. In the first case no other wagons (flows) would be allowed to become attached to the train, in the latter case other wagons (flows) would be allowed to become attached, but priority is given to the flow it is intended for.

Other important information which is given for each train path comprise the maximum train length, maximum train gross weight and number and class of locomotives. All these parameters can also independently vary between different sections of the train path.

6.4 The freight-flow level

A flow is a certain amount of cargo sent between an origin and a destination within the period of one year. The quantity of cargo can be given in:

- tons
- cubic-metres
- number of pieces / number of load units

Each flow consists of at least one transport – often more – on which a certain share of the total annual volume is transported. In EvaRail desired departure days and departure times can be specified for up to five periods per year. This makes it possible to depict seasonal variations in demand.

Origin and destination of a flow can only be stations, i.e. a node in the railway network defined on the infrastructure level. However, it is possible to specify road feeder transports from and to the stations, but these are only defined by distance and certain information about the type and capacity of trucks used on the feeder transport leg of the transport chain; road feeder transports are not assigned to any (road) network model.

For the origin and destination of a flow even the minimum time, for which wagons are required to be at place for loading and unloading, as well as the weekdays and time windows for loading and unloading at origin and destination. In this way it is ensured that a wagon is assigned to a transport from the beginning of loading at the place of origin until it is unloaded at destination, and that realistic time windows for loading and unloading are taken into account. This are factors which tend to have big impact on wagon utilization and, as a consequence, transport costs.

6.5 Utilization model

In order to calculate unit costs it is necessary to know the utilization of resources. The *total* utilization of resources in EvaRail always refers to a period of one year.

EvaRail offers two possibilities to quantify the total utilization of a resource:

- One is to calculate the total utilization exclusively on the basis of flow data. This requires that all flows to which a resource is allocated over a year are known and specified in EvaRail. This solution is practicable if a resource is allocated to a limited number of flows.
- The other possibility is to set a default value for the total utilization. This solution can be used if not all flows to which a resource is allocated over a year are known and specified. At least one flow – the flow for which transport costs have to be calculated – must always be specified.

The following situations can thus occur in EvaRail:

Specified flows		Non-specified flows	Condition	Total utilization
Flow to be cost-calculated	Other specified flows			
Yes	No	No	-	Utilization in specified flow
Yes	Yes	No	-	Sum of utilization in specified flows
Yes	No	Yes	Default-value \geq Utilization in specified flow	Default utilization value
			Default-value $<$ Utilization in specified flow	Utilization in specified flow
Yes	Yes	Yes	Default-value \geq Sum of utiliz. in specified flows	Default utilization value
			Default-value $<$ Sum of utiliz. in specified flows	Sum of utilization in specified flows

Table 6.2: *Quantification of total utilization of resources in EvaRail – possible situations (G.Troche)*

The resource utilization is calculated both on the level of individuals (e.g. wagon individuals) and on class level (e.g. all wagons of a certain class). The following utilization factors are calculated within EvaRail for wagons and – as far as applicable – locomotives:

Information	Loaded	Empty
Distance	X	X
Number of load runs	X	-
Number of shunting events	X	X
Number of marshalling events	X	X
Number of transloading events	X	X
Time assigned to transports	X	X
Time at origin		X
Time at destination		X
Time in transit	X	X
Time in train moving	X	X
Time in train waiting	X	X
Time at intermediate station	X	X

Table 6.3: Utilization factors calculated in EvaRail (G.Troche)

The utilization model consists of the following steps:

- I) Assignment of wagon individuals to transports
- II) Assignment of transports to train pathes (transport route choice)
- III) Derivation of empty wagon movements
- IV) Assignment of locomotives to trains
- V) Derivation of empty locomotive movements
- VI) Calculation of utilization factors

For intermodal transports no load unit individuals can be assigned yet. For locomotive drivers utilization factors are calculated independently on the basis of the working time per year, average sickness and holiday absence and fixed preparation times per shift. The latter factor can be replaced by an average effective working time factor.

7 Databases in EvaRail

7.1 Overview

EvaRail contains a total of 13 databases, plus one output database. Figure 7.1 illustrates the databases and how they are interconnected with each other. The three databases ‘Infrastructure’, ‘Trains’, and ‘Freight Flows’ represent the three “levels” of the model, as they are shown in figure 6.1 in the previous chapter.

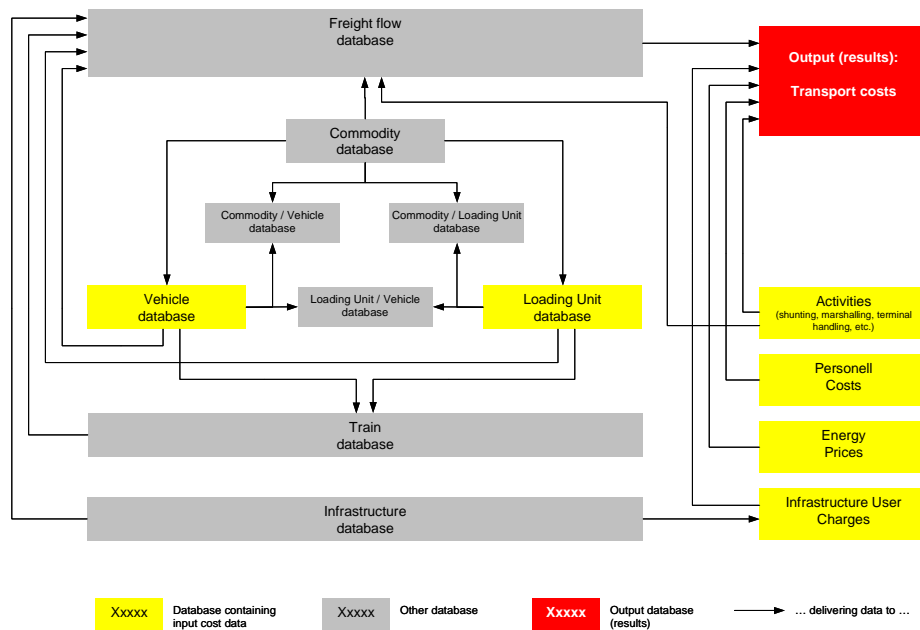


Figure 7.1: Overview of the databases in EvaRail (Fig.: G.Troche)

As can be seen in the figure, the Infrastructure and Train databases are only interconnected with each other in one direction (the Infrastructure database delivers data to the Train database, but not vice versa). This is because EvaRail is not a rail *traffic* model, but exclusively a rail *cost* model. It does not check whether the timetable specified for a certain train

implicates any train path conflicts and consequently neither whether line or node capacity is exceeded or not.

The primary role of the Infrastructure database is to deliver distance data for cost calculation purposes and line speed data for a rough – and for this purpose accurate enough – calculation of running times. This also means that it is not necessary to include *all* trains operating over a certain link, but only those which carry the flow(s) which is(are) subject of the cost calculation. An integration of EvaRail with a capacity analysis and traffic simulation model is one of a number of future options.

While the Train database contains information on the train pathes, information on individual vehicles themselves and the cargo of is found in the Vehicle, Load Unit and Commodity databases. These contain both comprehensive technical and – in the case of the Vehicle and Loading Unit databases – cost information. Seen from the point of view of amount of cost information, the Vehicle and Load Unit-databases form the core of the EvaRail model.

The Vehicle, Loading Unit and Commodity databases are in their turn interconnected by the Commodity/Vehicle, Commodity/Load Unit and Load Unit/Vehicle databases respectively, which contain information about which commodities can be carried on/in which wagons or loading units and which loading units on which wagons, and in which quantity. This information could certainly have been included in the first-mentioned three databases but for technical reasons has been gathered into separate databases. Especially the Load Unit/Vehicle database is quite comprehensive, since it has to depict several different loading patterns of a wagon.

In addition to the aforementioned databases, EvaRail contains a number of auxiliary databases with cost data for infrastructure usage, energy, personnel and activities (see on the right-hand side of figure 7.1). The latter refer to activities such as shunting, marshalling, loading/unloading, terminal handling, etc. The database contains standard values for these activities. However, it should be noted that EvaRail allows more detailed calculations in many cases, *if* the required information is available. A user may for example use a standard value for shunting at a local yard. Alternatively, given that he or she has detailed information about the type of locomotive used for shunting, the number of personnel required, the total number of wagons handled at that yard, the time consumption, etc., EvaRail allows to make more detailed calculations of the shunting costs

and consequently include more variables in the analyses of total transport costs (see even chapter 8.9.1).

The model allows the user to make cost calculations on both system and flow level, depending on the accuracy required in each specific case and the level of detail in the available information. In this way EvaRail offers a flexibility resembling that offered by the Canadian CRCS model, which was described in chapter 2.3.6. In the example above, it would also be possible to make a detailed calculation of shunting costs at one end of the transport chain, while using a standard value at the other end. This may be useful for international flows, where detailed information sometimes is not available for one end of the flow.

EvaRail comprises an output database where all results on disaggregated level, as well as all user-defined input data, are stored. In this way it is always possible to reproduce a calculation. The output database can comprise results for one flow, or for several flows together. It is not necessary to carry out all flow calculations for a multiple flow system at once, but flows can be added at any time, provided that the results of earlier calculations have been saved. Since the addition of a flow to an existing transport system may affect the transport costs of the earlier flows, these are automatically recalculated in EvaRail.

In the following, the content and structure of all databases except the output database are described in more detail. Of the more complex databases excerpts are shown as figures. For the handling and presentation of output data in EvaRail, please see chapter 9.

7.2 Freight flow database

The freight flow database represents the demand side in EvaRail. This database contains information on all flows on an origin/destination basis. The information given is the commodity, the quantity per desired departure, the desired departure days and times – up to five periods with different departure patterns can be specified – and the required wagon class(es).

Connected to the freight flow database is a Journey database, in which the transport route, used wagon-individuals, used train runs and activities during the journey (such as shunting, marshalling, etc.) are stored.

	A	B	C	D	E	F	G	H	I	J	K
1	#tb_FLOW	Commodity:	Relation:	QuaPerDe	Wagons:	JourneyDays:	DesDepTimeFro	WagonsAt	OperHrsOrig:	WagonsAt	OperHrsDest:
2	F0	Timber	MRA-R	123 m3	#1*Timber-wagon	#1-3,0,2,4#	0,25	4	#0-4,0-24#		4 #0-4,0-24#
3	F1	Timber	R-MRA	123 m3	#1*Timber-wagon	#1-3,1,3,5#	0,208333333	4	#0-4,0-24#		4 #0-4,0-24#
4	F2	Fruits	R-SAV	75 t	#3*Volymvagn#	#1-5,1,3,5#0-52:	0,625	6	#0-5,9-18#		6 #0-4,9-18#
5	F3	Palletized goods	MRA-F	120 pcs	#2*Volymvagn#	#1-4,0,1,2,3,4#0:	0,583333333	6	#0-4,6-18#		6 #0-4,6-18#5,10-15#
6	F4	Paper	SAV-R	100 pcs	#5*Multiurpose#	#1-5,1,4#0-8,3#	0,708333333	6	#0-4,6-18#		6 #0-4,6-18#5,9-15#
7	F5	Palletized goods	R-JO	120 pcs	#3*Multiurpose#	#1-10,1,3#	0,666666667	8	#0-4,6-18#		8 #0-4,9-18#
8	F6	13 6m-sermitaile	F-G	3 pcs	#3*Sdgmns	832# #1-3,0,2,4#	0,625	4	#0-4,6-18#		4 #0-4,6-18#
9	F7	Palletized goods	R-BLG	77 pcs	#2*Multiurpose#	#1-5,1,3,5#0-52:	0,625	6	#0-5,6-18#		4 #0-4,6-18#
10	F8	Palletized goods	MRA-N	111 pcs	#3*Multiurpose#	#1-5,1,4#0-52,1:	0,666666667	6	#0-4,6-18#		6 #0-4,6-18#5,9-15#
11	F9	Palletized goods	N-G	123 pcs	#3*Multiurpose#	#1-3,0,4#0-52,0:	0,635416667	6	#0-4,6-18#		1 #0-4,6-18#

Figure 7.2: Extract from part of the Freight flow database. In columns C to E the origin, destination, quantity and desired wagon type are given, in columns F and G the shipping days and desired departure time, and in columns H to K the minimum required time and time windows for loading and unloading at origin and destination. (G.Troche)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	#tb_JOUR	JourneyNr	Transport routes	Wagons	ReqToBeA	DesDepDa	DepDateFr	ArDateTot	ReqToBeA	Sel_VEHid:				
2	F0	J1	#-MRA-0(1)-R<#	#1*Lps#	0,208333	0,25	0,375	0,564051	0,730718	#Lps,1#				
3	F3	J1	#-MRA-1005(1)-HRBG-	#2*Volymvagn#	0,5	0,583333	0,8125	1,54816	2,29816	#Volymvagn,1+Volymvagn,2#				
4	F9	J1	#-N-1012(1)-HRBG-100	#3*Rs#	0,5	0,635417	0,760058	2,268576	2,310243	#Rs,1+Rs,2+Rs,3#				
5	F7	J24	#-R-1000(1)-MRA-1005	#2*Rs#	0,666667	362,625	1,416667	1,893611	2,416667	#Rs,4+Rs,5#				
6	F1	J1	#-R-1000(1)-MRA-<#	#1*Lps#	1,25	1,208333	1,416667	1,605718	1,772384	#Lps,1#				
7	F5	J1	#-R-1001(1)-AS-1002(1)	#3*Rs#	1,416667	1,666667	1,8125	2,437083	3,395417	#Rs,6+Rs,7+Rs,8#				
8	F2	J1	#-R-1001(1)-AS-1002(1)	#3*Volymvagn#	1,5	1,625	1,8125	2,235058	2,625	#Volymvagn,3+Volymvagn,4+Volymvagn,5#				
9	F3	J2	#-MRA-1005(2)-HRBG-	#2*Volymvagn#	1,5	1,583333	1,8125	2,54816	3,29816	#Volymvagn,5+Volymvagn,7#				
10	F6	J1	#-F-1002(1)-G<#	#3*Sdgmns	832#	1,583333	0,625	2,169583	2,268576	2,435243	#Sdgmns	832,1+Sdgmns	832,2+Sdgmns	832,3#
11	F8	J1	#-MRA-0(2)-R<#	#3*Rs#	1,625	1,666667	2,375	4,494167	4,744167	#Rs,9+Rs,10+Rs,11#				
12	F0	J2	#-MRA-0(2)-R<#	#1*Lps#	2,208333	2,25	2,375	2,564051	2,730718	#Lps,1#				
13	F4	J1	#-SAV-1003(3)-F-1007	#6*Rs#	2,333333	1,708333	2,583333	3,425556	3,675556	#Rs,12+Rs,13+Rs,14+Rs,15+Rs,16+Rs,17#				
14	F3	J3	#-MRA-1005(3)-HRBG-	#2*Volymvagn#	2,5	2,583333	2,8125	3,54816	4,29816	#Volymvagn,8+Volymvagn,9#				
15	F6	J2	#-F-1002(2)-G<#	#3*Sdgmns	832#	2,583333	2,625	3,169583	3,268576	3,435243	#Sdgmns	832,4+Sdgmns	832,5+Sdgmns	832,6#
16	F7	J1	#-R-1000(2)-MRA-1005	#2*Rs#	2,666667	1,625	3,416667	3,893611	4,416667	#Rs,18+Rs,19#				
17	F1	J2	#-R-1000(2)-MRA-<#	#1*Lps#	3,25	3,208333	3,416667	3,605718	3,772384	#Lps,1#				
18	F5	J2	#-R-1001(3)-AS-1002(3)	#3*Rs#	3,416667	3,666667	3,8125	4,437083	7,395417	#Rs,20+Rs,21+Rs,22#				
19	F2	J2	#-R-1001(3)-AS-1002(3)	#3*Volymvagn#	3,5	3,625	3,8125	4,235058	4,625	#Volymvagn,1+Volymvagn,2+Volymvagn,3#				
20	F3	J4	#-MRA-1005(4)-HRBG-	#2*Volymvagn#	3,5	3,583333	3,8125	4,54816	5,464826	#Volymvagn,10+Volymvagn,11#				
21	F0	J3	#-MRA-0(3)-R<#	#1*Lps#	4,208333	4,25	4,375	4,564051	4,730718	#Lps,1#				
22	F3	J5	#-MRA-1005(5)-HRBG-	#2*Volymvagn#	4,5	4,503333	4,8125	5,54816	7,42316	#Volymvagn,6+Volymvagn,7#				
23	F9	J2	#-MRA-1005(6)-HRBG-	#3*Rs#	4,5	4,666667	4,8125	7,494167	7,744167	#Rs,4+Rs,5+Rs,6#				

Figure 7.3: Extract from part of the Journey database. In columns A and B the flow and journey number are given, in column C the transport route, in column D the number and class of wagons, in column E to I different times of the transport chain and in column J the wagon individuals assigned to each transport. (G.Troche)

7.3 Infrastructure database

The Infrastructure database describes the rail network, consisting of nodes and links. In the database the links and nodes are – as in the real world – arranged by routes to improve readability and maintainability.

When adding a new route to the database, it is irrelevant in which direction the new route is added, since each route will in any case be read by the program in both directions.

689	ROUTE	64103101	ET	OXD	
690	64103101	ET	Eskilstuna C	--	-->LA ; -->SÖÖ
691	64103101	SKRP	Skogstorp	5,0	
692	64103101	HÄL	Hällsta	4,5	
693	64103101	BVG	Bälgviken	4,7	
694	64103101	HNÄ	Hälleforsnäs	5,8	
695	64103101	MLÖ	Mellösa	8,2	
696	64103101	FSÖ	Flens övre	5,8	-->FLE
697	64103101	SII	Silinge	7,3	
698	64103101	VRE	Vrena	20,0	
699	64103101	NKS	Nyköping S	23,2	-->NK
700	64103101	OXD	Oxelösund	12,1	
701	ROUTE	64103102	FSÖ	FLE	
702	64103102	FSÖ	Flens övre	5,8	-->ET ; -->OXD
703	64103102	FLE	Flen	0,7	-->CST ; -->NR
704	ROUTE	64103103	NK	NKS	
705	64103103	NK	Nyköping C	--	-->JN ; -->ÄBY
706	64103103	NKS	Nyköping S	0,8	-->ET ; -->OXD

Figure 7.4: Extract from part of the Infrastructure database. The first column contains the route number, the second and third the station names and the fourth the distance from the previous station. (G.Troche).

For each node the following information is given: The short name of the node, the long name, the distance from the foregoing node, the maximum line speed, whether the link between the foregoing node and the actual node is electrified or not, the maximum train length and in which direction the link may be used (normally both). The database also contains information about allowed activities at the node: Allowed activities can for example be starting and ending of trains, attaching and detaching of wagons, loading and unloading of intermodal load units, shunting, marshalling, etc.

If there are connections to other routes from the actual node, these are indicated as well. If there *are* connecting routes, it is also indicated from which and to which adjacent nodes the node can be passed without a change of travelling direction.

When it comes to so-called triangle tracks, which in the real rail network exist at several places in order to avoid forcing trains to change travelling direction, there are two options to depict this situation in EvaRail:

- 1) One is to consider the triangle as part of one node, and to specify all relations that are not requiring a change of travelling direction (the remaining then logically requiring a change of travelling direction)
- 2) The second is to consider each of the legs of the triangle as a separate link, and consequently define the corners of the triangle as three separate nodes.

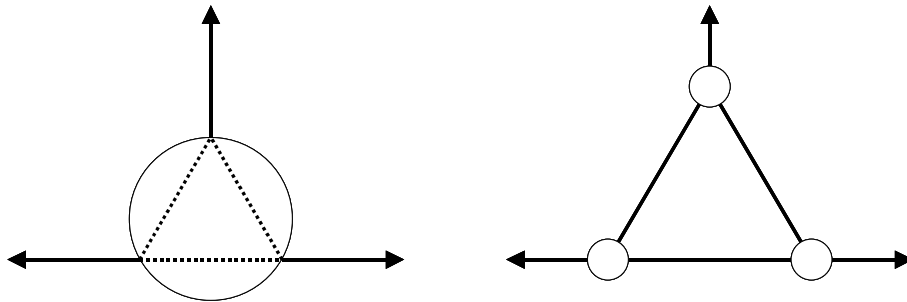


Figure 7.5: Different ways to depict triangle track arrangements in EvaRail. (Fig.: Gerhard Troche)

In most cases the second option is to be preferred, since it allows different parameter values to be assigned to the legs and distances to be depicted more correctly. In addition, if a station where wagons can be attached and detached is located at (only) one end of the triangle, this situation could not be depicted correctly if the whole triangle were depicted as one node. The figure below illustrates the different ways to depict a track triangle in EvaRail.

7.4 Train database

The Train database contains all train-related information. It comprises both technical and operational data, with the timetable as its core element. At this point it is necessary to clarify the use of the term ‘train’ in this context. In the Train database it describes a *train path*, not a specific train journey or a specific physical train. Consequently, a train in the Train database can have several departures. The train *consist* may vary between different journeys (departures), however, the actual train consist during a specific journey is not specified in the train database, but in an output database, the Trainrun database, which contains information about the train consist of each individual train departure and train path section.

The dataset for a train starts in the upper part with train number and route of the train. Other information given here comprises the maximum train length and weight, traction (number and class of locomotives), and the traffic periods and days. Up to five periods with different traffic days can be specified in order to reflect seasonal changes in the supply.

EvaRail allows the same train number to be kept even when motive power changes, which for example may occur when a train runs partly on electrified sections and partly diesel-only sections, when locomotives need to be changed at border stations, or when trains need pusher locomotives on mountain ramps.

Optional information comprises information about which types of vehicles are accepted, whether priority is given to a specific flow (and – if yes – to which) and whether the trains runs in TCS mode (Train-Coupling and Sharing). A train running in TCS mode means that other trains are running together with other trains for parts of or the entire route. Each train forms then a section of the train, but each section keeps its own train number.

There is also information about how many minutes the locomotive(s) is/are required to be available before and after the train run at the origin and destination. The maximum train speed is also indicated, as is the corresponding percentage for the average speed.

In the lower part of the dataset, the train’s timetable is found. In addition to distances and departure, arrival and dwell times for all stations (nodes)

passed, it also contains information about permitted activities (e.g. attaching/detaching of wagons, loading/unloading of loading units, etc).

465	#								
466	TRAIN	1009	F-JÖ-N			From week	1	23	
467	*					To week:	22	28	
468	*	Grenzlast:	#F-JÖ:1200#JÖ-N:800#			Monday	Yes	No	
469	*	Zuglaenge:	#F-JÖ:600#JÖ-N:500#			Tuesday	No	Yes	
470	*	Traction:	#F-JÖ:2*R	LocoToTr/L	#45/15#	Wednesda	Yes	No	
471	*					Thursday	No	Yes	
472	*					Friday	Yes	No	
473	*					Saturday	No	No	
474	*					Sunday	No	No	
475	*	AvSpeed	70						
476	Stations:	Dist	ArrTime	DwTime(m)	DepTime	Detach	Attach		
477	F	0	--:--	0	00-09:30:0	-	Yes		
478	VF	11,4	00-09:39:4	0	00-09:39:4	-	-		
479	SM	25,9	00-09:52:1	0	00-09:52:1	-	-		
480	MU	37,7	00-10:02:1	0	00-10:02:1	-	-		
481	BGD	48,5	00-10:11:3	0	00-10:11:3	-	-		
482	HO	50,4	00-10:13:1	0	00-10:13:1	-	-		
483	BRY	58,7	00-10:20:1	0	00-10:20:1	-	-		
484	JÖ	69,3	00-10:29:2	45	00-11:14:2	Yes	Yes		
485	HKA	75,9	00-11:20:0	0	00-11:20:0	-	-		
486	TH	85,4	00-11:28:1	0	00-11:28:1	-	-		
487	FM	96,5	00-11:37:4	0	00-11:37:4	-	-		
488	KRÖB	98,9	00-11:39:4	0	00-11:39:4	-	-		
489	ÄNG	103,8	00-11:43:5	0	00-11:43:5	-	-		
490	N	112,7	00-11:51:3	0	--:--	Yes	-		
491	#								

Figure 7.6: Extract of part from the Train database. In the upper part train number, train route, maximum length and weight and traction data are given. To the upper right part the traffic periods and traffic days are indicated. In the lower part contains the timetable.

7.5 Commodity database

The Commodity database contains information about the physical characteristics of the cargo. When defining the commodities it may be useful to follow a common classification system for freight commodities, e.g. as they are used for public statistics purposes. However, the user is free to define whatever commodity he or she likes and which best serves his or her purpose.

The database comprises the following information about each commodity:

- Name of the commodity
- Unit in which the commodity is normally measured:
 - Tons (e.g. coal, ore, ore and other pellets, other bulk commodities), *or*
 - Cubic metres (e.g. gases, furniture, insulation material, and other volume commodities), *or*
 - Number of pieces (e.g. new cars, house modules, palletized goods, and other indivisible commodities measured in integer values)
- Density in tons/cubic metres (obligatory if standard measure is cubic-metres, otherwise optional)
- Piece weight in tons/piece (obligatory only if the standard measure is in number of pieces)

The above information is needed both in order to calculate the number of required wagons or loading units and as a basis for the calculation of specific transport costs.

Since all wagons have to respect a payload limit and trains a gross-weight limit (always given in tons), it is necessary to specify density and piece weight in those cases when the commodity is not measured in tons. If the latter is the case, then density and piece weight – as far as is applicable – are optional. If this information is given, EvaRail will also deliver a “cubic-metre-kilometre cost” as well as a “piece-kilometre cost”. EvaRail also checks that the loading limit of a wagon or load units is not exceeded in volume nor weight.

7.6 Vehicle database

The Vehicle database is one of the most comprehensive input databases in EvaRail. It contains both technical and cost data for locomotives and wagons, and – if included in the list – other types of rail vehicles such as Freight Multiple Units.

In addition to the type denomination (normally the vehicle class), the database contains the following *technical* data for each vehicle type:

- Kind of vehicle
 - Locomotive
 - Wagon
 - Freight multiple unit
- Kind of propulsion (only for locomotives and freight multiple units)
 - Electric
 - Fuel
 - Dual-power
- Tare weight (service weight for locomotives, service weight without payload for freight multiple units)
- Length over buffers/couplers
- Maximum speed
- Marshalling restrictions, marshalling over bump allowed, Yes/No

Technical classification of rail freight vehicles in EvaRail

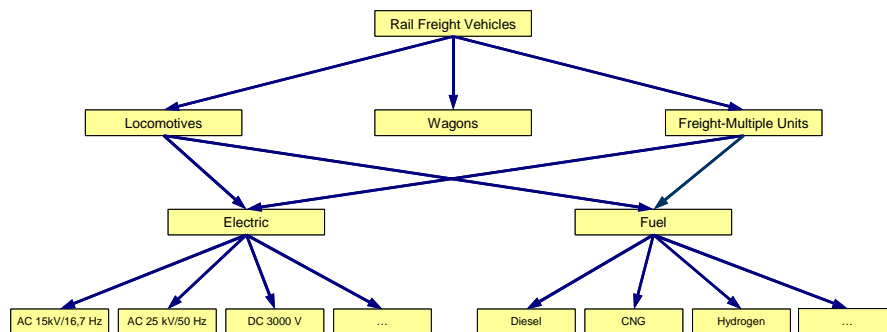


Figure 7.7: Technical classification of rail freight vehicles in EvaRail by kind of vehicle and propulsion system.(Fig.: Gerhard Troche)

It should be noted that the loading capacity is not given in the Vehicle database; this information is found in the separate Commodity/Vehicle database. Accordingly, the number of loading units which can be carried on a wagon (or on an FMU) is indicated in the separate Loading Unit/Vehicle database.

When it comes to economic information the database contains the following information:

- Vehicle purchase price
- Vehicle rent/leasing rate
- Vehicle maintenance costs

The database contains data for either owned or leased vehicles, or both. Two different leasing rates can be given, for example to distinguish short-term from long-term rental, or rates with and without maintenance. Vehicle maintenance data are always given, except when maintenance is included in the leasing rate.

More concretely, the following data are given in the case of *owned vehicles*:

- Purchase price
- Depreciation period
- Residual value
- Interest rate

The vehicle lease rate can consist of a fixed part and a variable – normally distance-based – part. In addition, it is also indicated whether maintenance is included or not. The database thus contains the following information in the case of *leased vehicles*:

- Fixed rate/month or day
- Km-based rate/km
- Maintenance included, Yes/No

Maintenance costs can be specified as follows:

- Fixed per year
- Per kilometre
- Per load run

7.7 Load unit database

There is a great variety of load units for intermodal traffic today. The most common are containers, swap-bodies and semitrailers. Within these groups there exist significant differences between different units and new types are appearing all the time. While the container has its origin in maritime traffic, swap-bodies and semitrailers come from road traffic, which explains some of the differences in construction, size and terminal handling.

In the model load units are described by the following physical parameters.

- name
- length
- loading capacity
- inner volume
- tare weight

As in the case of vehicles the database contains data for either owned or leased units, or both. Even here two different leasing rates can be given. Vehicle maintenance data are always given, except when maintenance is included in the leasing rate.

The following data are thus given in the case of *owned load units*:

- Purchase price
- Depreciation period
- Residual value
- Interest rate

The leasing rate is specified as a fixed monthly rate. In addition to this it is also indicated whether maintenance is included or not. The following information is thus given in the case of *leased load units*:

- Fixed rate/month or day
- Maintenance included, Yes/No

Maintenance costs can be specified as follows:

- fixed per year
- per load run

7.8 “Interconnecting” databases

The Commodity+Vehicle database, the Commodity+Load unit database and the Load unit+Vehicle database are summarized under Interconnecting databases. These three databases contain information about what commodities can be carried on/in which vehicles or loading units, and which loading units on which vehicles, and in what quantities.

The structure of the databases is identical and essentially forms an XY array with one aspect, for example commodities, on one axis and the other, for example vehicles, on the other axis (fig. 7.8).

	A	B	C	D	E	F
1	#db_COMonVEH#wb	Machinery	Europallets	Cars	Timber	Oil
2	Hbbis		38			
3	Hbins-v 972		45			
4	Habbins		63			
5	Kbps	4				
6	Lnps				yes	
7	Laaeilprss 931		144	14		
8	Zaces					yes

Fig. 7.8: Extract from the Commodity+vehicle database.

When adding a commodity, vehicle or load unit to the respective database, a dataset is generated automatically in the interconnecting databases, and the user is requested to specify loading patterns and capacity.

In the Commodity+Vehicle and Commodity+Load unit databases the loading capacity is always specified in *tons* and optionally also in *cubic metres* and/or *pieces*. If a commodity is normally measured in cubic metres and tons it is strongly recommended that the loading capacity of the vehicles and/or loading units, which are to carry this commodity be specified in these measures as well. It is certainly possible to calculate a transport capacity via the density or piece weight information but this guarantees only that the payload limit (in tons) will not be exceeded.

In the Load unit+Vehicle database the loading capacity is specified both in tons and number of load units. While the first information will be the same irrespective of the type of load unit, the latter can vary between different types of loading units. Many intermodal four-axle wagons can for example carry three 20' containers, but only two 7.15 - 7.82 m swap-bodies. The combination of different types of loading-units on the same wagon (e.g. one 20' container and one 7.15 - 7.82 m swap-body) cannot yet be depicted in EvaRail. Using some kind of equivalent measure – for example TEU – has not been considered feasible, since loading units are indivisible and only a few types of loading-unit actually fit into the TEU system. It would, for example, be quite difficult if semitrailers or even swap-bodies were included in the TEU system; not even all kinds of containers fit in this system. The TEU system is certainly useful for statistical purposes, but scarcely for specifying loading patterns or capacities of railway wagons.

7.9 Other cost databases

7.9.1 Activity database

The Activity-database contains information about costs for certain activities, which can be assigned to a train, a wagon or a load unit or a transport at different points of the transport chain, or even to an empty run. The following table gives an overview of the activities contained in this database.

Activity	Activity can be assigned on...		Cost allocated to	Cost given in...	Comment
	Load run:	Empty run:			
Loading of cargo into/onto wagon	X	-	Cargo	SEK per ton, <i>or</i> SEK per m ³ , <i>or</i> SEK per unit	Cost is specified individually for each commodity
Unloading into/onto wagon	X	-	Cargo	SEK per ton, <i>or</i> SEK per m ³ , <i>or</i> SEK per unit	Cost is specified individually for each commodity
Loading of cargo into ILU	X	-	Cargo	SEK per ton, <i>or</i> SEK per m ³ , <i>or</i> SEK per unit	Cost is specified individually for each commodity
Unloading into ILU	X	-	Cargo	SEK per ton, <i>or</i> SEK per m ³ , <i>or</i> SEK per unit	Cost is specified individually for each commodity
Transloading of ILU	X	X	ILU	SEK per occasion	Cost is specified individually for each type of ILU. Different cost levels can be specified for different transloading techniques
Shunting	X	X	Wagon	SEK per occasion	Model allows alternative calculation of shunting costs (see chapter 8.9.1)
Marshalling	X	X	Wagon	SEK per occasion	
Road feeder transport of ILU	X	-	ILU	SEK per occasion + SEK per km	
Road feeder transport of cargo	X	-	Cargo	SEK per occasion + SEK per km	Cost is given for a certain amount of cargo (measured in ton, m ³ or units)

Table 7.1: Activities specified in the Activity database

7.9.2 Personnel cost database

The Personnel cost database contains information, which is used to calculate locomotive driver and shunting personnel costs and contains the following data:

- Personnel category
- Salary per month, in SEK
- Effective utilization, in percent (driving time/working time)
- Sick leave/holiday leave, etc. in per cent

7.9.3 Energy price database

The energy price database contains prices for electricity – at catenary/pantograph – and fuel. Prices can be specified for different infrastructure managers.

Electricity prices are given in EUR per kWh, fuel prices in EUR per litre. Electricity prices can be differentiated by time of the day. The following figure gives an example of a time-differentiated pricing scheme.

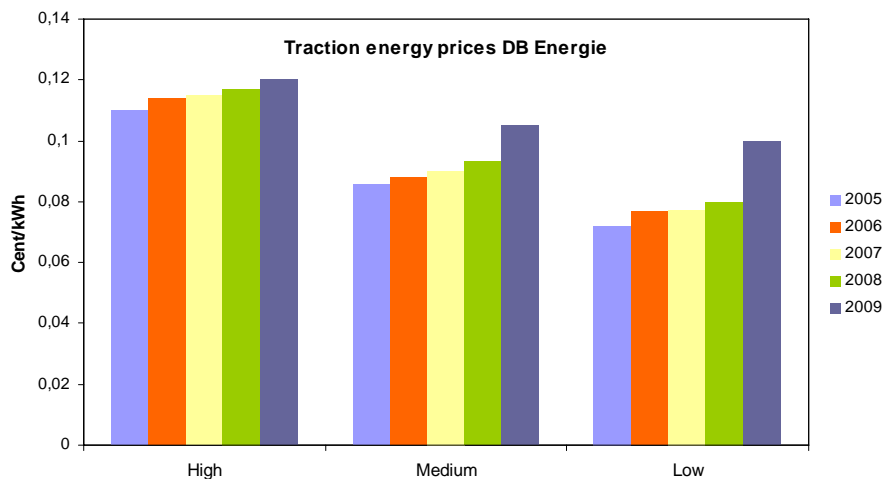


Figure 7.9: Time-differentiated pricing scheme from Deutsche Bahn (DB Energie) for traction electricity. The high tariff is applied during peak-hours morning and afternoon (5:30 – 08:59, 16:00 – 18:59), low tariff during night-time (22:00 – 05:29). (Data: DB Energi, DVZ, 13 Dec. 2008)

7.9.4 Infrastructure User Charge database

Infrastructure user charges normally consist of relatively large number of components, which can be related to train-kilometres, (gross-)ton-kilometres, axle-kilometres, etc. They can also vary between different types of trains, for example intermodal trains or unit trains. Even different weight classes can be defined. There may also be fixed annual charges. Furthermore charges can be general – valid on a whole network – or vary between different lines, and sometimes even between different times.

EvaRail is currently able to depict several different user charge regimes. The user charge regimes of the following infrastructure managers are currently included in the Infrastructure User Charge database:

- Banverket
- Inlandsbanan AB
- Öresundskonsortiet
- Banestyrelsen (Öresundsbron – Padborg)
- Deutsche Bahn Netz AG (simplified)
- ADIF (Spain)

All user charge regimes are general except that of Öresundskonsortiet, which if a fixed fee applied on the Öresund bridge. For Deutsche Bahn Netz user charges are simplified, since Deutsche Bahn has adopted a link-specific charging system.

8 Cost calculation in EvaRail

8.1 Overview

EvaRail is a computer-based model written in VBA (Visual Basic for Applications). Excel worksheets are used to store input and output data, which facilitates further processing, e.g. for graphical presentation or deeper analyses of the data. EvaRail already contains some possibilities for graphical presentation.

An important starting point in the development of EvaRail was to offer the user the possibility to make calculations with different levels of resolution in the input data. It is therefore possible to make a calculation with detailed input data for only one single flow, while other flows are taken into account by means of default values.

There are several reasons for this approach. One is that different types of user will need the model to answer different questions and need different type of information. Nor will all users have detailed information or knowledge about the data required as input. In order to keep the model user-friendly it should be able to work with varying quantities and quality of input data. Finally, for certain types of calculation, it is not necessary to make a detailed description of all flows in a transport system; it may also be that the time (and cost) budget for a project does not allow all information to be entered on a detailed level. A similar justification has been chosen by (Rand) to develop a family of mutually consistent models at two different levels of resolution. The difference here is that the approach in EvaRail has been realized within the same model

Figure 8.1 on the next page shows the main steps in the workflow in the EvaRail-program. Before being able to carry out a transport cost calculation it is necessary to specify a rail network – which in the simplest case can consist of only a single line - vehicles, loading units – if intermodal transport is involved in the transport system – and commodities, as well as costs for activities, energy, infrastructure usage, etc. (the latter are not shown in the diagram). In addition to this it is also possible to create trains in advance. However, it is also possible to do this

later when specifying the freight flows. For wagonload systems it may be useful to specify trains in advance since they will serve multiple flows, while it will be more comfortable to specify the trains together with the flow(s) in the case of a unit train system with one or only very few flows.

Workflow EvaRail

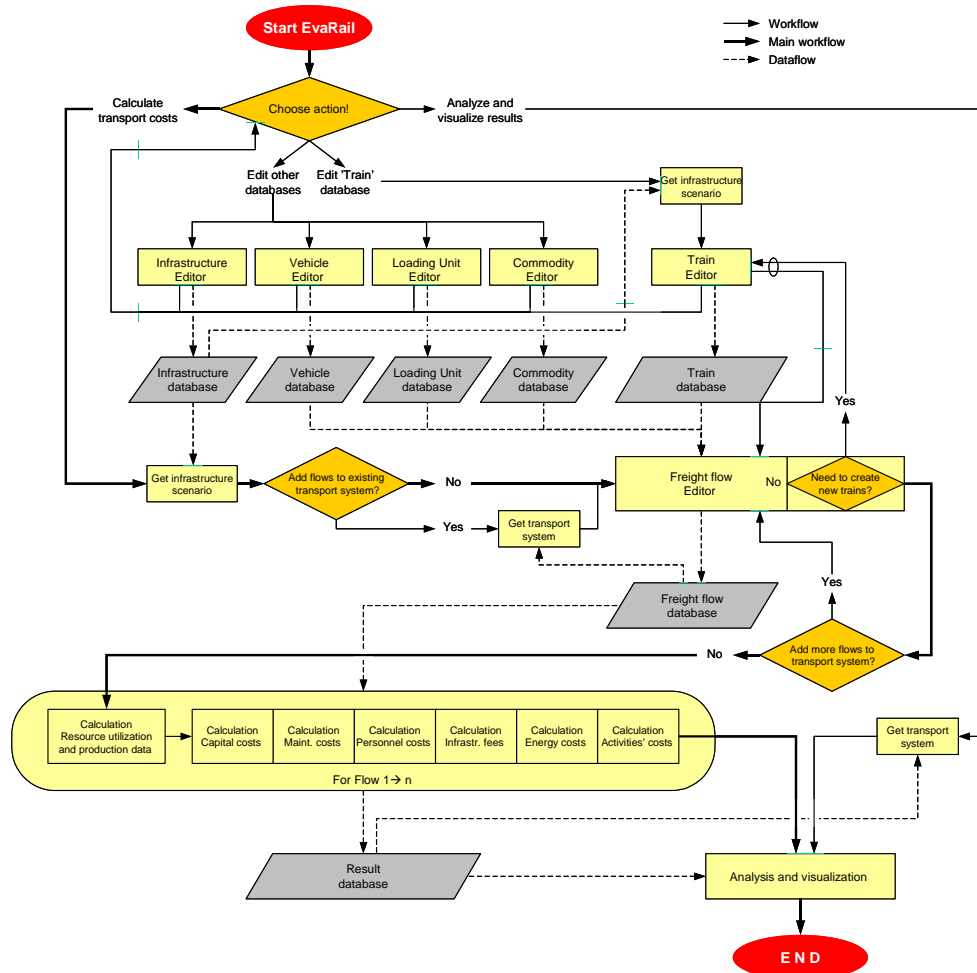


Figure 8.1: Workflow diagram of the EvaRail program. The figure illustrates only the main steps. The bold line marks the workflow when calculating a single freight flow, which is not yet defined and which does not form part of an already existing transport system. (Fig. Gerhard Troche)

A transport cost calculation can be made for one single freight flow – or a transport system with multiple flows. The program also allows freight flows to be added to a transport system at a later stage. In this case all freight flows – even those which have been specified earlier (and already been calculated once) – will be recalculated, since their costs may be (and most likely are) influenced by the added flows.

All input data is processed in a number of modules, which can be said to form the core of the EvaRail model, and whose content and function is described in more detail in this chapter.

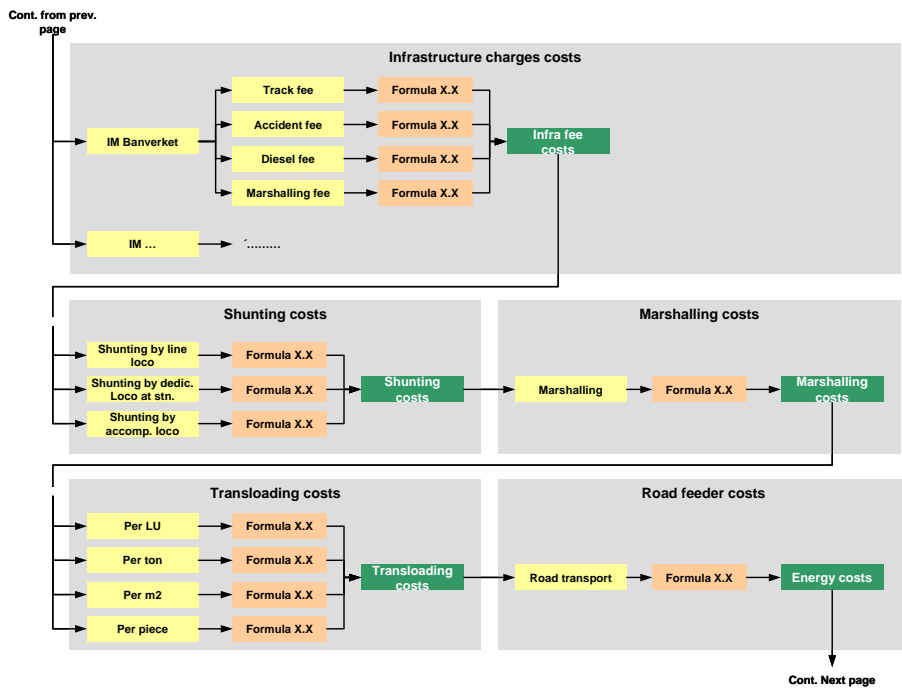
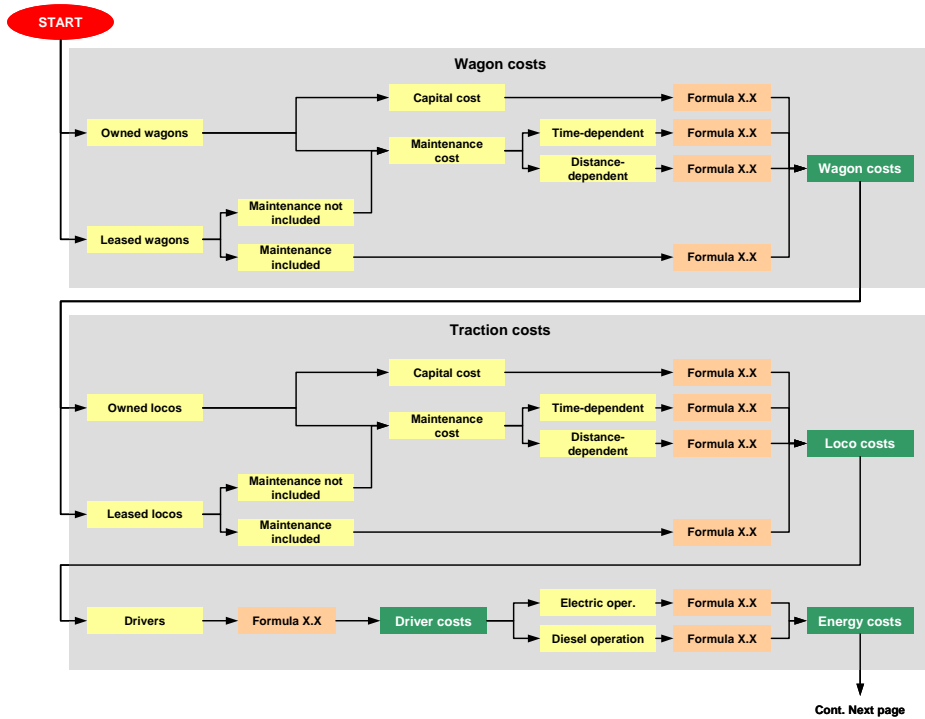
The calculation results are stored in an output database – together with all the corresponding input, in order to be able to reconstruct any scenario later. A special data analysis and visualization tool allows the user to present the main results in both graphical and table form.

The modules in the data procession part of EvaRail are as follows:

- Capital cost calculation, Vehicles
- Maintenance cost, Vehicles
- Personnel costs
- Energy costs
- Infrastructure charges
- Activities' costs

Each of these modules produces output data which are assigned to different cost items. The output data can later be analyzed and summarized in different ways in order to calculate specific cost aspects. When calculating traction costs for example, these will contain output data from at least the capital cost, the maintenance cost, personnel cost and energy cost modules, and – depending on the user's exact definition of 'Traction', also the remaining cost modules.

In the following the content and functioning of the modules is dealt with in more detail. The workflow chart below shows the calculation steps carried out in the model.



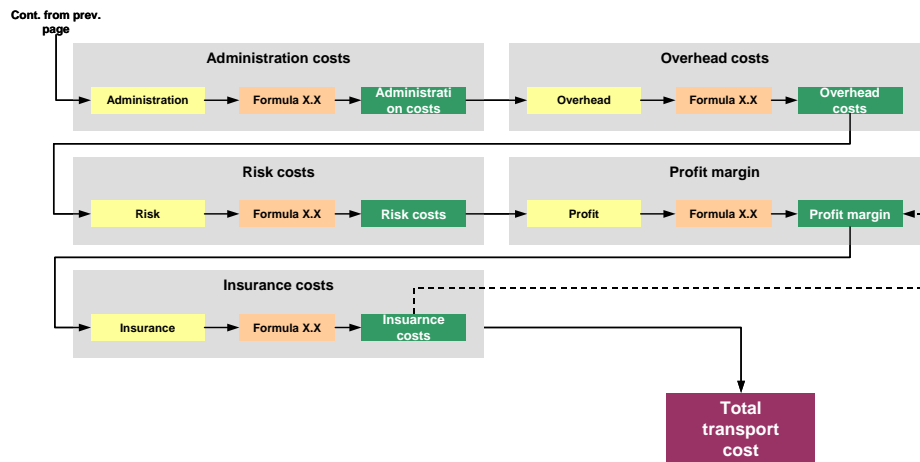


Figure 8.2: Workflow diagram of the calculation steps in EvaRail. The formula numbers refer to those indicated in sections 7.2 to 7.6. (Figure: Gerhard Troche)

In the following the formulas used to calculate the costs for a transport are described in detail. A transport is a chain of nodes and links and for all cost components costs are calculated for each node and link, giving a very detailed picture of the cost situation for each individual transport. The costs for a flow are the sum of the costs for all transports belonging to that flow.

8.2 Wagon capital or leasing costs

Railways use both owned or rented/leased freight wagons. EvaRail allows both situations to be depicted. Opting for owned freight wagons has the advantage of being able to accurately calculate the impact of purchase price, depreciation period and interest rate. This is not possible when opting for rented freight wagons. Although the above mentioned parameters, of course, form an important input for the setting of rental/leasing rates, the model only contains the rental/leasing rate itself – since it is this that is charged to the train operator.

8.2.1 Cost calculation with owned wagons

If the wagons are owned, the total freight wagon costs in a specific flow are calculated as follows:

First, an annuity is calculated based on the input parameters (1) purchase cost, (2) depreciation period, (3) residual value at the end of the depreciation period and (4) interest rate. For all these parameters default values are specified in the 'Vehicle'-database. Note that the purchase cost need not necessarily represent the price of new wagons; it can also be the price for second-hand rolling stock. If relevant repair costs or costs of a redesign should in this case be included in the purchase cost.

In the second step, the annuity is allocated to a specific transport 'ThisTrp'.

As can be seen from the formula the wagon capital cost of a specific transport is not depending on the annual utilization of the wagon individuals used for that transport, but from the average utilization of all wagons belonging to the same class. This solution has been chosen in order to not "punish" a transport, which happens to get allocated wagon individuals carrying out only very few transports. For wagonload traffic it can be assumed that there normally is no causality between the annual utilization of a wagon individual and the characteristics of one specific transport.

In case of a unit-train operation, where all wagons are allocated to transports of one specific flow – and where consequently the traffic patterns of that flow influence the utilization of the wagons – the user should define a specific wagon class for that unit-train operation, at least if several independent unit-train operations use the same wagon class or

if wagons of this class are also used in wagonload traffic. By doing so the user avoids that the wagon utilization rates in different, independent traffic systems influence each other. (Doing so is also recommendable in order to avoid that EvaRail “kidnaps” a wagon and allocates it to transports in another system).

The wagon capital costs of a transport are broken down to the links and nodes of a transport chain in relation to each links’ and nodes’ share of the total wagon occupation time. This means that EvaRail allocates wagon capital costs not only to links, i.e. times when the wagon is moving, but also to nodes, i.e. times when the wagon is standing still (but assigned to a transport, i.e. not available to carry out other transports). When it comes to the places of origin and destination of a transport, a wagon is considered being assigned to a transport from/until the time when the customer requires the wagon to be at place. These points of time do not need to be identical with those, when the (empty) wagon actually is placed or collected.

$$\text{ThisTrp_WCAP} = \frac{\text{ThisTrp_WagonOccuTime}}{\text{AllTrp_WagonOccuTime} * \text{WagonAnnuity} * \text{EmpFactor_WagonOccuTime} * \text{ThisTrp_NrOfWagons}}$$

Where:

ThisTrp_WCAP = Wagon capital costs for a specific transport

ThisTrp_WagonOccuTime = Time period, during which a wagon individual used for the specific transport, are allocated to that transport.

ThisTrp_VEHOccuTime starts with the time from which on the wagons are required at the place of loading and ends with the time when the wagon(s) are released at the place of unloading

AllTrp_WagonOccuTime = Average time period over one year, during which all wagons of the same class as those used for the specific transport, are allocated to any transport

WagonAnnuity = Annuity of a wagon used for the specific transport

EmpFactor_WagonOccuTime = Factor taking into consideration the time the wagon is occupied in empty runs (see ch. 8.11)

ThisTrp_NrOfWagons = Number of wagons used for the specific transport

8.2.2 Cost calculation with leased wagons

Freight wagons can be rented or leased for short or long periods. The length of the period influences the leasing rate. EvaRail therefore allows different leasing rates to be specified. The leasing rates can be inclusive or exclusive of maintenance. This is also taken into account in EvaRail and the user can make calculations for both situations.

The leasing rate often consists of a fixed weekly/monthly/annual (depending on the length of the contract) portion and a distance-based portion. The formula for calculating the leasing cost for a certain flow is as shown below.

As can be seen different 'Empty-factors' are applied on the time-dependent portion and the distance-dependent portion of the wagon rental cost. For details about the 'Empty-factors' see chapter 8.11.

The time-dependent portion of the wagon rental cost for a specific transport is then – in the same way as wagon capital costs – broken down to the links and nodes of a transport chain in relation to each links' and nodes' share of the total wagon occupation time for that transport. The distance-dependent portion is broken down to the links of the transport chain in relation to their share of the total distance of that transport.

$$\text{ThisTrp_WLEASE} = \left(\left(\text{ThisTrp_WagonOccuTime} / \text{AllTrp_WagonOccuTime} * \text{WagonPeriodLeaseRate} * \text{NrOfLeasePeriods} * \text{EmpFactor_WagonOccuTime} \right) + \left(\text{ThisTrp_TrpDist} * \text{WagonKmLeaseRate} * \text{EmpFactor_TrpDist} \right) \right) * \text{ThisTrp_NrOfWagons}$$

Where:

ThisTrp_WLEASE = Wagon lease costs for a specific transport

ThisTrp_WagonOccuTime = Time period, during which a wagon individual used for the specific transport, are allocated to that transport.

AllTrp_WagonOccuTime = Average time period over the contract period, during which all wagons of the same class as those used for the specific transport, are allocated to any transport

WagonPeriodLeaseRate = Rate for the fixed portion of the leasing rate

NrOfLeasePeriods = Number of leasing periods

EmpFactor_WagonOccuTime = Factor taking into consideration the time the wagon is occupied in empty runs (see ch. 8.11)

ThisTrp_TrpDist = Transport distance of the transport

WagonPeriodLeaseRate = Rate for the distance-dependent portion of the leasing rate

EmpFactor_TrpDist = Factor taking into consideration the distance, which the wagon is running empty (see ch. 8.11)

ThisTrp_NrOfWagons = Number of wagons used for the specific transport

8.3 Wagon maintenance and service costs

Wagon maintenance and service costs – in the following called maintenance costs – can be (1) fixed (e.g. per year), (2) dependent on distance or (3) dependent on a number of load runs. When collecting input data it is very seldom possible to obtain exact data on how maintenance costs are distributed among these three categories since maintenance costs are often only given per kilometre, or in the worst case only as an annual cost. The last category, maintenance costs per load run is meaningful to use for costs incurred directly by the cargo or during loading and unloading, as damage to wagon doors, walls and load securing equipment, while the other categories are mainly related to the running gear, brake and couplers. EvaRail allows in principle specify maintenance costs for all three cost dependencies, which enables the user to make very exact calculations even for varying levels of wagon utilization.

For each of the three categories, maintenance costs are calculated and allocated to a specific flow as follows:

Note that an ‘Empty-factor’ is applied only on the fixed and distance-based portions of the wagon maintenance costs, not on the maintenance costs per loadrun.

The fixed and distance-dependent portion of the maintenance cost of a transport is broken down to the links of the transport chain in relation to their share of the total distance of that transport. The cost portion dependent related to loadruns is broken down half each on the first and last node of the transport chain, where loading and unloading is taking place. It can be assumed that the by far major part of loading run-related maintenance costs are related to the loading and unloading processes.

Wagon maintenance costs are not calculated if leased wagons are used, whose lease rate include maintenance.

$$\begin{aligned} \text{ThisTrp_WMAINT} = & ((\text{ThisTrp_TrpDist} / \text{AllTrp_TrpDist} \\ & * \text{WMAINTperYear} * \text{EmpFactor_TrpDist}) + \\ & (\text{ThisTrp_TrpDist} * \text{WMAINTperKm} * \text{EmpFactor_TrpDist}) \\ & + \text{WMAINTperLoadrun}) * \text{ThisTrp_NrOfWagons} \end{aligned}$$

Where:

ThisTrp_WLEASE = Wagon maintenance costs for a specific transport

ThisTrp_TrpDist = Transport distance of a specific transport

AllTrp_TrpDist = Average transport distance of all transports carried out by wagons of the same class as that or those used for the specific transport

WMAINTperYear = Fixed annual wagon maintenance cost

EmpFactor_TrpDist = Factor taking into consideration the distance, which the wagon is running empty (see ch. 8.11)

WMAINTperKm = Distance-dependent maintenance cost per kilometre

WMAINTperLoadrun = Maintenance cost per loadrun

$\text{ThisTrp_NrOfWagons}$ = Number of wagons used for the specific transport

8.4 Locomotive capital or leasing costs

As is the case with freight wagons, railways use both owned or rented/leased locomotives; both situations can be depicted in EvaRail. The calculation principles are basically the same as for freight wagons.

However, in contrast to wagons, which are allocated directly to a transport and thus stay with it from origin to destination, locomotives are instead allocated to trains, which convey the wagons allocated to a transport. Since a transport chain can make use of more than one train – and furthermore, locomotives can change during a trainrun (EvaRail allows to allocated different number and class of locomotives to different sections of a trainrun), and – in addition – a transport may not necessarily make use of a train over the whole length of its trainrun, but may only travel a shorter section in it, locomotive costs have to be calculated on the link- (and some cases node-) level of a transport chain and then summed up to get the total locomotive costs for a transport.

For links locomotive capital or leasing costs always have to be calculated, since a link by definition represents a transport in a train. In addition they have to be calculated for a node, if the node in question represents an intermediate stop of a train, i.e. if both the wagon(s) carrying out a transport and the locomotive stays in the train. However, no locomotive capital or leasing costs are allocated to the wagons (transports) in the train if the locomotive is assigned to other duties during the intermediate stop, as for example shunting of wagons to be picked up or set out. In this case the locomotive capital or leasing costs are allocated to the wagons being shunted. No costs are allocated even in the case that locomotives are changed at that node.

8.4.1 Cost calculation with owned locomotives

As with the wagon capital costs first an annuity is calculated based on the input parameters (1) purchase cost, (2) depreciation period, (3) residual value at the end of the depreciation period and (4) interest rate. For all these parameters default values are specified in the ‘Vehicle’-database. Note that the purchase cost need not necessarily represent the price of new locomotives; it can also be the price for second-hand motive power. If relevant repair costs or costs of a redesign should in this case be included in the purchase cost.

Based on the aforementioned prerequisites the locomotive capital costs are then calculated for each link and node of a trainrun according to the following formula:

$$\text{TrainrunSec_LOCOCAP} = \frac{\text{TrainrunSec_LocoOccuTime}}{\text{All_LocoOccuTime} * \text{LocoAnnuity} * \text{Trainrunsec_NrOfLocos}}$$

Where:

TrainrunSec_LOCOCAP = Locomotive capital costs for a trainrun-section (link or node)

TrainrunSec_LocoOccuTime = Time period, during which a locomotive is allocated to a trainrun-section; identical to the time between departure and arrival, if a link, and between arrival and departure, if a node

All_LocoOccuTime = Average total time period, during which all locomotives of the same class as those used for the trainrun in question are allocated to any transport or locomotive empty run

LocoAnnuity = Annuity of a locomotive used on the specific section of the trainrun

Trainrunsec_NrOfLocos = Number of locomotives used on the specific section of the trainrun

After having calculated the locomotive capital costs for a trainrun-section, a transport has to be allocated that portion of the cost, which corresponds to that transport's share in the train.

EvaRail takes into account the two most important limiting factors for train capacity: (1) Train weight and (2) train length:

$$\text{ThisTrpsec_LOCOCAP} = 0.5 * \text{TrainrunSec_LOCOCAP} * (\text{ThisTrp_GrWeight} / \text{Trainrunsec_TrGrWeight}) + (0.5 * \text{TrainrunSec_LOCOCAP} * (\text{ThisTrp_Length} / \text{Trainrunsec_TrLength}) * \text{EmpFactor_TrainTime}$$

Where:

$\text{ThisTrpsec_LOCOCAP}$ = Locomotive capital costs for a transport-section (link or node)

$\text{TrainrunSec_LOCOCAP}$ = Locomotive capital costs for a trainrun-section (link or node)

ThisTrp_GrWeight = Grossweight of the wagon(s) used for a transport

$\text{Trainrunsec_TrGrWeight}$ = Train-grossweight in the transport-section

ThisTrp_Length = Length of the wagon(s) used for a transport

$\text{Trainrunsec_TrLength}$ = Train-length in the transport-section

$\text{EmpFactor_TrainTime}$ = Factor taking into consideration the time the wagon is running empty in trains (see ch. 8.11)

By default length and weight are weighted equal (shown in formula), however, it is possible to weight each factor according to which degree the maximum train length and the maximum train weight is reached by the train in the trainrun-section in question.

8.4.2 Cost calculation with leased locomotives

Locomotives can be rented or leased for short or long periods. The length of the period influences the leasing rate. EvaRail therefore allows different leasing rates to be specified. The leasing rates can be inclusive or exclusive of maintenance. This is also taken into account in EvaRail and the user can make calculations for both situations.

The rental/leasing rate often consists of a fixed weekly/monthly/annual (depending on the length of the contract) portion and a distance-based

portion. The formula for calculating the leasing cost for a trainrun-section is as shown in the table below.

$$\text{TrainrunSec_LOCOLEASE} = ((\text{TrainrunSec_LocoOccuTime} / \text{All_LocoOccuTime} * \text{LocoPeriodLeaseRate} * \text{NrOfLeasePeriods}) + (\text{Trainrunsec_Dist} * \text{LocoKmLeaseRate})) * \text{Trainrunsec_NrOfLocos}$$

Where:

TrainrunSec_LOCOLEASE = Locomotive lease cost for a trainrun-section (link or node)

TrainrunSec_LocoOccuTime = Time period, during which a locomotive is allocated to a trainrun-section; identical to the time between departure and arrival, if a link, and between arrival and departure, if a node

All_LocoOccuTime = Average total time period, during which all locomotives of the same class as those used for the trainrun in question are allocated to any transport or locomotive empty run

LocoPeriodLeaseRate = Rate for the fixed portion of the leasing rate

NrOfLeasePeriods = Number of leasing periods

Trainrunsec_Dist = Length of trainrun-section

LocoKmLeaseRate = rate for the distance-dependent portion of the leasing rate

Trainrunsec_NrOfLocos = Number of locomotives used on the specific section of the trainrun

After having calculated the locomotive leasing costs for a trainrun-section, a transport has to be allocated that portion of the cost, which corresponds to that transport's share in the train. This is done in the same way as with locomotive capital costs; the formula is thus:

```

ThisTrpsec_LOCOLEASE = 0.5 * TrainrunSec_
LOCOLEASE * (ThisTrp_GrWeight /
Trainrunsec_TrGrWeight)) + (0.5 * TrainrunSec_
LOCOLEASE * (ThisTrp_Length / Trainrunsec_TrLength)
* EmpFactor_TrainTime

```

Where:

ThisTrpsec_LOCOLEASE = Locomotive lease costs for a transport-section (link or node)

TrainrunSec_LOCOLEASE = Locomotive lease costs for a trainrun-section (link or node)

ThisTrp_GrWeight = Grossweight of the wagon(s) used for a transport

Trainrunsec_TrGrWeight = Train-grossweight in the transport-section

ThisTrp_Length = Length of the wagon(s) used for a transport

Trainrunsec_TrLength = Train-length in the transport-section

EmpFactor_TrainTime = Factor taking into consideration the time the wagon is running empty in trains (see ch. 8.11)

Even in this case by default length and weight are weighted equal (shown in formula), however, it is possible to weight each factor according to which degree the maximum train length and the maximum train weight is reached by the train in the trainrun-section in question.

8.5 Locomotive maintenance and service costs

Locomotive maintenance and service costs – in the following called maintenance costs – can be (1) fixed or (2) dependent on distance. EvaRail allows data to be specified in both ways. As with all locomotive-related costs, even locomotive maintenance costs have to be calculated on the link-level of a transport chain and then summed up to get the total locomotive costs for a transport. The formula used is the following:

$$\text{TrainrunSec_LOCOMAINT} = ((\text{TrainrunSec_Dist} / \text{All_LocoDist} * \text{LOCOMAINTperYear}) + (\text{TrainrunSec_Dist} * \text{LOCOMAINTperKm})) * \text{Trainrunsec_NrOfLocos}$$

Where:

TrainrunSec_LOCOMAINT = Locomotive maintenance costs for a trainrun-section (link or node)

TrainrunSec_Dist = Length of trainrun-section

All_LocoDist = Average annual running distance of all locomotives of the same class as those used for the trainrun-section in question

LOCOMAINTperYear = Fixed annual locomotive maintenance cost

LOCOMAINTperKm = Distance-dependent locomotive maintenance cost per kilometre

Trainrunsec_NrOfLocos = Number of locomotives used on the specific section of the trainrun

After having calculated the locomotive maintenance costs for a trainrun-section, a transport has to be allocated that portion of the cost, which corresponds to that transport's share in the train. The costs are allocated following the same principles as for the allocation of locomotive capital and leasing costs, taking into account both (1) weight and (2) length:

```

ThisTrpsec_ LOCOMAINT = 0.5 * TrainrunSec_
LOCOMAINT * (ThisTrp_GrWeight /
Trainrunsec_TrGrWeight)) + (0.5 * TrainrunSec_
LOCOMAINT * (ThisTrp_Length / Trainrunsec_TrLength)
* EmpFactor_TrainTime

```

Where:

ThisTrpsec_ LOCOMAINT = Locomotive maintenance costs for a transport-section

TrainrunSec_ LOCOMAINT = Locomotive maintenance costs for a trainrun-section

ThisTrp_GrWeight = Grossweight of the wagon(s) used for a transport

Trainrunsec_TrGrWeight = Train-grossweight in the transport-section

ThisTrp_Length = Length of the wagon(s) used for a transport

Trainrunsec_TrLength = Train-length in the transport-section

EmpFactor_TrainTime = Factor taking into consideration the time the wagon is running empty in trains (see ch. 8.11)

By default length and weight are weighted equal (shown in formula), however, it is possible to weight each factor according to which degree the maximum train length and the maximum train weight is reached by the train in the trainrun-section in question.

8.6 Driver costs

Driver costs for a transport are calculated in three steps:

In a first step the cost per effective driving hour is calculated based on the three parameters (1) total annual personnel cost, (2) effective working time, taking into account holidays, sick-leave, etc., (3) effective personnel utilization, i.e. driving hours in percent of effective working hours.

In the second step, after having obtained the driver costs per driving hour, the driver costs are calculated for each link of a trainrun, which is used for a transport, using the following formula:

$$\text{Trainrunsec_DRIVER} = \text{TrainrunSec_RunTime} * \text{DriverCostPerHour} * \text{NrOfDrivers}$$

Where:

Trainrunsec_DRIVER = Driver costs for a trainrun-section

TrainrunSec_RunTime = Running time for a trainrun-section (identical to **Trpsec_LocoOccuTime**)

DriverCostPerHour = Average cost per effective driving hour

NrOfDrivers = Number of drivers in a trainrun-section

The number of drivers is in Sweden and most other European countries 1 (one), but in certain countries still two drivers are required. There are even certain circumstances, when more than 1 driver may be required, for example on line sections with helper locomotives, which are not remote-controlled.

After having calculated the driver costs for a trainrun-section, a transport has to be allocated that portion of the cost, which corresponds to that transport's share in the train. This is done in the same way as with locomotive costs; the formula is thus:

$$\text{ThisTrpsec_DRIVER} = 0.5 * \text{TrainrunSec_DRIVER} * (\text{ThisTrp_GrWeight} / \text{Trainrunsec_TrGrWeight}) + (0.5 * \text{TrainrunSec_DRIVER} * (\text{ThisTrp_Length} / \text{Trainrunsec_TrLength}) * \text{EmpFactor_TrainTime})$$

Where:

ThisTrpsec_DRIVER = Driver costs for a transport-section (link or node)

$\text{TrainrunSec_DRIVER}$ = Driver costs for a trainrun-section (link or node)

ThisTrp_GrWeight = Grossweight of the wagon(s) used for a transport

$\text{Trainrunsec_TrGrWeight}$ = Train-grossweight in the transport-section

ThisTrp_Length = Length of the wagon(s) used for a transport

$\text{Trainrunsec_TrLength}$ = Train-length in the transport-section

$\text{EmpFactor_TrainTime}$ = Factor taking into consideration the time the wagon is running empty in trains (see ch. 8.11)

By default length and weight are weighted equal (shown in formula), however, it is possible to weight each factor according to which degree the maximum train length and the maximum train weight is reached by the train in the trainrun-section in question.

8.7 Energy costs

Today it is possible to calculate the consumption of traction energy quite precisely, not least thanks to an increased interest from different actors – railway companies, transport customers as well as political decision-makers – to improve the knowledge about energy consumption in the transport sector.

However, for the calculation of traction energy costs in EvaRail a method had to be found, which does not require a highly detailed and disaggregated description of infrastructure, vehicles and trainruns. The EvaRail model does for example not contain detailed information on railway lines' gradients and curvature, a locomotives propulsion system, or the running dynamics of vehicles.

For this reason the calculation of traction energy consumption is calculated on the basis of a gross-tonkilometre consumption. The calculation method is derived from that in the EcoRail-project, which is used by a large number of railway undertakings for general energy consumption calculations. The calculation method takes into consideration a transports grossweight, train grossweight and the character of the line, where a rough classification is made into three classes: flat, hilly and mountainous. A railway line is considered as hilly if the gradient on longer sections exceeds 10‰ and/or if it has narrow curves over longer sections. A line is considered as mountainous if the gradient on longer sections exceeds 18‰. In Sweden most lines are flat.

In addition to the parameters mentioned above, EvaRail also offers the possibility to take into consideration train speed with help of a correction factor. In this way the significantly higher energy consumption of fast running freight trains – alternatively reduced energy consumption of slow-moving trains – is taken into account, too.

Figures 8.4 and 8.5 show the energy consumption diagrams and formulas on which the calculation of electricity and fuel consumption in EvaRail is based.

The correction factor for speed can be derived from BREIMEIER (2008), who calculated the energy consumption of a 1.487 t freight-train on a reference line of 100 km as shown in figure 8.3.

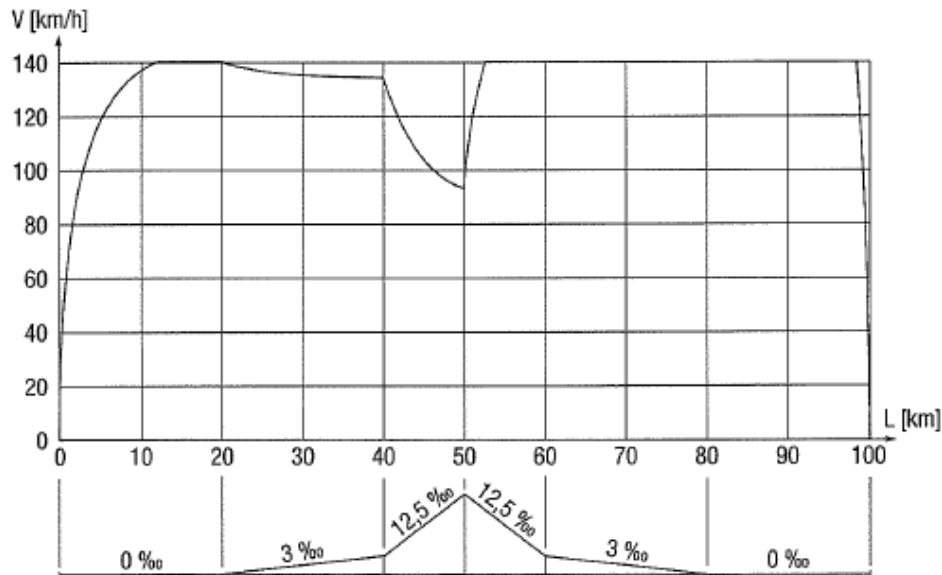


Figure 8.3: Reference line for the calculation of energy-consumption of a freight train at different speed (Source: BREIMEIER (2008), p.576)

BREIMEIER(2008) calculated the following energy consumption for a freight train at different speeds. Note, that the calculated consumption does not correspond exactly with that, which would be obtained applying the formula in figure 8.4. However, for use in the EvaRail model only the *relative* difference is relevant and has been included in the model.

Vmax	Vaverage	Energy consumption at pantograph	Regenerated energy	Net consumption	Index (correction factor in EvaRail)
60 km/h	59,3 km/h	2.232 kWh	296 kWh	1.936 kWh	0,581
80 km/h	78,4 km/h	2.835 kWh	268 kWh	2.567 kWh	0,771
100 km/h	96,1 km/h	3.557 kWh	226 kWh	3.331 kWh	1,000
120 km/h	112,0 km/h	4.375 kWh	170 kWh	4.205 kWh	1,262
140 km/h	125,3 km/h	5.227 kWh	114 kWh	5.113 kWh	1,535

Table 8.3: Energy consumption of a 1.487 t freight train on a reference line (see figure 8.3) at different speeds (Source: BREIMEIER (2008), p.576, modified and extended)

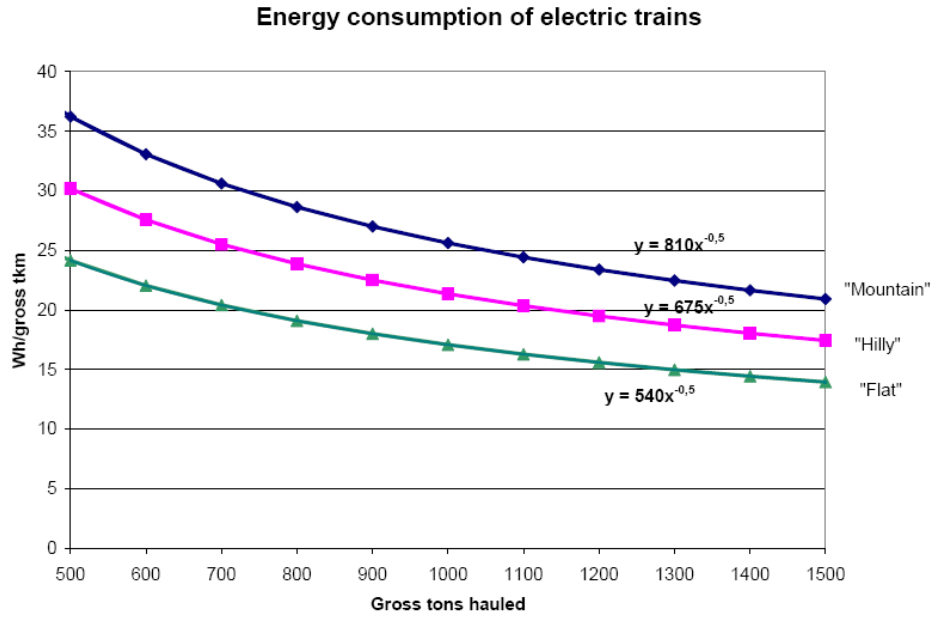


Figure 8.4: Energy consumption of electric trains in Wh/gross-tonkilometre (Source: IFEU (2008), p.23)

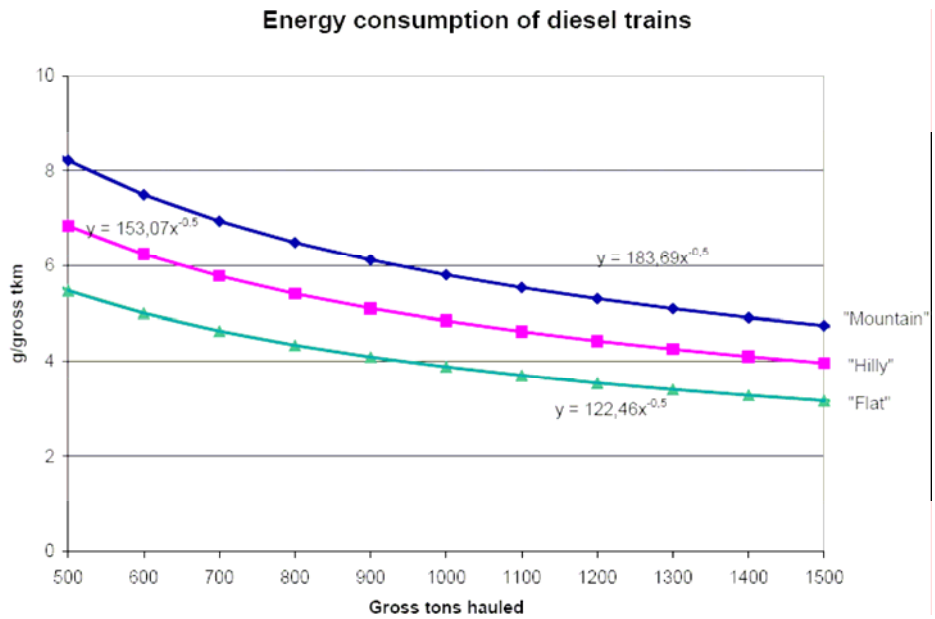


Figure 8.5: Energy consumption of diesel trains in gram fuel/gross-tonkilometre (Source: IFEU (2008), p.24)

Energy consumption for stationary processes is not calculated and therefore not explicitly covered by EvaRail. In freight traffic, energy consumption for stationary processes is normally low compared to passenger traffic. To some extent they are even covered in lump sums for other cost items, e.g. marshalling costs. From a cost perspective, the additional energy consumption for stationary processes not already included in other cost items is considered negligible.

After calculating the energy consumption the obtained value is multiplied by the unit cost for electricity and fuel respectively.

Concerning electric energy, EvaRail allows for a time-differentiated energy price, as it is applied by German DB Energie for example (table 8.2).

Time	Price EUR / kWh	Refund for regenerated energy EUR/ kWh
00:00 – 05:29	0.0420	0.0320
05:30 – 08:59	0.1170	0.0400
09:00 – 15:59	0.0810	0.0370
16:00 – 18:59	0.1170	0.0400
19:00 – 21:59	0.0810	0.0370
22:00 – 23:59	0.0420	0.0320

Table 8.2: Time-differentiated price system for electric traction energy as applied by DB Energie (DB ENERGIE, 2003, p.1).

Based on these above described preconditions and principles the energy cost per transport section is calculated according to the formulas on the next page. The energy costs have to be calculated per transport section because the grossweight of the train can vary between different sections.

In case of electric traction the following formula is used for the calculation of energy costs for a transport section:

$$\text{ThisTrpSec_ELENERGY} = \text{ThisTrp_GrWeight} * \text{Trainrunsec_Dist} * (F * \text{Trainrunsec_TrGrWeight} ^ - 0.5 * S) * \text{PricePerWh} * \text{TareEmpFactor_TrpDist}$$

Where:

ThisTrpSec_ELENERGY = Energy cost for a transport-section

ThisTrp_GrWeight = Grossweight of the wagon(s) used for a transport

Trainrunsec_Dist = Length of trainrun-section

F = Factor dependent on route characteristic (flat, hilly, mountainous; see fig.8.3)

Trainrunsec_TrGrWeight = Train-grossweight in the transport-section

S = Correction factor to take into consideration deviation from normal speed (default = 1)

PricePerWh = Price per Watt-hour

TareEmpFactor_TrpDist = Factor taking into consideration the distance, which the wagon is running empty, only tareweight taken into account (see ch. 8.11)

In case of diesel traction the following formula is used for the calculation of energy costs for a transport section:

$$\text{ThisTrpSec_FUEL} = \text{ThisTrp_GrWeight} * \text{Trainrunsec_Dist} * (F * \text{Trainrunsec_TrGrWeight} ^ - 0.5 * S) * \text{Trainrunsec_Dist} * \text{FuelDens} * \text{PricePerLitre} * \text{TareEmpFactor_TrpDist}$$

Where:

ThisTrpSec_FUEL = Energy cost for a transport-section

ThisTrp_GrWeight = Grossweight of the wagon(s) used for a transport

Trainrunsec_Dist = Length of trainrun-section

F = Factor dependent on route characteristic (flat, hilly, mountainous; see fig.8.3)

Trainrunsec_TrGrWeight = Train-grossweight in the transport-section

S = Correction factor to take into consideration deviation from normal speed (default = 1)

FuelDens = density of fuel in gram / litre

PricePerLitre = Fuel price per litre

TareEmpFactor_TrpDist = Factor taking into consideration the distance, which the wagon is running empty, only tareweight taken into account (see ch. 8.11)

8.8 Infrastructure charges

EvaRail is able to handle infrastructure charges, which are based on

- train-kilometres
- gross ton-kilometres
- number of wagons
- number of locomotives
- litres of consumed fuel, and
- pantograph-kilometres.

Most infrastructure charge schemes in Europe are based on one – or often a combination of several – of these parameters. In principle, EvaRail therefore allows the infrastructure charges to be calculated for the networks of most European infrastructure managers. It also allows fixed fees to be assigned to certain links. Such link-specific charges are raised for example on the Öresund link between Sweden and Denmark. They can also be raised on industrial spurs.

In certain countries infrastructure fees vary from line to line. A solution to depict this situation at least approximately and with reasonable effort is to specify separate networks, for example “DB Netz – Main lines” and “DB Netz – Secondary lines”. Different infrastructure fees can then be assigned to the networks.

In its current state Banverket’s infrastructure charges are implemented in EvaRail (and hereby also Inlandbanan AB’s, which adopts the same charges as Banverket). The relevant charge components for freight traffic are shown in the table below.

Charge component	Price SEK	Cost refers to ...
Track fee	0,0028	gross ton-km
Accident fee	0,55	train-km
Fuel fee (full)	0,31	litres of diesel in line traffic
Fuel fee (reduced)	0,155	litres of diesel in line traffic
Marshalling fee	4	wagon

Table 8.3: Infrastructure charge components in Banverket’s network relevant for freight

Below the formulas are given to calculate the infrastructure charge costs on Banverket's net. The track fee, fuel fee and marshalling fee can be calculated directly for a transport, while the accident fee is calculated on train-level first and then a portion of it allocated to a transport. The following formulas are used to calculate the infrastructure fees for a transport sections.

For the calculation of the track fee for a transport section (link) the following formula is used:

$$\text{ThisTrpSec_FEETRACK} = \text{ThisTrp_GrWeight} * \text{TrackFee} * \text{EmpFactor_TrpDist}$$

Where:

$\text{ThisTrpSec_FEETRACK}$ = Track fee for a transport-section

ThisTrp_GrWeight = Grossweight of the wagon(s) used for a transport

TrackFee = Track fee per gross-tonkilometre

For calculation of the fuel fee for a transport section (link) the following formula is used

$$\text{ThisTrpSec_FEEFUEL} = \text{ThisTrp_GrWeight} * \text{Trainrunsec_Dist} * (F * \text{Trainrunsec_TrGrWeight} ^ - 0.5 * S) * g / l * \text{FuelFee} * \text{EmpFactor_TrpDist}$$

Where:

ThisTrpSec_FUEL = Energy cost for a transport-section

Trainrunsec_Dist = Length of trainrun-section

F = Factor dependent on route characteristic (flat, hilly, mountainous; see fig.8.3)

$\text{Trainrunsec_TrGrWeight}$ = Train-grossweight in the transport-section

S = Correction factor to take into consideration deviation from normal speed (default = 1)

g = gram fuel

l = litre

FuelFee = Fuel fee per litre (full or reduced fee)

For the calculation of the marshalling fee for a transport section (node) the following formula is used:

$$\mathbf{ThisTrpSec_FEEMARSH = ThisTrp_NrOfWagons * MarshFee}$$

Where:

$ThisTrpSec_FEEMARSH$ = Marshalling fee for a transport-section (node)

$ThisTrp_NrOfWagons$ = Number of wagon(s) used for a transport

$MarshFee$ = Marshalling fee per wagon

For the calculation of the accident fee for a trainrun section (link) the following formula is used:

$$\mathbf{Trainrunsec_FEEACC = Trainrunsec_Dist * AccFee}$$

Where:

$Trainrunsec_FEEACC$ = Accident fee for a trainrun-section (link)

$Trainrunsec_Dist$ = Length of trainrun-section

$AccFee$ = Accident fee per kilometre

After having calculated the accident fee for a trainrun-section, a transport has to be allocated that portion of the cost, which corresponds to that transport's share in the train. This is done in the same way as with locomotive costs; the formula is thus:

$$\text{ThisTrpsec_FEEACC} = 0.5 * \text{TrainrunSec_FEEACC} * (\text{ThisTrp_GrWeight} / \text{Trainrunsec_TrGrWeight}) + (0.5 * \text{TrainrunSec_FEEACC} * (\text{ThisTrp_Length} / \text{Trainrunsec_TrLength}) * \text{EmpFactor_TrpDist}$$

Where:

ThisTrpsec_FEEACC = Accident fee for a transport-section (link)

$\text{Trainrunsec_FEEACC}$ = Accident fee for a trainrun-section (link)

ThisTrp_GrWeight = Grossweight of the wagon(s) used for a transport

$\text{Trainrunsec_TrGrWeight}$ = Train-grossweight in the transport-section

ThisTrp_Length = Length of the wagon(s) used for a transport

$\text{Trainrunsec_TrLength}$ = Train-length in the transport-section

EmpFactor_TrpDist = Factor taking into consideration the distance, which the wagon is running empty (see ch. 8.11)

By default length and weight are weighted equal (shown in formula), however, it is possible to weight each factor according to which degree the maximum train length and the maximum train weight is reached by the train in the trainrun-section in question.

8.9 Activity costs

8.9.1 Shunting

Shunting describes the movement of wagons – as single wagons, wagon groups or entire trains – within a yard or between a yard and a place in close proximity to the yard. Shunting is almost always necessary to spot and pick up wagons to and from their loading/unloading positions and, when there are no marshalling yards, to consolidate and deconsolidate trains. In contrast to line services, cost for shunting services are almost entirely time-dependent. For this reason, a distance-dependent cost component is missing in EvaRail. When it comes to serving places, e.g. industrial sidings, which are located further outside a yard, the user can decide whether these should be considered – and calculated – as a shunting operation, where costs are entirely time-dependent, or whether they also include a train haul with distance-dependent cost components in the cost calculation. In most cases the first option will probably be most adequate, but for very long distances, it may be reasonable to consider the movement to be more of a line-haul nature.

Shunting movements can be carried out

- 1) by dedicated shunting engines located at the yard, or
- 2) by the line locomotive of a train, or
- 3) by a dedicated shunting engine, which is attached to the train and runs empty (not operating) during the train haul.

The first solution is the standard for larger yards, where the volume of arriving and departing wagons is sufficient to economically justify to supply one, or sometimes several, shunting engines. Access to local shunting engines is often a necessity, since industrial spurs are often not electrified, while arriving and departing trains normally are hauled by electric engines.

However, in case diesel locomotives – or dual-mode locomotives – are used in line operation, train locomotives can be used even for local shunting. This solution is often advantageous in liner-train operations and when serving places where only few wagons are handled and dedicated shunting engines consequently could not be economically justified. In this case a possibly increased cost for line operation could be compensated by the lower cost for local shunting.

The third solution is realized mainly by some private train operators with the intention to combine the efficiency of electric traction in line service with the flexibility of diesel locomotives in local shunting, without the need to purchase dual-mode locomotives (which would require high initial investments). However, in total the third solution is not very common. EvaRail allows all three solutions to be depicted – and thus also compared.

From a cost allocation point of view solution 1 – dedicated local shunting engines – and 3 – dedicated shunting engines accompanying a train – are easier to handle since the locomotives used for shunting are exclusively assigned to this function and the costs related to them can thus also be fully allocated to the shunting function.

The shunting costs, which are allocated to a specific flow, represent the share of the total service time during which the resources (shunting locomotive and shunting personnel) are used to shunt the wagons belonging to the flow in question. The total service time is here the time during which the resources are available for shunting (service shifts), irrespective of whether they are actually shunting or not. In order to take into consideration even dead time, EvaRail requires information about the effective utilization of locomotives and personnel in percent of total service time.

In solution 2 the locomotive costs – as well as the driver costs – have to be shared between the train hauling function and the shunting function. As allocation rule for how the costs are to be allocated to different functions the time consumption is used. In this case the locomotive costs – as well as the driver costs – are allocated to the train hauling and shunting functions according to the duration for which the engines are allocated to each function. The allocation of costs to specific flows follows the same principles as described above.

Since in EvaRail shunting costs are time-dependent, the shunting cost per wagon is also dependent on the number of wagons in a shunting movement. The total shunting cost is the same for a single wagon as for a wagon-group. Thus the costs per wagon decrease with the number of wagons in a shunting movement.

A special situation can occur when the shunting resources carry out shunting operations for two or more flows at the same time, for example when spotting wagons for various customers along a industrial trunk line.

In this case the user has to divide the time between the different flows in a reasonable way.

Based on the aforementioned reasoning the following formulas are used in EvaRail to calculate shunting costs for a transport and each shunting occasion.

When local shunting engines or dedicated shunting engines attached to a train are used (shunting method 1 and 3, see above), the following formula is used:

$$\text{ThisTrp_SHUNT} = \left(\frac{\text{ThisTrp_NrOfWagons}}{\text{ShuntGroup_NrOfWagons}} \right) * \text{ShuntMovement_Duration} / (\text{TotalShiftTime} * \text{ShiftTimeUtil}) * (\text{Shift_LOCOCAP} + \text{Shift_LOCOMAINT} + \text{Shift_DRIVER} + \text{Shift_SHUNTPERS} * \text{NrOfShuntpers} + \text{ShiftFuelCons} * \text{FuelPrice}) * \text{EmpFactor_Shunt}$$

Where:

ThisTrpsec_SHUNT = Shunting cost for a flow at a certain station

ThisTrp_NrOfWagons = Number of wagons of a transport (flow)

ShuntGroup_NrOfWagons = Total number of wagons in a shunting movement

ShuntMovement_Duration = Duration of a shunting movement

TotalShiftTime = Duration of a shunting shift

Shift_LOCOCAP = Locomotive capital costs per shunting shift (if leased locomotives are used replace by **Shift_LOCOLEASE**)

Shift_LOCOMAINT = Locomotive maintenance costs per shunting shift

Shift_DRIVER = Driver costs per shunting shift

Shift_SHUNTPERS = Personnel cost per shunting shift per personnel (excl driver)

NrOfShuntpers = Number of personnel for shunting (excl driver)

ShiftFuelCons = Units of fuel consumption per shift

FuelPrice = Fuel price per unit

EmpFactor_Shunt = Factor taking into consideration the number of occasions, when the wagon is shunted empty (see ch. 8.11)

When the line locomotive is used for shunting (shunting method 2), the following formula is used:

$$\text{ThisTrp_SHUNT} = (\text{ThisTrp_NrOfWagons} / \text{ShuntGroup_NrOfWagons}) * (\text{Trainrunsec_LOCOCAP} + \text{Trainrunsec_LOCOMAINT} + \text{Trainrunsec_DRIVER} + \text{ShuntMovement_Duration} * (\text{TimeCost_Shuntpers} * \text{NrOfShuntpers} + \text{FuelConsPerTimeUnit} * \text{FuelPrice})) * \text{EmpFactor_Shunt}$$

Where:

ThisTrpsec_SHUNT = Shunting cost for a flow at a certain station

$\text{ThisTrp_NrOfWagons}$ = Number of wagons of a transport (flow)

$\text{ShuntGroup_NrOfWagons}$ = Total number of wagons in a shunting movement

$\text{Trainrunsec_LOCOCAP}$ = Locomotive capital costs for a trainrun-section (node) (if leased locomotives are used replace by $\text{Trainrunsec_LOCOLEASE}$)

$\text{Trainrunsec_LOCOMAINT}$ = Locomotive maintenance costs for a trainrun-section (node)

$\text{Trainrunsec_DRIVER}$ = Driver costs for a trainrun-section (node)

$\text{ShuntMovement_Duration}$ = Duration of a shunting movement (time units)

$\text{TimeCost_Shuntpers}$ = Personnel cost per time-unit for shunting personnel (excl driver)

NrOfShuntpers = Number of personnel for shunting (excl driver)

$\text{FuelConsPerTimeUnit}$ = Fuel consumption per time unit

FuelPrice = Fuel price per unit

EmpFactor_Shunt = Factor taking into consideration the number of occasions, when the wagon is shunted empty (see ch. 8.11)

As an alternative to the calculation method above, EvaRail also allows shunting costs to be depicted as a fixed lump sum per wagon. This may be necessary when the above-mentioned input data are not available.

8.9.2 Marshalling

In general marshalling costs do not vary between different places and different flows as much as shunting costs, because the number of wagons handled at a marshalling yard is much bigger and costs can be shared among a larger number of wagons. The unit cost- (here: per wagon-cost-) depression is much lower than in shunting, where fewer wagons are handled.

For this reason marshalling costs are in EvaRail so far only depicted as a lump sum per wagon. However, the lump sum can be specified individually for each place where marshalling occurs.

For the calculation of the marshalling costs for a transport and each marshalling occasion the formula therefore looks as follows:

$\text{ThisTrp_MARSH} = \text{ThisTrp_NrOfWagons} * \text{MarshCostPerWagon}$

Where:

ThisTrp_MARSH = Marshalling cost for a flow at a certain station

$\text{ThisTrp_NrOfWagons}$ = Number of wagons of a transport (flow)

MarshCostPerWagon = Marshalling cost per wagon

8.9.3 Transloading

Transloading describes the transfer of cargo or a load unit from one vehicle to another. Transloading can happen between two transport modes, e.g. from rail to a road (wagon to truck) or within a transport mode, where – within the scope of EvaRail – only transloading rail-rail is relevant. In EvaRail transloading costs can be expressed in four different ways:

- (1) per load unit (3) per m³
- (2) per ton (4) per piece

In each of the groups further differentiations are made. In the case of load units different transloading costs can be specified depending on the type of load unit (e.g. 20'-ct, 7.15–7.82m swap body or 13.6 m semitrailer) and type of transloading equipment (e.g. portal crane, reach stacker, etc).

When transloading costs are given per ton, m³ or piece, transloading costs can be specified depending on commodity and transloading equipment.

The formula used for the calculation of transloading costs for a specific flow at a certain place thus is:

$$\text{ThisTrp_TRANSLOAD} = \text{ThisTrp_NrOfUnits} * \text{TransloadCostPerUnit}$$

Where:

ThisTrp_TRANSLOAD = Transloading cost for a flow at a certain place

ThisTrp_NrOfUnits = Quantity to be transloaded, expressed in measurement unit (ton, m³ or piece)

TransloadCostPerUnit = Transloading cost per measurement unit

8.9.4 Road feeder transport

Road feeder transport can be found in both intermodal traffic and in connection with wagonload and trainload services. EvaRail contains a simplified model for calculating road feeder costs, where the cost for each feeder run consists of a fixed part and a distance-dependent part.

Thus the formula for the calculation of road feeder costs for a specific flow at a certain place is the following :

$$\text{ThisTrp_FEEDER} = (\text{ThisTrp_NrOfUnits} / \text{TrpCapFeederVeh}) * (\text{FixCostPerVeh} + \text{FeederDist} * \text{FeederCostPerKm})$$

Where:

ThisTrp_FEEDER = Transloading cost for a flow at a certain place

ThisTrp_NrOfUnits = Quantity to be moved, expressed in measurement unit (ton, m³ or piece)

TrpCapFeederVeh = Transport capacity of the feeder vehicle

FixCostPerVeh = Fixed cost per feeder transport and feeder vehicle

FeederDist = Feeder distance in kilometres

FeederCostPerKm = Feeder cost per kilometre

8.10 Other costs

A number of cost components are in EvaRail calculated as percentage surcharges. To simplify the formulas in this chapter, the sum of costs in chapters 8.2-8.9 is here expressed as Subtotal I.

Thus, Subtotal I for a specific transport comprises the following cost components:

$$\begin{aligned} \text{ThisTrp_Subtotal1} = & \text{ThisTrp_WCAP} + \text{ThisTrp_WMAINT} + \\ & \text{ThisTrp_LOCOCAP} + \text{ThisTrp_LOCOMAINT} + \\ & \text{ThisTrp_DRIVER} + \text{ThisTrp_ELENERGY} + \text{ThisTrp_FUEL} + \\ & \text{ThisTrp_FEETRACK} + \text{ThisTrp_FEEFUEL} + \\ & \text{ThisTrp_FEEMARSH} + \text{ThisTrp_FEEACC} + \text{ThisTrp_SHUNT} + \\ & \text{ThisTrp_MARSH} + \text{ThisTrp_TRANSLOAD} + \text{ThisTrp_FEEDER} \end{aligned}$$

Where:

ThisTrp_Subtotal1 = Subtotal I for a specific transport

ThisTrp_WCAP = Wagon capital costs for a transport (replace by ThisTrp_WLEASE, if leased locomotives are used)

ThisTrp_WMAINT = Wagon maintenance costs for a transport

ThisTrp_LOCOCAP = Locomotive capital costs for a transport (replace by ThisTrp_LOCOLEASE, if leased locomotives are used)

ThisTrp_LOCOMAINT = Locomotive maintenance costs for a transport

ThisTrp_DRIVER = Driver costs for a specific transport

ThisTrp_ELENERGY = Electricity costs for traction for a transport

ThisTrp_FUEL = Fuel costs for traction for a specific transport

ThisTrp_FEETRACK = Track fee (infrastructure charge) for a transport

ThisTrp_FEEFUEL = Fuel fee (infrastructure charge) for a transport

ThisTrp_FEEMARSH = Marshalling fee (infrastructure charge) for a transport

ThisTrp_FEEACC = Accident fee (infrastructure charge) for a transport

ThisTrp_SHUNT = Shunting costs for a transport

ThisTrp_MARSH = Marshalling costs for a transport

ThisTrp_TRANSLOAD = Transloading costs for a transport

ThisTrp_FEEDER = Road feeder transport for a transport

8.10.1 Administration costs

Administration costs represent a train operator's costs for contract acquisition, planning, supervision and invoicing for a specific flow. In contrast to Overhead costs the activities summarized under the Administration costs are – at least in principle – to a high degree traceable to a specific flow. This requires, however, that the train operator registers the resource consumption for these activities on a flow basis. Often this is not the case or information about this is not available. Therefore the costs for these activities are in EvaRail so far handled in the same way as overhead costs, i.e. as a percentage surcharge on the sum of subtotal I.

Thus, the formula for calculation of administration costs for a specific transport are is the following:

$$\mathbf{ThisTrp_ADMIN = ADMINsurcharge\% * ThisTrp_Subtotal1}$$

Where:

$ThisTrp_ADMIN$ = Administration costs for a specific transport

$ADMINsurcharge\%$ = Surcharge for administration in percent

$ThisTrp_Subtotal1$ = Subtotal I (see above)

8.10.2 Overhead costs

Overhead costs represent the costs for the central management of the company, including the company's constitutional organs and legally required activities such as accounting, as well as activities not traceable to specific flows, such as general public relations activities, etc.

Overhead costs are calculated as a percentage surcharge on the sum of Subtotal I and Administration costs:

$$\text{ThisTrp_OH} = \text{OHSurcharge\%} * (\text{ThisTrp_Subtotal1} + \text{ThisTrp_ADMIN})$$

Where:

ThisTrp_OH = Overhead costs for a specific transport

OHSurcharge% = Surcharge for overhead in percent

ThisTrp_Subtotal1 = Subtotal I (see above)

ThisTrp_ADMIN = Administration costs for a transport

8.10.3 Risk costs

Risk costs reflect the costs for the risk that a contract or expected contract will not be realized as planned, that expenses related to it will not be covered, and that resources allocated to the contract cannot immediately be deployed in other services.

Risk costs are calculated as a percentage surcharge on the sum of Subtotal I, Administration costs and Overhead costs:

$$\text{ThisTrp_RISK} = \text{RISKsurcharge\%} * (\text{ThisTrp_Subtotal1} + \text{ThisTrp_ADMIN} + \text{ThisTrp_OH})$$

Where:

ThisTrp_RISK = Risk costs for a specific transport

RISKsurcharge% = Surcharge for risk in percent

ThisTrp_Subtotal1 = Subtotal I (see above)

ThisTrp_ADMIN = Administration costs for a transport

ThisTrp_OH = Overhead costs for a specific transport

8.10.4 Profit margin

The primary purpose of each enterprise – which in the end justifies its existence – is to earn more money than it spends. A profit margin thus has to be added to the total costs in order to reflect the price to the customer, under the assumption that prices are strictly cost-based – which is a truth with modifications (see even chapter 2.2.3).

The profit is calculated as a percentage surcharge on the sum of Subtotal I, Administration costs, Overhead costs and Risk costs:

$$\text{ThisTrp_PROFIT} = \text{PROFITsurcharge\%} * (\text{ThisTrp_Subtotal1} + \text{ThisTrp_ADMIN} + \text{ThisTrp_OH} + \text{ThisTrp_RISK})$$

Where:

ThisTrp_PROFIT = Profit for a specific transport

PROFITsurcharge% = Profit margin in percent

ThisTrp_Subtotal1 = Subtotal I (see above)

ThisTrp_ADMIN = Administration costs for a transport

ThisTrp_OH = Overhead costs for a specific transport

ThisTrp_RISK = Risk costs for a specific transport

8.10.5 Insurance

Insurance costs consist of

- material damage to vehicle insurance
- third party liability insurance
- other type of insurance

From a cost point of view the often most important part is third party liability insurance.

The insurance market in the railway sector is still under development. When the railways were still operated as part of a state's administration, insurance of the kinds available in the private sector did not exist. The exact calculation of the insurance charges is complicated and due to the small market, individual solutions still prevail. However, insurance charges are often to some degree related to the turnover. It was therefore decided to depict insurance costs in EvaRail in the form of a percentage surcharge on the total income, which a flow generates, i.e. the sum of all costs plus the profit margin:

$$\text{ThisTrp_INSUR} = \text{PROFITsurcharge\%} * (\text{ThisTrp_Subtotal1} + \text{ThisTrp_ADMIN} + \text{ThisTrp_OH} + \text{ThisTrp_RISK} + \text{ThisTrp_PROFIT})$$

Where:

ThisTrp_INSUR = Insurance costs for a specific transport

INSURsurcharge% = Insurance surcharge in percent

ThisTrp_Subtotal1 = Subtotal I (see above)

ThisTrp_ADMIN = Administration costs for a transport

ThisTrp_OH = Overhead costs for a specific transport

ThisTrp_RISK = Risk costs for a specific transport

ThisTrp_PROFIT = Profit for a specific transport

8.10.6 Summary of percentage surcharges

The figure below gives an overview of the cost components which are handled as percentage surcharges in EvaRail and in which order they are added, i.e. to which subtotal they relate.

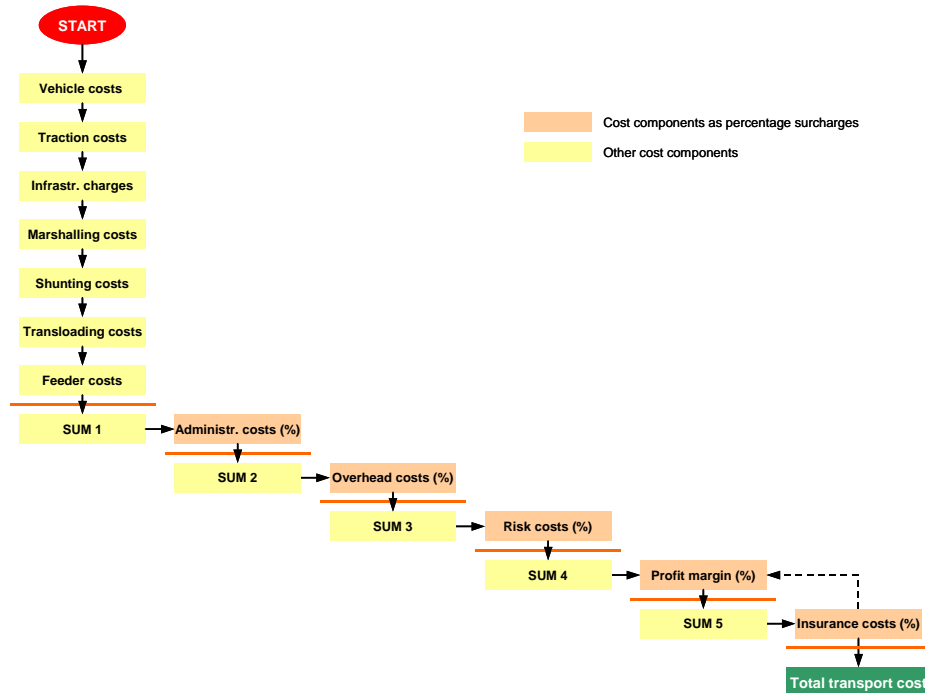


Figure 8.3: Overview of cost components, showing in which order components which are handled as percentage surcharges are added and to which subtotals they relate (Fig.: Gerhard Troche)

8.11 Empty running factors

In order to get a correct cost for a transport, the fact that wagons and locomotives sometimes are running empty has to be taken into account. Since there is no paying load for these empty runs, their costs have to be allocated to the load runs. In EvaRail the underlying principle of charging for empty runs is that a transport is charged with costs for empty running of the resources (e.g. wagons) used for that transport, corresponding to that transport's share of the overall average (loaded) utilization of the resources. The averages are calculated on vehicle class level, since it can be assumed that there is a certain relation between the characteristics of a wagon class and its utilization (here: its share of empty running). Multipurpose wagons, which can take a wide variety of commodities tend to show a lower empty running rate than highly specialized wagons, since the chance to be reloaded is higher for a multipurpose-wagon than for a wagon specialized in for example one commodity. Even the total utilization can be class-specific.

The aforementioned also means that in EvaRail the cost for empty running, which a transport has to bear, is *not* depending on the share of empty wagons in a train – or in other words: the load factor of a train – , to which the wagons for that specific transport are attached, *but instead* on the empty running of the wagon (or more exact: the average empty running of the wagon class), which are used for that transport.

In simple transport cost calculations cost for empty running are often added after summing up all cost components, multiplying the sum by a factor, which normally is based on the (average) distance a wagon is running empty. However, since not all cost components are depending on distance, but also time, and furthermore the relevant time periods are not the same for all cost components, in EvaRail three “Empty-factors” are calculated within the model to allocate costs for empty running to a specific transport, see below. By taking costs for empty running into account already on cost component level a much more exact allocation of empty running costs to specific transports is possible.

For wagon capital costs, which are time-dependent, the formula used to calculate the correct 'Empty-factor' is based on the period, during which a wagon is allocated to transports and empty runs. Note that this is not identical with the running time, but also includes dwell times at origin and destination of a transport and time spend on yards and for intermediate stops (the latter could also be considered being part of the running time, however, not the aforementioned).

$$\text{EmpFactor_WagonOccuTime} = \left(\frac{\text{ThisTrp_WagonOccuTime}}{\text{AllTrp_WagonOccuTime}} * \text{EmpRuns_WagonOccuTime} \right) / \text{ThisTrp_WagonOccuTime}$$

Where:

EmpFactor_WagonOccuTime = Empty-factor of the wagon occupation time

ThisTrp_WagonOccuTime = Time period, during which a wagon individual is allocated to a specific transport. **ThisTrp_VEHoccuTime** starts with the time from which on the wagons are required at the place of loading and ends with the time when the wagon(s) are released at the place of unloading

AllTrp_WagonOccuTime = Average time period over one year, during which wagons of the same class as those used for the specific transport, are allocated to any transport

EmpRuns_WagonOccuTime = Average time over one year, during which all wagons of the same class as those used for the specific transport, are running empty

The following formula is used to calculate the 'Empty-factor' to be applied on distance-dependent wagon maintenance costs and distance-based infrastructure user fees:

$$\text{EmpFactor_TrpDist} = 1 + ((\text{ThisTrp_TrpDist} / \text{AllTrp_TrpDist}) * \text{EmpRuns_Dist}) / \text{ThisTrp_TrpDist}$$

Where:

EmpFactor_TrpDist = Empty-factor of transport distance

ThisTrp_TrpDist = Transport distance of a specific transport

AllTrp_TrpDist = Average transport distance of all transports carried out by wagons of the same class as that or those used for the specific transport

EmpRuns_Dist = Average empty running distance of all transports carried out by wagons of the same class as that or those used for the specific transport

For energy-costs and infrastructure user fees, which also are weight-dependent, a modified formula is used where the transport distances are weighted with the gross-weight of the wagon in loaded and empty condition.

The formula for the 'Empty factor', which is applied on locomotive costs and driver costs is based on the train time. The term train time instead of run time is chosen here to mark that it also includes waiting time at intermediate stops, i.e. it comprises both link and node time.

$$\text{EmpFactor_TrainTime} = ((\text{ThisTrp_TrainTime} / \text{AllTrp_TrainTime}) * \text{EmpRuns_TrainTime}) / \text{ThisTrp_TrainTime}$$

Where:

$\text{EmpFactor_TrainTime}$ = Empty-factor of the train time

ThisTrp_TrainTime = Time period, during which a specific transport forms part of a train

AllTrp_TrainTime = Average time period over one year, during which wagons of the same class as those used for the specific transport are allocated to a transport and form part of a train

EmpRuns_TrainTime = Average time period over one year, during which wagons of the same class as those used for the specific transport form part of a train, running empty

The formula for the 'Empty factor', which is applied on shunting costs is based on the number of shuntings:

$$\text{EmpFactor_Shunt} = \left(\left(\frac{\text{ThisTrp_NrOfShunt}}{\text{AllTrp_NrOfShunt}} \right) * \text{EmpRuns_NrOfShunt} \right) / \text{ThisTrp_NrOfShunt}$$

Where:

EmpFactor_Shunt = Empty-factor for shunting

$\text{ThisTrp_NrOfShunts}$ = Number of shuntings of a wagon individual in a specific transport

AllTrp_NrOfShunts = Average number of shuntings over one year of all wagons of the same class as those used for the specific transport

$\text{EmpRuns_NrOfShunts}$ = Average number of shuntings over one year of all wagons of the same class as those used for the specific transport

The same formula is used for the 'Empty factor' applied on marshalling, with the only difference that the number of shunting occasions is replaced by the number of marshalling occasions.

9 Examples of results in EvaRail

9.1 Applications with analysis of cost structure

Some transport concepts and calculation results are presented below as examples of how EvaRail can be used and how output data from the model can be presented.

The concepts are not illustrations of actual concepts but can be regarded as realistic. They are not, however, necessarily “average”, i.e. representative for wagonload or unit train transportation as a whole, which should be remembered when interpreting the results.

The following types of concept were selected to illustrate the range of different transport concepts that the model can handle:

- A unit train concept
- A wagonload concept with heavy freight
- A wagonload concept with volume freight
- A comparison between a node-system with conventional traction and a liner-train system with dual-power locomotives
- A comparison between a conventional intermodal system and a light-combi intermodal system
- A comparison between locomotive-hauled and multiple unit trains in high-speed freight traffic

The calculation examples give both information about how different measures taken in the railway system – here axle loads and enlarged loading gauge – affect transport economy in defined concepts and an overview of some of the evaluation and analysis capabilities that EvaRail offers.

9.2 Unit train Mora-Gävle

Transport assignment:

- 225,000 tons raw timber/year (= 45 weeks à 5,000 tons)
- 6 departures/week
- No return load
- ~320 km

Transport plan:

- Lomsmyren: Loading/switching
- Train Lomsmyren to Mora: Dep. 12.00, T44
- Mora: Locomotive change
- Train Mora-Gävle (Fliskär): Dep. 13.00, Rc4, $V_{avg} = 65$ km/h
- Gävle (Fliskär): Switching, unloading. Train returns at 12.00 (day 2)

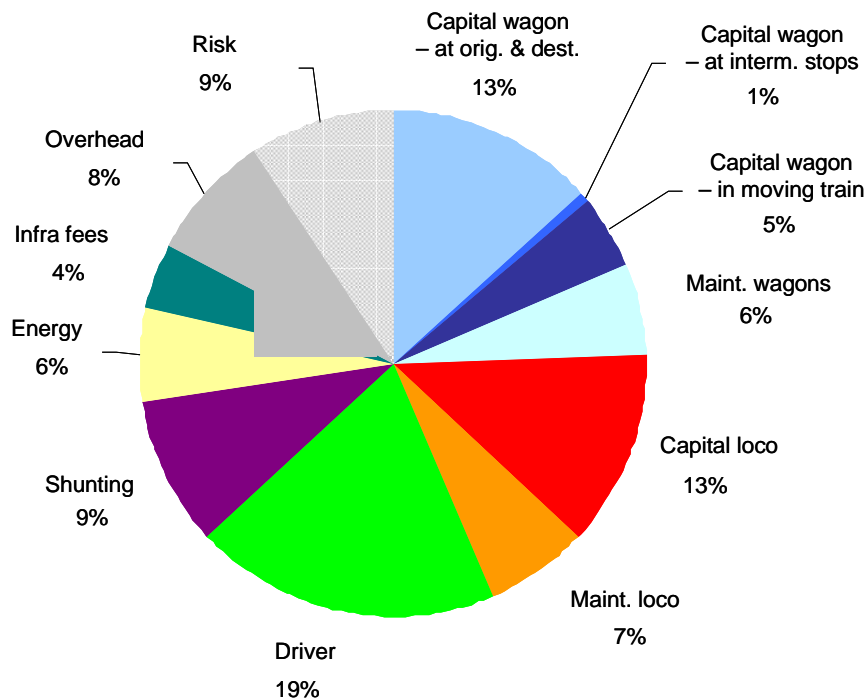
A total of three scenarios have been calculated, one with an axle-load of 22.5 t, one with an axle load of 25.0 t, and one with the axle-load increased to 30.0 t. Some of the results are shown in the figures that follow.

Figure 9.1 shows the distribution of costs by cost item in the base scenario. This figure can be created automatically in EvaRail.

It can be seen that the capital costs for the wagons accounts for not quite a fifth ($13 + 1 + 5 = 18\%$) of the total costs. Most of these costs are related of the time the wagons are at the consigner or the consignee and not the transport itself. When the capital costs for the locomotive (13%) is added, the total capital costs for the vehicles is one third. If the maintenance costs for the locomotive and wagons are also added, the vehicles then account for approx. 40% of the total costs. Driver costs account for approx. one fifth. Shunting refers to the cost of shunting the train at the consigner and the consignee. No marshalling takes place in this concept.

System flow Mora – Gävle (flow 28, all transports)

Cost structure



Figur 9.1: Distribution of costs by cost item in the base scenario (Figure: EvaRail/Gerhard Troche)

The next figure shows the effect of increasing the axle load to 25 and 30 tons respectively. It can be seen that an increase in axle load to 25 tons in this concept would reduce costs by approx. 5%. An increase to 30 tons would reduce costs by 11% compared to the original concept.

The lower figure shows the costs by cost item in all three scenarios in öre/net train km and the change between the scenarios as percentages.

System flow Mora – Gävle
225.000 t timber/year, no backload

Scenario comparison

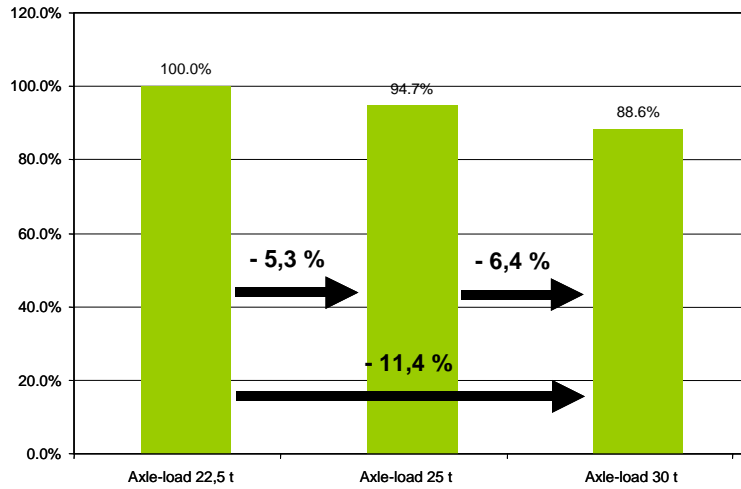


Figure 9.2: Cost comparison of different axle loads for unit-trains Mora-Gävle.

System flow Mora - Gävle
(flow 28, all transports)

Costs and cost changes in percent

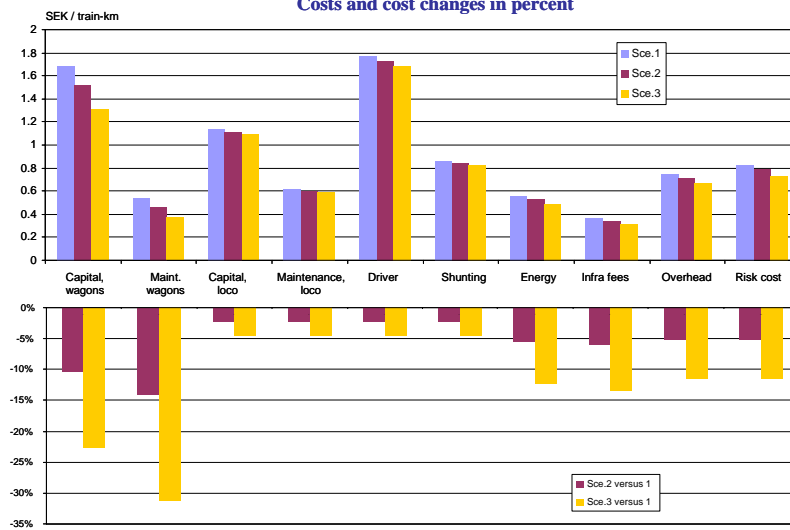


Figure 9.3: Comparison of cost and cost changes for specific cost items.

9.3 Wagonload Helsingborg–Sundsvall – heavy freight

Transport assignment:

- 2 covered bogie wagons, loaded with heavy freight) loading limit 100% utilised)
- 25% return load
- ~990 km

Transport plan:

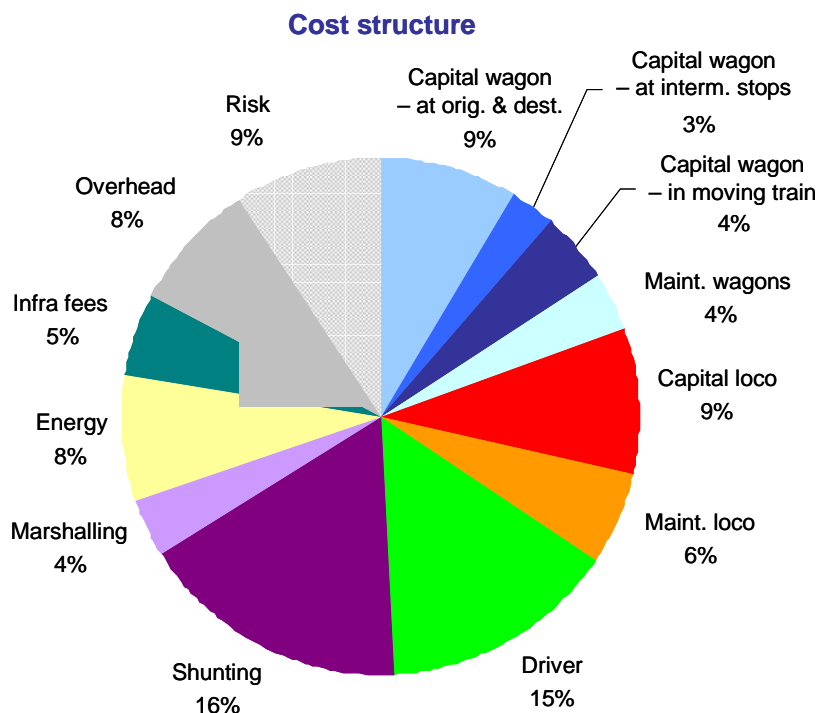
- Helsingborg: Loading, switching with T44, driver + 1 switchman
- Train Helsingborg-Malmö: Dep. 16.00, Rc4, 300 tons
- Malmö: Marshalling
- Train Malmö-Hallsberg: Dep. 20.00, Rc4, 1,000 tons
- Hallsberg: Marshalling
- Train Hallsberg-Sundsvall: Dep. 9.00, Rc4, 1,000 tons
- Sundsvall: Switching with T44, driver + 1 switchman, unloading

A total of three scenarios are calculated, one with an axle-load of 22.5 t, one with an axle-load of 25.0 t and one with the axle-load increased to 30.0 t. Some of the results are shown in the figures that follow.

The figure on the next page, created by EvaRail, shows the distribution of costs by cost item in the base scenario. Compared to the unit train transport (see above), a number of differences can be seen. The most important of these is that marshalling costs arise and that switching costs account for a considerably higher proportion of the total costs. It is striking that the marshalling costs are still relatively modest compared to the switching costs, despite the fact that marshalling occurs twice along the way (in Malmö and Hallsberg). The reason for this is that the marshalling yards handle a very large number of wagons, which means that the high costs can be spread over a great many units. The marshalling cost per wagon is thus relatively small. Switching, on the other hand, takes place at both ends of the transport chain, often in

smaller yards where relatively few wagons are handled. Such places often have less extensive resources and the unit cost is thus relatively higher.

Wagonload Helsingborg – Sundsvall (flow 52, all transports)



Figur 9.4: Cost distribution by cost item in the base scenario (Figur: EvaRail/Gerhard Troche)

The two figures on the next page show where in the transport chain the costs arise. The upper figure can be created automatically in EvaRail.

What was hinted at in the previous figure becomes even clearer here, i.e. a large part, almost one third (32%) to be more precise, of the total costs arise at the end-points, mainly due to the switching costs and the capital costs that burdens the wagons for the time that they spend at the ends of the transport chain.

Standstill costs, i.e. the cost of intermediate stops, in this case in Malmö and Hallsberg, represent a fairly small proportion (7%) in this concept. The picture would be somewhat different if the wagons were to stand still

in the yard, for example over a weekend, since the capital expenditure would then have a much greater impact.

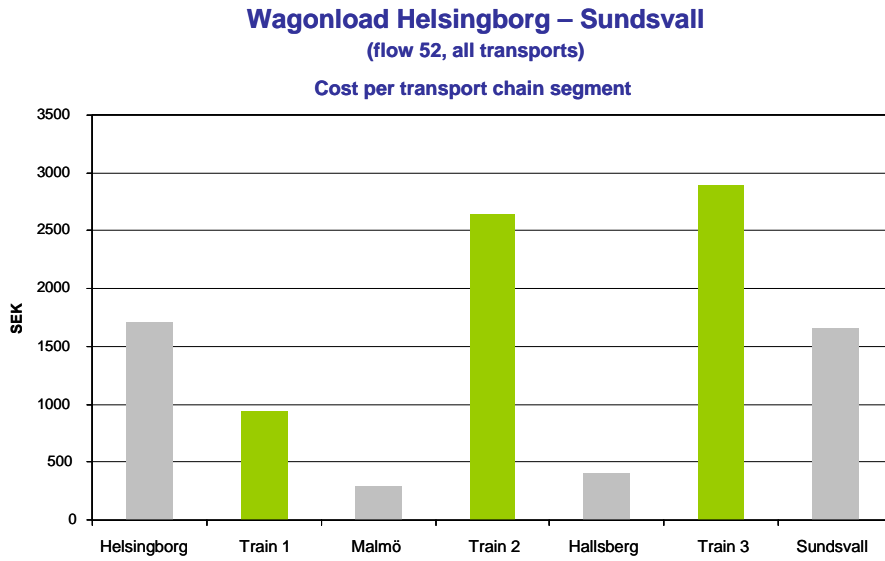


Figure 9.5: Distribution of costs by location for a wagonload concept (Figure: Gerhard Troche)

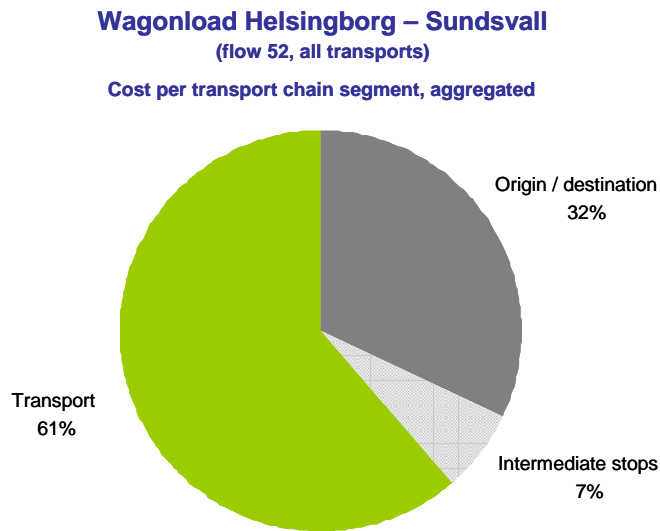


Figure 9.6: Distribution of costs by location, aggregated, for a wagonload concept (Figure: Gerhard Troche)

The figure below shows the effects of an increase in axle load to 25 tons and 30 tons, respectively. As can be seen, an increase in axle load to 25 tons gives a decrease in costs of approx. 9% and an increase to 30 tons a reduction of approx. 23%. Note that this applies to heavy freight that utilizes the wagon's loading capacity to the full already in the base scenario and where volume is not a limiting factor. This means that the increased loading capacity can be utilized to the full. It should also be taken into consideration that the calculation is based on the assumption that the customer can or needs to ship more freight on each occasion since the number of wagons (in this case 2) is the same in all three scenarios. This means that the switching and marshalling costs, for example, can be spread over a greater quantity of freight.

Wagonload Helsingborg – Sundsvall Heavy cargo, 2 wagons, 25% backload

Scenario comparison

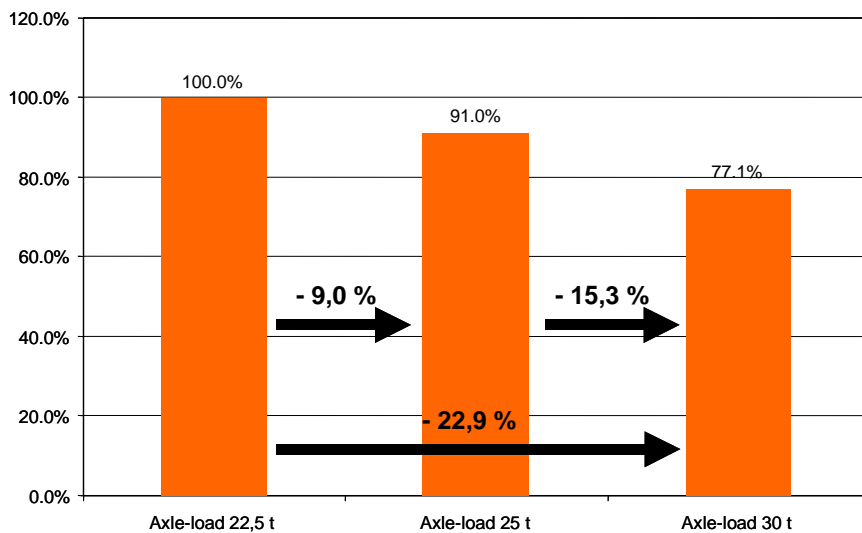


Figure 9.7: Impact on costs of higher axle loads in a wagonload concept with heavy freight (Figure: Gerhard Troche)

9.4 Wagonload Helsingborg–Sundsvall – light freight

Transport assignment:

- 2 covered two-axle wagons, loaded with volume freight (100% load volume utilized)
- 25% return load
- ~990 km

Transport concept:

- Helsingborg: Loading, switching with T44, driver + 1 switchman
- Train Helsingborg-Malmö: Dep. 16.00, Rc4, 300 tons
- Malmö: Marshalling
- Train Malmö-Hallsberg: Dep. 20.00, Rc4, 1,000 tons
- Hallsberg: Marshalling
- Train Hallsberg-Sundsvall: Dep. 9.00, Rc4, 1000 tons
- Sundsvall: Switching with T44, driver + 1 switchman, unloading

Two scenarios are calculated; a base scenario using wagons with a load capacity of 101 m³/ wagon, equivalent to today's wagons, and one using wagons with a load capacity of 149 m³/ wagon, i.e. 50% more. These wagons utilize, and require, the new Swedish C loading gauge. The transport route and timetable is the same as in previous chapter 9.3. The wagons could be transported in the same train.

The figure on the next page shows the effects of the increase in volume on the total costs. It can be seen that the costs could be lowered by approximately one quarter. Note, however, that this assumes that the load volume can be fully utilized and that the load limit is not a limiting factor.

Here, too, the calculation assumes that the customer is able or needs to ship more freight on each departure, in this case approx. 50% more. Otherwise, the differences in cost between the two scenarios would be considerably smaller.

Wagonload Helsingborg – Sundsvall

Volume cargo, 2 wagons, 25% backload

Scenario comparison

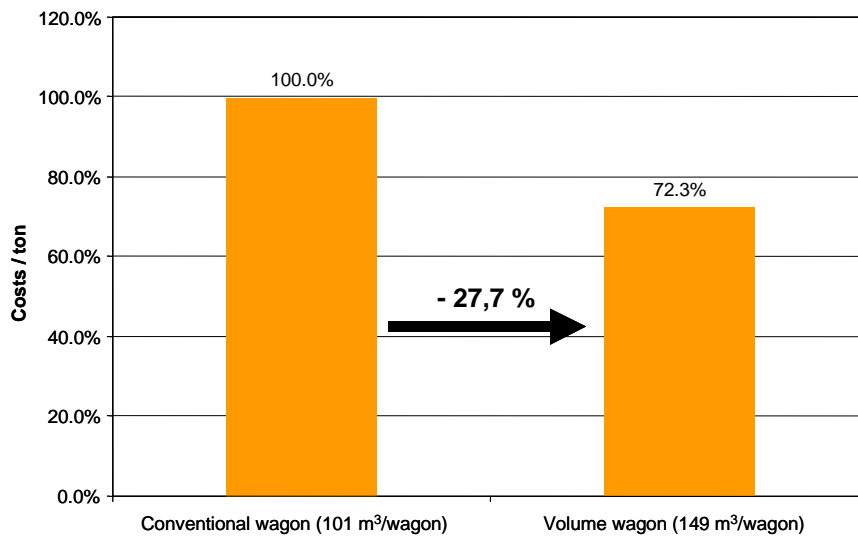


Figure 9.8: Impact on costs of higher load volume in a wagonload concept with volume freight (Figure: Gerhard Troche)

9.5 Liner train system and dual-power locomotives

While the intention in the transport schemes in the chapters above was to quantify the effects of improved economies of scale by increasing axle-loads and loading gauges, the intention here is to compare different production systems.

Figure 9.9 shows the effects of transferring a wagonload transport between Helsingborg and Sundsvall from a node-system-based traffic solution to a liner train system.

As can be seen the cost in this case can be reduced by about 17%, mainly due to the fact, that the costs for consolidation and deconsolidation of traffic flows is lower in the liner train system.

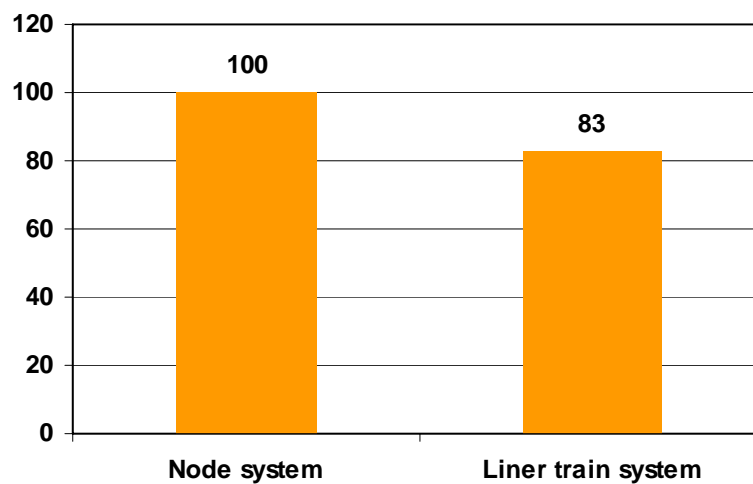


Figure 9.9: Transportation cost index for node system and loop train system. Two fully loaded covered bogies between Helsingborg and Sundsvall.

Another way to reduce the costs at the ends of the transport chain is to use hybrid locomotives. Hybrid locomotives can be used both for mainline haul and for haulage over non-electrified secondary lines or shunting on non-electrified tracks, as in local yards, terminals and industrial spurs.

Figure 9.10 shows, for a unit train scheme between Lomsmyren and Flisskär, that hybrid locomotives can even improve transport economy in already quite efficient transport schemes. In this case the costs could be lowered by about 12%.

From this we can draw the conclusion that it is very important to reduce the cost of feeder transportation both for single wagons and wagon groups, as well as for unit-trains, either through new technology or production methods.

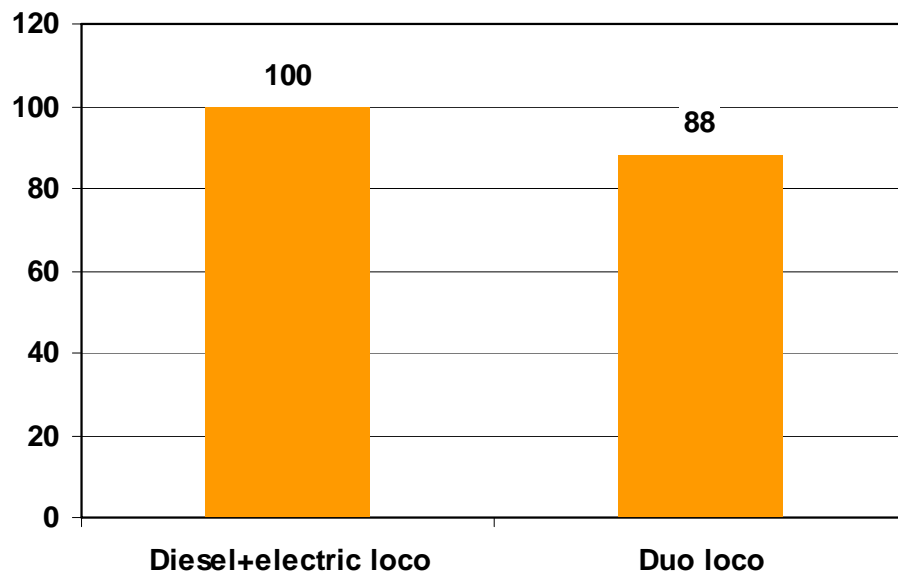


Figure 9.10: Transportation cost index for the T44 and Rc4 locomotives compared to the duo locomotive. Transportation of pulpwood between Lomsmyren and Fliskär, 6 trains a week.

9.6 Intermodal traffic

New production methods can not only be used in wagonload traffic but also widen the market for intermodal traffic. Liner-train operation in connection with small-scale low-cost terminals, the so-called LightCombi concept, are one approach.

The LightCombi system uses unit loads of maximum weight 24 tons and maximum length 11 m that can be lifted by normal industrial forklifts. This not only means lower lifting costs but it is also cheaper to build the terminals. Instead of large terminals, it is possible to have many small ones, and thus come closer to the customers, shortening feeder transportation distances and thereby reducing costs.

With liner trains, more relations can be covered to expand the market. The trains may be smaller and thus more expensive but this is of only minor significance as regards the total cost. With duo locomotives and efficient wagons, the cost of hauling the train can be reduced, but this also applies to the heavy intermodal system.

The figure below shows the cost of transporting two swap-bodies between Helsingborg and Trollhättan. In this case, the heavy intermodal terminals are located in Malmö and Göteborg and the light intermodal terminals in Helsingborg and Trollhättan. The calculation shows that the total transportation cost is 25% lower with the light intermodal system.

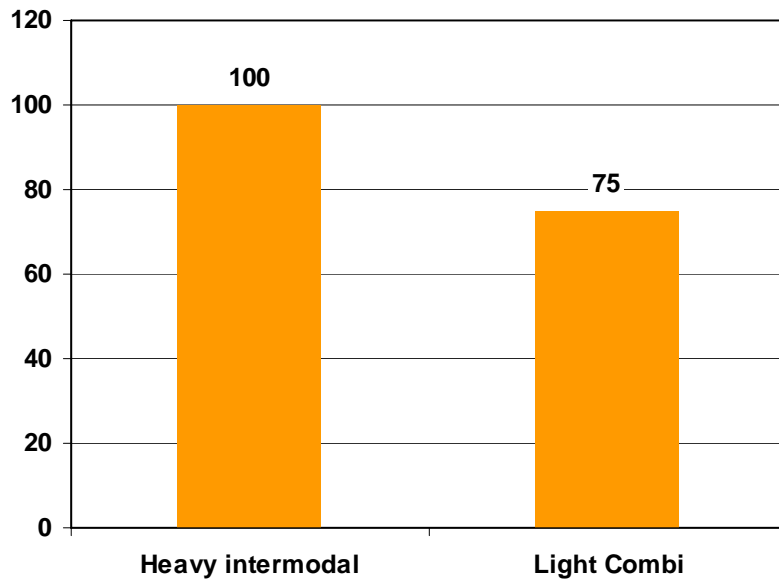


Figure 9.11: Example of cost of transportation by heavy intermodal and light intermodal. Two swap-bodies on a bogie wagon between Helsingborg and Trollhättan.

9.7 Express freight trains

Express freight trains have a cost structure similar to that of passenger trains, if we only consider train hauling between terminals. In the short term, it is economically viable to use locomotives and wagons if this can be done by modernising old rolling stock with low capital expenditure. In the long term multiple-unit trains might be more economical, especially if speed can be increased, which is a critical factor for express freight trains.

The figure below shows the cost of a complete express freight train, carrying mail for example, with locomotive and wagons compared to a multiple unit train. The transport cost in EUR/ton is then approx. 34% lower using the multiple-unit train. This is partly because no locomotive is needed and partly because productivity is higher at the higher speed.

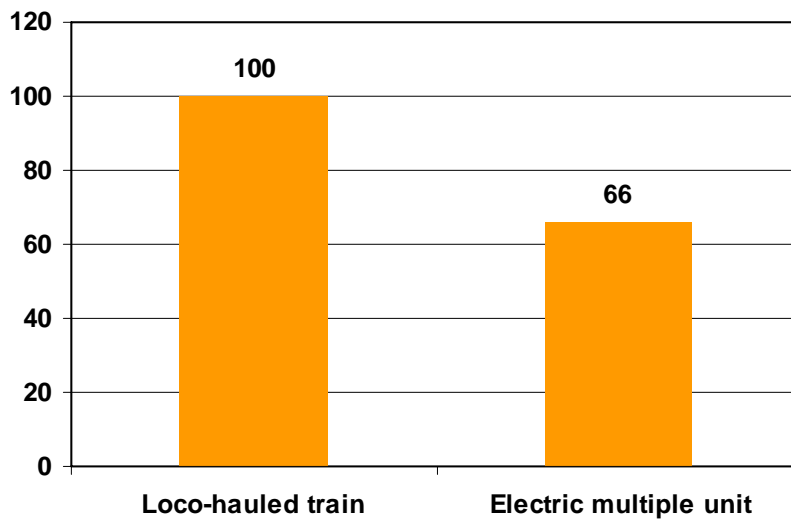


Figure 9.12: Cost of transportation by express freight train. Complete train carrying for example mail, and consisting of a locomotive with a maximum permitted speed of 160 km/h and 8 2-axle wagons with a loading capacity of 14 tons/wagon or a multiple unit train with a maximum permitted speed of 250 km/h with 4 bogie wagons and equivalent load.

10 Discussion and conclusions

10.1 Methodological issues

The railways use a number of different production methods in freight traffic. There are many traffic systems, not always clearly delimited against each other; a transport assignment may sometimes pass through several of them during the course of the journey. Nor is there any single production method that is wholly predominant with all the others of such a marginal nature that they could be ignored in a cost model without considerable proportions of the transport assignments not being illustrated correctly. This is in particular true if the model is also to be able to handle future scenarios. The organizational changes that the railways are at present undergoing and that are not least resulting in the appearance of new train operators are already today contributing to greater diversity among the production methods.

The railways are thus characterized by a complexity that is greater than for other kinds of transport. They are therefore also characterized, among other things, by a large proportion of shared costs. One strongly contributing factor in this respect is the ability to form trains, which is central to the railway system and unique to the railways. For this reason, it is also very difficult to use and adapt by simple means transportation cost models that have been developed for other kinds of transportation and apply these to rail transportation. When developing a transportation cost model the greatest difficulties are consequently partly to describe the railway system in a model, and partly to distribute the shared costs.

In order to be able to construct a cost model for rail freight transportation, it is just as important to have knowledge of how the railway system is built up and functions as it is to have knowledge of economic theory. The shortcomings – or limitations – of many transportation cost models, that (also) illustrate rail transportation, seem to have their origin precisely in a lack of the former. This project has therefore focused on the railway system aspect, while applying existing

theory. The approach is therefore system-analytical rather than economic-theoretical and the project has a clear railway system character.

Activity Based Costing (ABC) is a suitable method for a business-economic transportation cost model and to be preferred to the alternatives of Traditional Cost Accounting (TCA) and Life-Cycle-Costing (LCC). TCA does not link costs to activities with the same accuracy and rather follows legal book-keeping requirements, and LCC would assume that the utilization of a resource is known over the whole life-cycle, which is often not the case in railway contexts.

A bottom-up approach when modelling the costs gives a flexible model through its ability to handle in particular those changes in utilization of resources that result from changes in the railway system better than a top-down approach. The latter, however, can be useful to a certain extent when validating and calibrating the model.

The choice of cost components to be explicitly included in the model has to a large extent been determined by (1) their proportion of the total cost, in which respect the initial selection was based on expert knowledge, (2) the degree to which the cost changes with utilization, where cost components subject to substantial variation have been illustrated if possible, and (3) whether the cost component can be expected to be of great importance in the future.

The same reasoning has been applied as regards the degree of detail with which a cost component is illustrated; the larger the proportion of the total cost, the more effort has gone into illustrating it in as much detail as possible. For this reason, among others, the switching costs at each end of the transport chain, for example, have been modelled with greater accuracy than the marshalling costs along the way.

As mentioned before, the organizational structure of the railways has an impact on the construction of the model. In addition to its tendency to strengthen the diversity of different production methods, the liberalization of the European railway sector has led to a greater diversity of different organizational forms for railway companies and has thus added a further dimension that complicates the construction of a model. The model must suit different organizational forms and for example be able to handle both owned locomotives and rented locomotives; the latter is a phenomenon that was hardly ever seen before and thus would not even have been relevant for inclusion not so very long ago.

At the same time, the restructuring of the railway sector as a consequence of increasing outsourcing linked to this process, is leading to the externalization of internal costs. From the point of view of model construction, this has the desirable advantage that market prices are developing for a range of cost factors, for example in the area of vehicle maintenance.

The availability of data is a general problem when developing transportation cost models. The availability of data primarily affects the validation and calibration of the model. To a certain degree it also controls the model's construction insofar as some cost components must be illustrated in such a way as to suit precisely the available input data rather than be optimal from a theoretical point of view. The difficulties related to the availability of data are particularly pronounced in the railway sector.

Almost no official statistics exist in this area, at the same time as the railway companies, partly for understandable reasons, regard cost data as confidential – this is especially true since intramodal competition began to make itself felt in the market. In addition, railway companies' cost data often has its origin in book-keeping and accounting systems that primarily conform to existing legislation and regulatory frameworks in this area and do not always contain information in the form that is needed, for example for cost models. Management information systems are still under development and the quality and quantity of their data are still in need of improvement.

The input data needed for the model is therefore primarily based on expert knowledge, mostly obtained through interviews. The lack of printed publicly available sources may be regarded as a weakness from a scientific point of view. There are, however, no alternatives in this type of project. Necessary data can seldom be found in scientific literature, or this is regarded as a secondary source since the information is also most often based on interviews with experts. Another problem is that the costs vary between different countries, so that cost data in (scientific) publications from one country is not always usable in a model that is to illustrate conditions in an other country. This severely limits selection from the very outset.

The costs also vary over time. This means that publications that are more than approx. five years old should be used with great discretion as input data in a model. Input data can sometimes be upvalued using a cost

index, but the degree of uncertainty increases the longer the period that the upvaluation refers to. It can also be difficult to find a relevant cost index that suits the very specific cost items that are used in the context.

Interviews with experts have thus often proved to be the best – and in some cases the only practicable – means of obtaining the necessary input data. For the same reason, expert knowledge has also been used when calibrating the model. The future will show when the situation described above will change. It is worth pointing out in this context that for other types of transportation, not least road haulage, there are a number of different, relatively detailed cost data and cost indices of several different kinds available. This might possibly be explained by the fact that there are many more players in these types of transportation and the cost data can thus not be attributed to one specific player. As more and more players are now appearing in the railway sector it is possible – and highly desirable not just from the point of view of research – that corresponding data compilations will also be produced for the railways.

10.2 Model results

On the basis of the model runs executed for a number of typical transportation assignments, a number of conclusions can be drawn.

All forms of standstill time entail high costs – unless capital expenditure can be distributed by time instead of by kilometre. Since the model does the latter, it reveals the “real” costs of the rolling stock when standing still in yards during transportation, but also when the wagons are with the consigner or the consignee for loading and unloading. The way of showing the costs in part leads to other conclusions than if models had been used that do not distribute capital expenditure by time: one conclusion is, for example, that methods that considerably shorten the time required for train formation and loading and unloading might be a way of reducing these costs and utilising the wagons more effectively.

In this context further studies are needed of how, for example, fully or partly automated transshipping can be combined with new traffic solutions, principally in wagonload traffic, for example by using liner trains. In this respect, the value of having a model that is flexible enough to handle different transportation methods and is not limited to a specific production system also becomes clear.

Utilization is a very important factor as regards transportation costs; both the utilization of the wagons throughout the chain but not least the utilization of resources for handling wagons at both ends of the chain, for example shunting locos and personnel for switching onto industrial sidings and in shared terminals.

Other factors that have an impact on the railways' possibilities to exploit advantages of scale are axle load, load volume per wagon and train weight. These factors interact depending on the type of freight. The greatest effect is achieved if an increase in axle load and load volume is combined with an increase in train weight/length. When the axle load is increased from 22,5 to 25 tons with the same train length (i.e. increased train weight), approximately half of the effect is in respect of an increase in loading capacity per axle and half in respect of a greater payload per train .

New traffic systems such as liner trains and – partly in combination with these – new traction vehicle concepts in the form of dual-power locomotives have a significant potential to reduce transportation costs.

The model calculations show that both measures that aim to strengthen the railways' advantages of scale and measures that lead to new production methods can substantially reduce transportation costs. The size of the savings varies widely with the nature of the freight and the concrete prerequisites in the individual case. From this, the conclusion can be drawn that a strategy that aims to strengthen the railways' role in the transportation market should in general contain ingredients from both types of measure. Naturally, the cost effects can not be added together, but it is often precisely a combination of advantages of scale and new production methods that has the greatest impact.

10.3 Further model development and improvements

The model, as it is today, is operable and can be used for a wide range of applications. However, it has been from the beginning developed in a way, which allows for continuous development. Several possible further developments have been already taken into account in the design of the model. Some possibilities for further development are discussed in this chapter.

An integration with or interface with a rail traffic-simulation model would allow the operational feasibility of timetable scenarios to be verified. To do this, of course, passenger trains also have to be included in the simulation, though these are not needed for the transport cost calculation itself.

An automatic import of goods flows to the model. At the moment all freight flows have to be specified “manually”. This sets a practical limit on the number of freight flows, which can be handled within the model. If this task could be automated, even very large number of freight flows could be handled, which would be useful when comprehensive wagonload systems have to be dealt with. This step requires that decisions, e.g. on desired departure times and frequencies, can be taken by the system. These decisions have to be (at least) of the same quality as those taken by transport and production planners (and the users of the model as well) today. To specify the set of rules for these decisions is a highly demanding challenge. In this context one should be aware that decision-making in the case of freight transport is much more complex than in the case of passenger transport.

Full automation of the decision-process has therefore to be considered as a medium-term goal. A short-term goal could be to develop some assistive tools, which can improve and accelerate the manual specification of freight flows. One possibility would be to assign certain parameters to classes of e.g. commodities.

In order to handle multi- and intermodal transport chains even better, feeder transports by truck could be depicted more accurately in EvaRail. This should imply that different operating principles for trucks in pick-up and delivery can be modelled. For practical reasons – and in contrast to

rail transport in EvaRail – this should be done without the need to specify a road network.

An interface to a demand model would be highly desirable. The output of EvaRail would serve as input for a demand model. In a second step the demand model would give “feedback” to EvaRail, for example by adjusting the flow database using the outcomes of the demand model. In the end both models, EvaRail and a future demand model, would together form an integrated model system. This step requires development both of the current EvaRail model, as well as of a demand model, an area, where there is considerable need for development as well.

Improved visualization and analysis tools for output data can be developed in a relatively short time. Today, EvaRail focuses on individual freight flows. It may be interesting to even include tools visualizing and analysing the performance of a whole transport system, to analyse a specific train within a network of train services or to analyse a specific link within a railway network. This information is already available in the output data but the data need to be visualized in a suitable ways, preferably both in table and graphic form.

The figure below shows a possible further development of EvaRail by integrating an improved Transport-Route Assignment Model (TRAM) and an improved Resource Utilization Model (RUM). The TRAM model automates import of flow data and improves route-finding for a flow, including pre- and post-haulage by truck. It thus enables the model to handle large numbers of flows much more efficiently. The RUM model improves the calculation of utilization of rolling stock (locomotives and wagons) and terminal equipment. Both models are network-based and are currently being developed by the author independently of the EvaRail model. The TRAM model is today operable in a first version, while the RUM model is still under development. A pre-condition for an integration of these models is an improved network module in EvaRail. This could be achieved by connecting a Geographical Information System to EvaRail.

An integration of EvaRail, TRAM and RUM into a new improved model, here called EvaRail+, would make it possible to handle more flows and calculate more data within the model. In a next step, the EvaRail+ model could be linked to a Demand and Mode Choice model in order to – in the long term – create an integrated cost and demand model for rail freight, as has been discussed above.

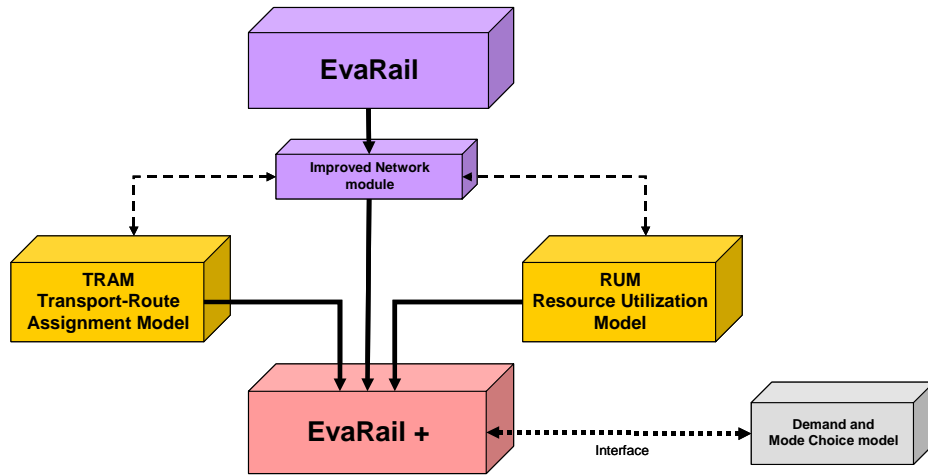


Figure 10.1: Possible further development of EvaRail by integrating a Transport Route Assignment Model (TRAM) and a Resource Utilization Model (RUM). (G.Troche)

11 Literature

- ALLIANZ FÜR SCHIENE (2008): Marktanteil zum Schienengüterverkehr im internationalen Vergleich, Marktanteil zum Straßengüterverkehr im internationalen Vergleich, <http://www.allianz-pro-schiene.de/deutsch/Themen/Gueterverkehr/> (2008-12-14)
- ANIANDER, M., BLOMGREN, H., ENGWALL, M., et.al (1998): Industriell ekonomi, Studentlitteratur, Lund
- BACKHAUS, K., MEYER, M., HILKER, J. (1989): Eine Marketingkonzeption für den grenzüberschreitenden Güterfernverkehr der Deutschen Bundesbahn – Die Relation Rhein/Ruhr–Paris., Münster
- BANKS, J. & CARSON, J.S. & NELSON, B.L. & NICOL, D.M. (2001): Discrete-event system simulation, 3.ed., Upper Saddle River, N.J./USA
- BANVERKET (2004): Järnvägsnätbeskrivning/Network Statement T04.2. Borlänge.
- BAUMGARTNER, J.P. (1996): Orders of magnitude of costs in the railway sector, Lausanne
- BERRY, L.E. (2005): Introduction to managerial accounting, <http://www2.gsu.edu/~accleb/mod1.htm> (2005-02-10)
- BREIMEIER, R. (2008): Schnellere Güterzüge, in: Eisenbahn-Revue International ERI, nr 11/2008, p. 572 – 579
- BROWN, S.J., SIBLEY, D.S. (1986): The Theory of Public Utility Pricing
- BRUGGEMAN, W., EVERAERT, P., ANDERSON, S.R., LEVANT, Y. (2005): Modeling Logistics Costs using Time-Driven ABC: A Case in a Distribution Company, Working Paper, Gent, 2005
- BUKOLD, S. (1994): New production models for combined transport. WCRR '94 – Les actes du congrès, vol 1, sid 133-138
- BUREAU OF INDUSTRY ECONOMICS, ed. (1992): Rail Freight – International performance indicators. Research Report nr 41, Canberra 1992

- CTA CANADIAN TRANSPORT AGENCY (2006): Overview of the Agency's Regulatory Costing Model, http://www.cta-otc.gc.ca/rail-ferro/finance/red-costing_e.html (2006-04-12)
- COOPER, D.R., SCHINDLER, P.S. (2000): Business Research Methods, VII edition
- CRUM, R.L., GOLDBERG, I. (1998): Restructuring and Managing the Enterprise in Transition, Economic Developing Institute of the World Bank
- DB ENERGIE (2003): Anlage 4 zum Rahmenstromliefervertrag, Preisblatt
- DFT, DEPARTMENT FOR TRANSPORT (2008): GB Freight Model – upgrade report and user's guide, <http://www.dft.gov.uk/pgr/economics/rdg/gbfreightmodel/> (2009-01-04)
- EU – DG TREN/EUROSTAT (2007): Transport in figures 2007, part 3, ch. 3.2, Performance of Freight Transport – expressed in tonne-kilometres
- EURAILPRESS (2006): EU-Kommission: Gutachten zu Trassengebühren, 2006-05-10, <http://www.eurailpress.com/news/news.php3?id=13004> (2006-05-11)
- EWERS, H.-J., FONGER, M. (1993): Gesamtwirtschaftliche Effizienz multimodaler Transportketten, Münster
- FLODÉN, J. (2007): Modelling Intermodal Freight Transport – The Potential of Combined Transport in Sweden, Doctoral thesis, Göteborg
- FREDERICH, F. (1994): Chaos als Konzept – Schienengütertransport mit selbstorganisierenden Fahrzeugen. ZEV+DET Glasers Annalen, nr 7/1994, pp. 329-338
- FREDERICH, F., LEGE, B. (1996): SST und SOG, Neuerungen für den Schienen-Güterverkehr. Eisenbahntechnische Rundschau, nr 10/1996, sid 611-616
- FREEBAIRN, J. (2000): Evaluating Changes for Rail Freight Transport, www.ecom.unimelb.edu.au/ecowww/Econonchat/FreebairnEcon6.html , (2000-11-16)
- FREIDANK, C.-C., GÖTZE, U. HUCH, B., WEBER, J. (1997): Kostenmanagement – Aktuelle Konzept und Anwendungen, Springer
- GERDIN, J. (1995): ABC-kalkylering, Lund
- GLOBAL INSIGHT (2009): Costline Rail Analyzer, <http://www.globalinsight.com/gcpath/Costline.pdf> (2009-01-15)

- GRANOF, M.H., PLATT, D.E., VAYSMAN, I. (2000): Using Activity-Based Costing to Manage More Effectively, Austin (Texas)/USA, 2000
- GRIFUL-MIQUELA, C. (2001): Activity-Based Costing Methodology for Third-Party Logistics Companies, *International Advances in Economy Research*, 7(1), pp. 133-146, February 2001
- HANSSON, M., OTTOSSON, P. (2003): The Cost, The Model and The Logistics – A Cost Measurement System at Volvo Logistics Corporation, Master thesis 2003:8, Graduate Business School, Göteborg
- HERBST, W. (1997): Steigerung der Effektivität beim Wagenladungsverkehr. *Eisenbahningenieur*, nr 8/1997, sid 34-40
- HICKS, S.T. (1999): Activity-Based Costing for Small and Mid-sized Businesses: An Implementation Guide, John Wiley & Sons, Inc.
- IFEU (2008): EcoTransIT: Ecological Transport Information Toll – Environmental Methodology and Data – Update 2008, Heidelberg
- JENSEN, A. (1990): Combined Transport: Systems, economics and strategies, Swedish Transport Research Board report 1990:4, Gothenburg
- JENSEN, M (1994): Värdeskapande ABC & ABM, Göteborg, IHM Förlag AB
- KAPLAN (2001): Management Accounting, <http://classes.bus.oregonstate.edu/ba422/Management%20Accounting%20Table%20of%20Contents.htm>, (2002-01-24)
- KAPLAN, R.S., BRUNS, W.J. (1988): Accounting and Management: Field Study Perspectives, Harvard Business School Press, 1st edition, Jan. 1988
- KESSEL, P., RÖHLING, W. (1990): Das Transportmittelwahlmodell der Deutschen Bundesbahn, in: *Die Bundesbahn*, nr 2, 1990, pp. 213-214
- KORTSCHAK, B.H.: Bimodale Systeme: Auch ein Kostenvorteil von 5% rechtfertigt keinen Systemwechsel. *Internationales Verkehrswesen*, nr 6/1992, pp. 239-241
- LIN, B., COLLINS, J., SU, R. (2001): Supply Chain costing: an activity-based perspective, *International Journal of Physical Distribution & Logistics Management*, Vol.31, nr.10, 2001, pp. 702-713, MCB University Press
- LJUNGHAMMAR, O. (1996): Svensk järnvägspolitik i ett internationellt perspektiv, FJT-report, Stockholm
- MDS TRANSMODAL (2008). The Great Britain Freight Model, <http://www.mdst.co.uk/articles/pages/GBFM> (2007-08-20)

- MIERAU, U., EMMERMANN, M. (1997): Innovationen für Güterverkehrssysteme – Bewertung von Innovationen für Güterverkehrssysteme im Forschungs- und Technologiebereich der Deutschen Bahn AG, in: Eisenbahningenieur, nr 6, 1997, pp. 54-57
- NELLDAL, B.-L. (ed.) (2005): Effektiva tågssystem för godstransporter – en systemstudie, Research Report, KTH Railway Group report 0504
- NELLDAL, B.-L. (1981): Lastbil eller järnväg, del I: Utbuds- och kostnadsstrukturen, KTH Trafikplanering, Stockholm
- NELLDAL, B.-L., TROCHE, G., WAJSMAN, J. (2000): Järnvägens möjligheter på den framtida godstransportmarknaden, KTH Transportation & Logistics, TRITA-IP FR 00-81, Stockholm
- NELLDAL, B.-L. (2000): Competition and co-operation between railways and trucking in long distance freight transport – an economic analysis, Proceedings of 3rd KFB research conferences in Transport Systems 2000, Stockholm
- NELLDAL, B.-L., TROCHE, G. (2000): How the railways should solve Europe's transport headaches, conference paper PTRC European Transport Conference 2000, Cambridge
- NELLDAL, B.-L., WAJSMAN, J. (2003): Framtida Järnvägstrafik, bilaga till Järnvägsutredningen SOU 2003:104, Stockholm
- NN (2007): Management for Accounting – traceable and common fixed costs, http://www.accountingformanagement.com/traceable_common_fixed_costs.htm (2007-05-03)
- OXERA (2005): How could Royal Mail undertake 'class costing?', Oxford, 2005, http://www.psc.gov.uk/postcomm/live/policy-and-consultations/consultations/price-control/Annex_8_-_Class_Costing.pdf (2007-01-12)
- PETERS, J.-H. (1997): Fahren und Sparen – Wie die DRG ihren Güterverkehr rationalisierte. Lok Magazin, nr 1/1997, sid 36-45
- PEGDEN, C.D. & SADOWSKI, R.P. & SHANNON, R.E. (1995): Introduction to simulation using SIMAN, 2.ed., N.Y/USA
- PETERSEN, E.R., TAYLOR, A.J. (1987): A Cost Model of the Canadian Railways, Kingston/Canada
- PORT OF GÖTEBORG (2006): Rail, Road and Logistics, Göteborg, [http://www.portgot.se/prod/hamnen/ghab/dalis2b.nsf/vyFilArkiv/Rail_Road_Logistics_0611.pdf/\\$file/Rail_Road_Logistics_0611.pdf](http://www.portgot.se/prod/hamnen/ghab/dalis2b.nsf/vyFilArkiv/Rail_Road_Logistics_0611.pdf/$file/Rail_Road_Logistics_0611.pdf) (2006-12-18)

- RAWNSLEY, A. (1978): Manual of Industrial Marketing Research, John Wiley & Sons
- RECORDIT (2001): Real cost reduction of door-to-door intermodal transport, Annexes to part 1: Methodology for the analysis of the mechanisms of cost and price formation in intermodal transport.
- ROZTOCKI, N. (1998): Introduction to Activity Based Costing (ABC), Pittsburgh, 1998, <http://www.pitt.edu/~roztocki/abc/abctutor/> (2006-01-14)
- SEIDELMANN, C. (1992): Zur Wirtschaftlichkeit Bimodaler Transportsysteme. Internationales Verkehrswesen, nr 4/1992, sid 106-111
- SIEGMANN, J. (1998): Wege zu einer anforderungsgerechten und wirtschaftlichen Güterbahn mit Ganzzügen und Einzelwagen. Eisenbahntechnische Rundschau, nr 6/1998, sid 342-349
- SOU (1949): Principer och metoder för kostnadsberäkningar vid SJ, Statens Offentliga Utredningar 1949:5, Stockholm
- SWAHN, H. (2001): The Swedish Model System for Goods Transport – SAMGODS
- TARKOWSKY, J., IRESTÅHL, B., LUMSDEN, K. (1995): Transportlogistik, Lund
- TROCHE, G. (2000): Organisational changes in the European rail freight industry and their impact on the prospects for international rail freight, Proceedings of 3rd KFB-research conference in Transport Systems 2000, Stockholm
- UNITED NATIONS, ESCAP (1998): Marketing the Railway Product in the Asia and Pacific Region – Guidelines for development of a marketing culture, systems and practices in the railway systems of the region
- VALENZUELA, D., SHRIVASTAVA, P.: Interview as a method for qualitative research, <http://www.public.asu.edu/~kroel/www500/Interview%20Fri.pdf> (2007-03-22)
- WAJSMAN, J. (2004): Godstransporterna, näringslivet och samhället, Transportindustriförbundet
- ZAREMBSKI, A.M., Hill, C.H. (1998): The Economics of Increasing Axle Loads. European Railway Review, 1998, sid 55-59

Publications of KTH Railway Group at the Division for Transportation & Logistics

TROCHE, G., ÖSTLUND, S., SKOGLUND, M. (2009): Pre-study for rebuilding of dielectric freight locomotive class TMz into a dual-power locomotive, Report, KTH Railway Group

TROCHE, G., CARRILLO ZANUY, A. (2009): FERRMED Freight Wagon Concept Study, Report, KTH Railway Group / Institute of Technology Berlin

FRÖIDH, O., LINDFELDT, O. (2008): Svealandsbanans första 10 år – erfarenheter för framtiden av tågtrafiken och resandet, Research report, KTH Railway Group, TRITA-TEC-RR 08-002

SIPILÄ, H. (2008): Körtidsberäkningar för Gröna Tåget, Report, KTH Railway Group

NELLDAL, B.-L., FRÖIDH, O., et.al (2008): Höghastighetståg – affärsmässighet och samhällsnytta – slutrapport, Report, KTH Railway Group / WSP Analys & Strategi

NELLDAL, B.-L., LINDFELDT, O., TROCHE, G. (2008): Godstrafikens utvecklingsmöjligheter som följd av en satsning på Europakorridoren, Report, KTH Railway Group

TROCHE, G. (2008): EvaRail – un modelo de costes para el transporte ferroviario de mercancías basado el el método Activity-Based Costing, Scientific paper, VIII Congreso de Ingeniería del Transporte CIT 2008, La Coruña, 2-4 July 2008

NELLDAL, B.-L. (2008): Höghastighetsbanor i Sverige – Götalandsbanan och Europabanan, Report, KTH Railway Group

LINDFELDT, O. (2008): Kapacitet för godståg på Västra och Södra stambanan, Sub-report, KTH Railway Group

NELLDAL, B.-L., LINDFELDT, O., SIPILÄ, H., WOLFMAIER, J. (2008): Förbättrad punktlighet på X2000 – analys med hjälp av simulering, Sub-report, KTH Railway Group

TROCHE, G. (2007): Possibilities for improvements of the rail cost module of the Swedish SAMGODS freight traffic forecasting model, Report

- LINDFELDT, O. (2007): Quality on single-track railway lines with passenger traffic – analytical model for evaluation of crossing stations and partial double-tracks, Licentiate thesis, KTH Railway Group, TRITA-TEC-LIC 07-003
- LINDFELDT, O. (2007): Effekter av partiella dubbelspår och fler mötesstationer på enkelspår, Research report, KTH Railway Group, TRITA-TEC-RR 07-009
- SUNDSTRÖM, J., KOTTENHOFF, K., BYSTRÖM, C. (2007): Visst skakar det – men är tågresenären beredd att betala för högre åkkomfort? Tillägg om lokala spårlägesfel, Research report, KTH Railway Group, TRITA-TEC-RR 07-008
- FRÖIDH, O., JANSSON, K., KOTTENHOFF, K. (2007): Kollektivtrafik värd priset för integrerad arbetsmarknad – fallstudie Mälardalen, Research Report, KTH Railway Group, TRITA-TEC-RR 07-006
- NELLDAL, B.-L. (2007): Möjligheter för tåget att konkurrera med och ersätta flyget, Report, KTH Railway Group
- FRÖIDH, O., NELLDAL, B.-L. (2006-08): Tåget till framtiden – järnvägen 200 år 2056, second edition, Research Report, KTH Railway Group, TRITA-TEC-RR 06-004
- TROCHE, G. (2006): Cómo reavivar el tráfico de mercancías por ferrocarril en líneas secundarias – un ejemplo de Suecia, Scientific paper, VII Congreso de Ingeniería del Transporte CIT 2006, Ciudad Real, 14-16 June 2006
- NELLDAL, B.-L. (2006): Nya fordon 1981 – 2006, Excerpt from 'Järnvägen 150 år', Research Report, KTH Railway Group, TRITA-TEC-RR 06-003
- FRÖIDH, O. (2006): Nytt liv med järnvägen, Excerpt from 'Järnvägen 150 år', Research Report, KTH Railway Group, TRITA-TEC-RR 06-002
- NELLDAL, B.-L., TROCHE, G. (2006): Utveckling av utbud och priser på järnvägslinjer i Sverige 1990-2005 samt utvecklingen av flyg- och busskonkurrens 2005, Research Report, KTH Railway Group, TRITA-TEC-RR 06-001
- LUNDBERG, S. (2006): Godskunders värderingar av faktorer som har betydelse på transportmarknaden, Licentiate thesis, KTH Railway Group, TRITA-TEC-LIC 06-001
- TROCHE, G. (2007/1): Möjligheter till utnyttjande av tvärbanan Arvidsjaur – Jörn för slig- och virkestransporter, April 2007

- TROCHE, G. (2007/2). Södra Inlandsbanan Mora–Vansbro–Persberg – Marknad och trafikeringskoncept för godstrafik, September 2007
- TROCHE, G. (2005): Planning and cost calculation of a new multimodal transport solution for a freight flow between Jämtland and Great Britain via the Port of Gothenburg, Report
- NELLDAL, B.-L., TROCHE, G., AHLSTEDT, L.G. (2005): Godstrafikutredning för Inlandsbanan, Research report, KTH Railway Group, TRITA-INFRA 05-006
- NELLDAL, B.-L. (ed.) (2005): Effektiva tågssystem för godstransporter – en systemstudie, Research Report, KTH Railway Group report 0504
- NELLDAL, B.-L. (ed.) (2005): Efficient train systems for freight transport – a systems study, Research Report, KTH Railway Group report 0505
- ÖSTLUND, S., et.al. (2005): Fordon och infrastruktur för effektiva godstransporter, Sub-report, KTH Railway Group report 0506
- BERGSTEDT, R. (2005): Automatkoppel, Sub-report, KTH Railway Group report 0507
- BERGSTEDT, R. (2005): Bromssystem, Sub-report, KTH Railway Group report 0508
- BERGSTEDT, R. (2005): IT-teknik för effektiva tågssystem för gods – Intelligent informationssystem (0509A), Fördelad dragkraft och fjärrstyrda lok (0509B), Sub-report, KTH Railway Group reports 0509A+B
- BARK, P. (2005): Effektiva tågssystem för vagnslast- och systemtåg, Sub-report, KTH Railway Group report 0510
- WAJSMAN, J. (2005): Transportmarknadens struktur och järnvägens konkurrenskraft, Sub-report, KTH Railway Group report 0511
- TROCHE, G. (2005): High-speed rail freight, Sub-report, KTH Railway Group report 0512
- NELLDAL, B.-L., BARK, P., WAJSMAN, J., TROCHE, G. (2005): Konkurrenskraftiga kombitransporter, Sub-report, KTH Railway Group report 0513

- FRÖIDH, O., JANSSON, T. (2005): Kapacitetsanalys av två principutförningar av bansystemet på Ostlänken, Research report, KTH Railway Group, TRITA-INFRA 05-017
- FRÖIDH, O., LINDFELDT, O., NELLDAL, B.-L. (2005): Framtida marknad, tågtrafik och kapacitet inom Stockholms Central, Research report, KTH Railway Group, TRITA-INFRA 05-010
- WAHLBORG, M., JANSSON, T. (2005): UIC capacity management methods – the Mälardalen line case, KTH Research report, TRITA-INFRA 05-009
- FÖRSTBERG, J., KOTTENHOFF, K., OLSSON, C. (2005): Visst skakar det – men är tågresenären beredd att betala för högre åkkomfort, Research report, KTH Railway Group, TRITA-INFRA 05-007
- NELLDAL, B.-L., TROCHE, G., AHLSTEDT, L.G. (2005): Godstrafikutredning för Inlandsbanan, Research report, KTH Railway Group, TRITA-INFRA 05-006
- HEINZ, W. (2003): Passenger service times on trains – theory, measurements and models, Licentiate thesis, KTH Railway Group, TRITA-INFRA 03-62
- NELLDAL, B.-L., TROCHE, G. (2005): Utveckling av utbud och priser på järnvägslinjer i Sverige 1990-2003 samt utvecklingen av tåg- och bilrestider 1958-2003, Research report, KTH Railway Group
- WOXENIUS, J., TROCHE, G., et.al. (2004): Liner train concept in Sweden for freight forwarding company Schenker Sverige AB, Scientific paper, World Congress of Transport Research WCTR 2004, Istanbul, July 2004
- NELLDAL, B.-L., TROCHE, G., JANSSON, K. (2003) : Europakorridoren – ett bredband för fysiska transporter – utbud, prognoser och samhällsekonomi, Research report, KTH Railway Group, TRITA-INFRA 04-052
- FRÖIDH, O. (2003): Introduction of regional high speed trains – a study of the effects of the Svealand line on the travel market, travel behaviour and accessibility, Doctoral dissertation, KTH Railway Group, TRITA-INFRA 03-041
- FRÖIDH, O. (2003): Introduktion av regionala snabbtåg – en studie av Svealandsbanans påverkan av resemarknaden, resbeteende och tillgänglighet, Research Report, KTH Railway Group, TRITA-INFRA 03-040

- LINDAHL, A. (2002): Infrastruktur för flexibel tågföring – kapacitetsanalys av förbigångar på en dubbelspårssträcka, Research Report, KTH Railway Group, TRITA-INFRA 02-021
- BÄCKMAN, J. (2002): Railway safety – risks and economics, Doctoral dissertation, KTH Railway Group, TRITA-INFRA 02-019
- KOTTENHOFF, K. (2002): Utvärdering av ny bred motorvagn – att sitta fem i bredd i Regina, Research report, KTH Railway Group, TRITA-INFRA 02-014
- BARK, P., LANDBORN, J., SUNDBERG, F. (2002): Effektiva tågssystem för godstransporter – analys av marknad samt utvecklingstendenser för paket-, stycke- och partigods, Research report, KTH Railway Group report 0202
- BARK, P., BACKMAN, H., BROLIN, H., OLSSON, M. (2002): Effektiva tågssystem för godstransporter – branschbeskrivningar avseende den svenska godstransportmarknaden, Research report, KTH Railway Group report 0201
- ROSENLIND, S., LIND, G., TROCHE, G. (2001): LIME – model for capacity utilization and profitability of a railway line, Research report, KTH Railway Group, TRITA-IP FR 01-99
- NELLDAL, B.-L. (2001): Järnvägssektorn efter järnvägsreformen 1988 – förändringar i omvärlden, trafikpolitiken och järnvägsbranschen och i järnvägens marknad 1990-2000, report, Railway Group KTH, TRITA-IP AR 01-98
- NELLDAL, B.-L., TROCHE, G. (2001): Europakorridoren – ett bredband för fysiska transporter, Report, KTH Railway Group, TRITA-IP AR 01-97
- NELLDAL, B.-L., TROCHE, G. (2001): Tåg för tillväxt i Östra Mellansverige – en studie av ett samverkande tågtrafiksystem för framtida resbehov och regional utveckling, Report, KTH Railway Group, TRITA-IP AR 01-95
- KOTTENHOFF, K. (2001): Tågresenärers upplevelse av utrymme – regressionsanalys av olika sittplatsegenskaper, Report, Railway Group KTH, TRITA-IP AR 01-94
- HEINZ, W., KOTTENHOFF, K. (2001): Effektiva handikappreducerande fordon – järnvägsfordon som på ett ekonomiskt sätt reducerar tågresenärers handikapp, Report, Railway Group KTH, TRITA-IP AR 01-93A
- KOTTENHOFF, K. (2000): Passenger preferences in terms of timetable, comfort and on-board service attributes on the X2000, Report, Railway Group KTH, TRITA-IP AR 00-87

- HEINZ, W. (2000): Passagerarutbyte i tåg – mätningar av av- och påstigningstider samt ansats till modell för att beskriva samband, Report, KTH Railway Group, TRITA-IP AR 00-86
- NELLDAL, B.-L., TROCHE, G., WAJSMAN, J. (2000): Järnvägens möjligheter på den framtida godstransportmarknaden, Research report, KTH Railway Group, TRITA-IP FR 00-81
- LINDAHL, A. (1999): Resandeundersökningar på trafiken Stockholm – Bollnäs – Östersund – Åre för Atlantbanan, Report, KTH Railway Group, TRITA-IP AR 99-79
- TROCHE, G. (1999): Efficient night-train traffic – problems and prospects, Report, KTH Railway Group, TRITA-IP-AR 99-77
- SCHILLING, R. (1999): Accessibility to train – from information to station – a study based on a literature review and other references, Report, KTH Railway Group, TRITA-IP AR 99-76
- NELLDAL, B.-L. (1999): Wide-body trains – vehicle concepts for different markets – a study of design, capacity and economy, Report, KTH Railway Group, TRITA-IP AR 99-75
- KOTTENHOFF, K. (1999): Utvärdering av Bombardier dubbeldäckt tåg 'Competence' – resenärernas kvalitativa och kvantitativa värderingar av tvåvåningståget och dess inredning på olika linjer, Report, KTH Railway Group, TRITA-IP AR 99-72
- FRÖIDH, O. (1999): Svealandsbanan – en studie av efterfrågan före och efter etableringen av ett nytt tågssystem mellan Stockholm och Eskilstuna, Research Report, KTH Railway Group, TRITA-IP FR 99-58
- KOTTENHOFF, K. (1999): Evaluation of passenger train concepts – methods and results of measuring travellers' preferences in relation to costs, Doctoral dissertation, KTH Railway Group, TRITA-IP FR 99-48
- BÄCKMAN, J. (1999): Railway, safety and economics, Research report, KTH Railway Group, TRITA-IP FR 99-47
- NELLDAL, B.-L. (1998): Breda tåg, fordonskoncept för olika marknader - en studie av utformning, kapacitet och ekonomi, Report, KTH Railway Group, TRITA-IP AR 98-69

KOTTENHOFF, K. (1998): Utvärdering av SJ's experimentvagn B20 – Resenärers kvalitativa och kvantitativa preferenser av högkapacitetsvagn 'IRmax' på olika linjer, Report, KTH Railway Group, TRITA-IP AR 98-68

TROCHE, G. (1998): Effektiv nattågstrafik – problem och möjligheter, Report, KTH Railway Group, TRITA-IP AR 98-67

NELLDAL, B.-L., FRÖIDH, O., TROCHE, G. (1998): Södra stambanan mellan Stockholm och Linköping – utvecklingsmöjligheter för trafik och bana via Nyköpingslänken, Report, KTH Railway Group, TRITA-IP AR 98-59

NELLDAL, B.-L., TROCHE, G. (1997): Effektiva tågssystem i Mälardalen, RTK pm nr 22

TROCHE, G. (1997): Effektiva Tågssystem – trafikering och kapacitet – analys av typlinjer, Sub-report, KTH Railway Group report 9713

TROCHE, G. (1997): Effektiva Tågssystem - utvecklingstrender och idéer, Sub-report, KTH Railway Group report 9712

KOTTENHOFF, K. (1997): Effektiva Tågssystem - marknad, konkurrenskraft och trafikproduktion, Sub-report, KTH Railway Group report 9711

NELLDAL, B.-L.(ed.) (1997): Effektiva Tågssystem för framtida persontrafik - analys av förutsättningar och möjligheter för attraktiv tågtrafik, Research report, KTH Railway Group report 9702

ROSENLIND, S., LIND, G. (1996): Tågtrafikering för olika delmarknader - en modell för analys av kostnader och intäkter för olika tågkoncept, Report, KTH Railway Group, TRITA-IP AR 96-51

KOTTENHOFF, K. (1996): Persontrafik i mindre skala – var går gränsen?, Report, KTH Railway Group, TRITA-IP AR 96-45

NELLDAL, B.-L., KOTTENHOFF, K., LIND, G., ROSENLIND, S. (1996): Tågtrafikens möjligheter på den framtida resemärknaden, Research report, KTH Railway Group, TRITA-IP FR 96-11

TRITA-TEC-PHD 09-002
ISSN 1653-4468
ISBN 13:978-91-85539-35-2